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**Synthesis and Review of the Best
Available Scientific Studies on Priority
Areas for Biodiversity Conservation
in Marine Areas beyond the Limits of
National Jurisdiction**

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FOREWORD

Vast expanses of the world's oceans, about 64% of the total area, lie beyond the limits of national jurisdiction. They include some of the least explored and studied areas on Earth, as well as some of the most intensively exploited and heavily degraded environments. With the technological advances of the past few decades, such as advanced acoustics, remotely operated vehicles, human occupied submersibles, and other advanced underwater technologies, much has been added to our knowledge of deep-sea habitats, and people have begun to realize the value and contribution of this large and remote habitat to life on Earth. In this regard, the Conference of the Parties to the Convention on Biological Diversity has noted that deep-seabed ecosystems beyond the limits of national jurisdiction, including hydrothermal vents, cold seeps, seamounts, cold-water coral and sponge-reef ecosystems, contain genetic resources of great interest for their biodiversity value and for scientific research as well as for present and future sustainable development and commercial applications.

Deep-seabed ecosystems beyond the limits of national jurisdiction are under increasing threat from various human activities, particularly overfishing, destructive fishing practices, and illegal, unreported and unregulated fishing activities. In addition, the discovery of the enormous potential value to various sectors, particularly the health and food sectors, of deep-seabed genetic resources, has intensified deep-seabed research and bioprospecting, albeit restricted to those actors who own the requisite technological capacity and the financial resources to access these remote areas. There are also increasing concerns that the loss of diversity can make oceanic ecosystems more vulnerable and less resilient to climate change and other environmental shifts caused by disease, invasive alien species, and the cascading effects of overexploitation.

The Convention on Biological Diversity has a key role in supporting the work of the General Assembly with regard to marine protected areas beyond national jurisdiction, by focusing on the provision of scientific and, as appropriate, technical information and advice relating to marine biological diversity, the application of the ecosystem approach and the precautionary approach, and in delivering the 2010 target.

This publication focuses on seamounts, cold-water coral reefs, hydrothermal vents and selected other ecosystems. Based on a document submitted to the 13th meeting of the Subsidiary Body on Scientific, Technical and Technological Advice, (UNEP/CBD/SBSTTA/13/INF/11), it was prepared to provide a synthesis and review of the best available scientific studies on priority areas for biodiversity conservation in marine areas beyond the limits of national jurisdiction.

It is our sincere hope that this publication can further enhance on-going efforts to improve our scientific understanding of important deep-sea habitats.



Ahmed Djoghlaif
Executive Secretary
Convention on Biological Diversity

ACKNOWLEDGEMENTS

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I. BACKGROUND

In paragraph 44 (a) of its decision VIII/24, the Conference of the Parties requested the Executive Secretary to synthesize, with peer review, the best available scientific studies on priority areas for biodiversity conservation in marine areas beyond national jurisdiction, including information on status, trends and threats to biodiversity of these areas as well as distribution of seamounts, cold-water coral reefs and other ecosystems, their functioning and the ecology of associated species, and to disseminate this through the clearing-house mechanism. In undertaking this task, the Executive Secretary was asked to work actively with, and to take into account scientific information available from, the range of relevant expertise available in governmental, intergovernmental, non-governmental, regional and scientific institutions, expert scientific processes and workshops, and, indigenous and local communities, where appropriate.

The present report is the first attempt to review and synthesize existing literature for the priority habitats listed in decision VIII/24, which include seamounts, cold-water coral reefs, hydrothermal vents and other ecosystems in areas beyond national jurisdiction. The report presents, in synthesized format, information about the distribution, status and trends (where available), as well as the threats facing these ecosystems. Information about the functioning of these ecosystems and the ecology of associated species is also presented. Finally, the report reviews work that has been undertaken to identify priority conservation areas beyond the limits of national jurisdiction. The report takes into consideration comments submitted by Parties, other Governments and organizations as well as expert groups, including the Census of Marine Life programme CenSeam (a global census of marine life on seamounts), Data Analysis Working Group and the participants in the Expert Workshop on Ecological Criteria and Biogeographic Classification Systems for Marine Areas in Need of Protection (held from 2 to 4 October 2007, in Azores, Portugal), from 26 October to 23 November 2007, during which time the report was posted on the Convention website for peer review (notification 2007-130). The research¹ for this report was conducted with financial support from the European Commission.

1 The study was undertaken by the United Nations University Institute of Advanced Studies.

II. SEAMOUNTS

A. GLOBAL DISTRIBUTION

Seamounts are isolated mountains or mountain chains beneath the surface of the sea. Traditionally, geologists have defined seamounts as topographic features with an elevation exceeding 1000m above the seabed and exhibiting a conical shape with a circular, elliptical or more elongated base². Seamounts are typically volcanic in origin. Smaller volcanoes between 500 and 1000m in elevation above the level of the surrounding seabed are sometimes called knolls and those less than 500m are abyssal hills. However, this definition holds little ecological relevance, and studies of seamount populations reveal that their size-frequency distributions are continuous with no obvious break.³ Thus, many biological publications have used a more relaxed definition of a seamount. For example, Rogers (1994)⁴ and others⁵ have applied the term “seamount” more generally to topographic “hill” elevations regardless of size and relief. Rather than arbitrarily pick absolute depth limits, Pitcher et al. (2007)⁶ chose to use functional criteria that are important in regulating biological productivity. Consequently, they defined shallow seamounts as those that penetrate the euphotic zone, intermediate seamounts as those that are shallower than the daytime depth of the deep scattering layer (but which do not reach the euphotic zone), and deep seamounts as those with summits below the deep scattering layer. Oceanic islands, many of which have the same origins as seamounts, share many common features and ecological effects on their submerged slopes.

Seamounts are generally formed over upwelling plumes (hotspots) and in island-arc convergent settings. Hotspots are points of frequent volcanic activity in the earth’s crust persisting over millions of years.⁷ The sea floor tectonic plates move over the stationary hotspots causing seamounts to form. As one seamount is carried away from the hotspot another forms in its place, meaning that the oldest seamounts are furthest away from the hotspot. The movement of tectonic plates often causes seamounts to form long chains or elongated clusters. Seamounts stay volcanically active while over the hotspot (two or three million years), and their volcanic activity wanes after they are carried away. Because of their volcanic nature, seamounts are found near mid-ocean spreading ridges, over upwelling plumes and in island-arc convergent settings.⁸ Studies suggest a connection between the height of the seamount and the age (and thus the strength) of the tectonic plate, and to a lesser extent melt availability and magma driving pressure.⁹

Because seamounts do not break the sea surface, our knowledge of their distribution comes primarily from remote sensing. Traditionally, seamounts have been mapped by acoustic echo sounders on oceangoing research vessels. However, because of the vastness of the oceans, it is unlikely that this method can be used to comprehensively map seafloor bathymetry despite the new extensive efforts on high resolution mapping of the sea-bed related to extended continental shelf claims. Alternative methods include the use

2 Menard, H. W. (1964) *Marine geology of the Pacific*. New York, McGraw-Hill

3 Pitcher, T.J., Morato, T., Hart, P.J.B., Clark, M.R., Haggan, N. and Santos, R.S. (eds) (2007) *Seamounts: Ecology, Conservation and Management*. Fish and Aquatic Resources Series, Blackwell, Oxford, UK

4 Rogers, A. D. (1994) The biology of seamounts. *Adv. Mar. Biol.* 30: 305–350.

5 E.g. Epp, D. and N. C. Smoot (1989) Distribution of seamounts in the North Atlantic. *Nature* 337: 254–257.

6 Pitcher, T.J., Morato, T., Hart, P.J.B., Clark, M.R., Haggan, N. and Santos, R.S. (eds) (2007) *Seamounts: Ecology, Conservation and Management*. Fish and Aquatic Resources Series, Blackwell, Oxford, UK

7 Epp, D. and Smoot, N. C. 1989. Distribution of Seamounts in the North Atlantic. *Nature* 337: 254–257.

8 Global Census of Marine Life on Seamounts. <http://censeam.niwa.co.nz/>

9 Wessel, P. (2001) Global distribution of seamounts inferred from gridded Geosat/ERS-1 altimetry. *Journal of Geophysical Research* 106: 19431–19441.

of satellite altimetry and satellite gravity mapping to infer seamount locations.^{10 11 12} Such studies indicate that seamount numbers are difficult to estimate, but, according to the Census of Marine Life project on seamounts (CenSeam), there are potentially up to 100,000 seamounts over 1 km high and many more of smaller elevation.¹³ They are found in every ocean basin and most latitudes. Nearly half of the world's known or inferred seamounts are found in the Pacific Ocean. The rest are mostly found in the Atlantic and Indian oceans, while the Southern Ocean has the fewest seamounts.¹⁴ Overall there is a considerable bias towards the southern hemisphere. Figure 1 presents a map of estimated seamount locations.

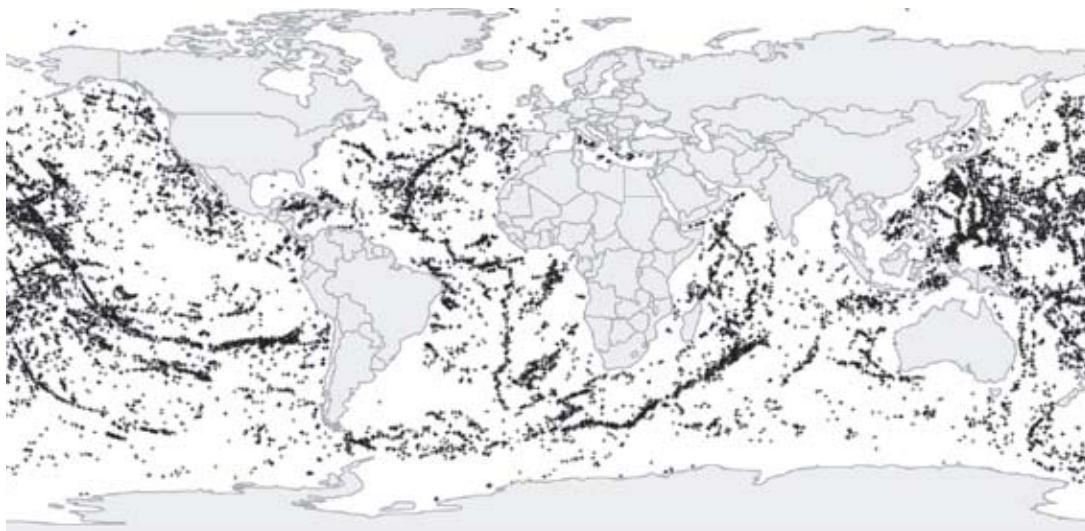


FIGURE 1: Estimated distribution of large seamounts.¹⁵ This map displays approximately 14,000 particularly well-defined (conical), seamounts. Including a wider range of seamount shape or ridge peak and size could increase their number to 100,000.¹⁶

B. STATUS AND TRENDS

Relatively few seamounts have been studied, with only about 350 having been sampled. Of these, fewer than 200 have been studied in any detail, many in waters within national jurisdiction.¹⁷ The sampling has not taken place evenly around the world, and for some regions, such as the Indian Ocean, very few seamount samples are available.¹⁸ Figure 2 presents a map of studied seamounts as prepared by SeamountsOnline, a global database on seamounts.

10 Kitchingman, A. and S. Lai. 2004. Inferences of potential seamount locations from mid-resolution bathymetric data. In *Seamounts: Biodiversity and Fisheries*. Fisheries Centre Research Report 12(5): 7–12.

11 Wessel, P. (2001) Global distribution of seamounts inferred from gridded Geosat/ERS-1 altimetry. *Journal of Geophysical Research* 106: 19431-19441.

12 Kitchingman, A. and S. Lai. 2004. Inferences of potential seamount locations from mid-resolution bathymetric data. In *Seamounts: Biodiversity and Fisheries*. Fisheries Centre Research Report 12(5): 7–12.

13 Global Census of Marine Life on Seamounts. <http://censeam.niwa.co.nz/>

14 Kitchingman, A. and S. Lai. 2004. Inferences of potential seamount locations from mid-resolution bathymetric data. In *Seamounts: Biodiversity and Fisheries*. Fisheries Centre Research Report 12(5): 7–12.

15 Kitchingman, A. and S. Lai. 2004. Inferences of potential seamount locations from mid-resolution bathymetric data. In *Seamounts: Biodiversity and Fisheries*. Fisheries Centre Research Report 12(5): 7–12.

16 Kitchingman, A. and S. Lai. 2004. Inferences of potential seamount locations from mid-resolution bathymetric data. In *Seamounts: Biodiversity and Fisheries*. Fisheries Centre Research Report 12(5): 7–12.

17 CenSeam, personal communication

18 Clark M.R., Tittensor D., Rogers A.D., Brewin P., Schlacher T., Rowden A., Stocks K., Consalvey M. (2006). Seamounts, deep-sea corals and fisheries: vulnerability of deep-sea corals to fishing on seamounts beyond areas of national jurisdiction. UNEP-WCMC, Cambridge, UK.

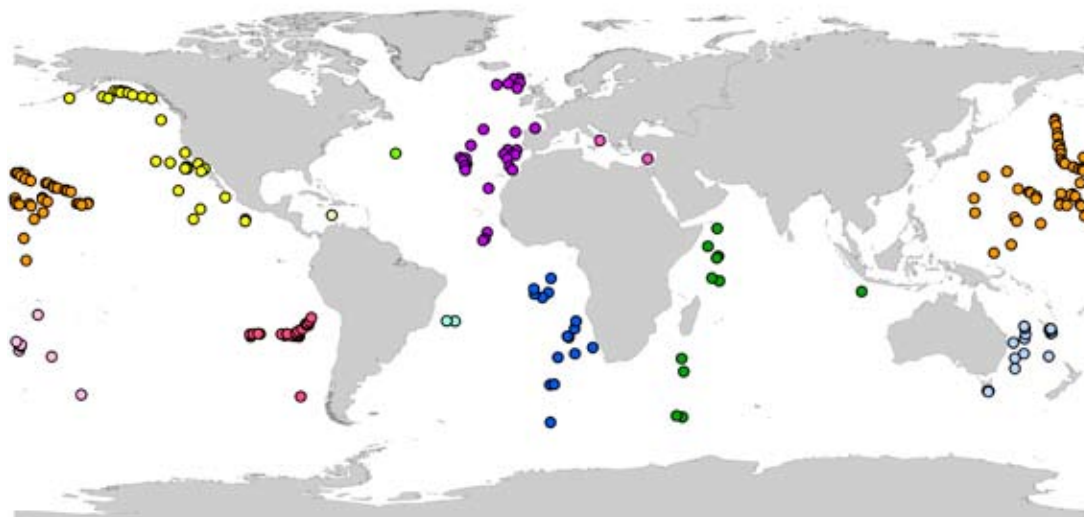


FIGURE 2: This map shows the seamounts for which SeamountsOnline currently has data. However, in many cases, the database only has records of one or a few species—the number of seamounts that have been well sampled is much smaller. In creating this map, a strict geological definition of “seamount” was not used—the map includes some features such as knolls and pinnacles that are less than 1000m high.¹⁹

Although seamount biodiversity is still poorly understood on a global scale due to lack of sampling and exploration, available research results suggest that seamounts are often highly productive ecosystems that can support high biodiversity²⁰ and special biological communities, including cold-water coral reefs, as well as abundant fisheries resources.^{21–22} Some evidence suggests high levels of endemic species on seamounts²³, although these levels may vary between individual seamounts,²⁴ regions and taxa,²⁵ and may, in some cases, be limited to species with low dispersal ability.²⁶ According to a Census of Marine Life workshop, “seamounts represent important ecosystems for study that have not, to date, received scientific attention consistent with their biological and ecological value.”²⁷ International initiatives such as the Census of Marine Life are attempting to fill key knowledge gaps relating to seamount community structure, diversity, endemism, and the impacts of exploitation on seamount communities. However, due to the large number of seamounts, their widespread distribution, and wide variability of physical and biological characteristics, it will take time before all questions can be answered.

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- 19 K. Stocks. 2008. Map of Seamounts in SeamountsOnline. SeamountsOnline: an online information system for seamount biology. World Wide Web electronic publication. <http://seamounts.sdsc.edu>.
- 20 Samadi S, Botton L, Macpherson E, Richer De Forges B, Boisselier M-C (2006) Seamount endemism questioned by the geographic distribution and population genetic structure of marine invertebrates. *Marine Biology* 149:1463–1475
- 21 Johnston PA, Santillo D (2004) Conservation of seamount ecosystems: application of a marine protected areas concept. *Archive of Fisheries and Marine Research* 51:305–319
- 22 Stocks, K.I. and P. J.B. Hart (2007) Biogeography and biodiversity of seamounts. Chapter 13 in Pitcher, T.J., Morato, T., Hart, P.J.B., Clark, M.R., Haggan, N. and Santos, R.S. (eds) Seamounts: Ecology, Conservation and Management. Fish and Aquatic Resources Series, Blackwell, Oxford, UK.
- 23 Stone, G, L Madin, K Stocks, G Hovermale, P Hoagland, M Schumacher, C Steve-Sotka, and H Tausig (2004). Chapter 2; Seamount Biodiversity, Exploitation and Conservation. In: *Defying Oceans End: an agenda for action*. Edited by Linda K. Glover and Sylvia Earle. Island Press. Pp 43–70
- 24 Stone, G, L Madin, K Stocks, G Hovermale, P Hoagland, M Schumacher, C Steve-Sotka, and H Tausig (2004). Chapter 2; Seamount Biodiversity, Exploitation and Conservation. In: *Defying Oceans End: an agenda for action*. Edited by Linda K. Glover and Sylvia Earle. Island Press. Pp 43–70
- 25 O’Hara, T.D. (2007) Seamounts: centres of endemism or species richness for ophiuroids? *Global Ecology and Biogeography* (OnlineEarly Articles).
- 26 Samadi S, Botton L, Macpherson E, Richer De Forges B, Boisselier M-C (2006) Seamount endemism questioned by the geographic distribution and population genetic structure of marine invertebrates. *Marine Biology* 149:1463–1475
- 27 Seamounts and Submarine Canyons. Report from a Census of Marine Life KUU Workshop. Hatfield Marine Science Center, Newport, Oregon, US 22–24 August 2003 Organizers: Karen Stocks, San Diego Supercomputer Center, U. of California San Diego, George Boehlert, Hatfield Marine Science Center, Oregon State University

Trend-related information is primarily available in regards to seamount fisheries. According to a preliminary assessment of global seamount fisheries,²⁸ estimated catches of primary seamount species such as *Oreosomatids* (oreo), *Hoplostethus atlanticus* (orange roughy) and *Dissostichus eleginoides* (Patagonian toothfish) remained low at less than 5,000 tonnes from the 1950s to the mid-1970s, but then increased to over 120,000 tonnes in the early 1990s. Catches of secondary seamount species (mainly tunas and mackerels) increased from less than 50,000 tonnes in the 1950s to around 350,000 tonnes in the 2000s. Other studies estimated that 150,000 to 250,000 tonnes of fish (primary and secondary seamount species) were caught from small-scale fisheries on seamounts globally, with half of the catch being tuna,²⁹ and that the total cumulative catch from seamount trawl fisheries may exceed 2.25 million tonnes.³⁰ Primary seamount species include those species whose survival depends on seamounts, while secondary seamount species are commonly found on seamounts, but are not exclusive to them.¹⁶

Rapid increase in catches of primary seamount species in the mid-1970s resulted from the availability of technology to find and explore deeper and distant fishing locations, such as seamounts^{16 31}. Catches of primary species appear to have peaked overall by the early 1990s, by which time it is likely that almost all productive seamounts were accessible to fisheries. It has been suggested that the apparent increase in catch was sustained by serial depletions of previously unexploited and inaccessible stocks.³² Serial expansion and depletion of seamount fisheries is also suggested by an increase, since the 1970s, in the catches of non-pelagic fishes from seamounts that are highly intrinsically vulnerable to fishing.³³ The increased interest of fishing fleets in seamounts beyond national jurisdiction may have been driven by the depletion of many coastal fisheries and the introduction and enforcement of 200 nautical mile exclusive economic zones (EEZs) around most nations' productive inshore waters.³⁴ Collectively, the studies cited here highlight the importance of seamount species to fisheries, and the concern for the sustainability of these fisheries.

C. THREATS

Seamount ecosystems may be vulnerable because of their geographical isolation,³⁵ which for some species may indicate genetic isolation.³⁶ They are also vulnerable because of the characteristics of their associated species, which include cold-water coral reefs that are fragile to physical disturbances from destructive

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- 28 Watson, R., A. Kitchingman, W. W. L. Cheung (2007) Catches from World Seamount Fisheries. Chapter 18 in Pitcher, T.J., Morato, T., Hart, P.J.B., Clark, M.R., Haggan, N. and Santos, R.S. (eds) Seamounts: Ecology, Conservation and Management. Fish and Aquatic Resources Series, Blackwell, Oxford, UK.
- 29 da Silva, H.M. and M. R. Pinho (2007) Small-scale fishing on seamounts . Chapter 16 in Pitcher, T.J., Morato, T., Hart, P.J.B., Clark, M.R., Haggan, N. and Santos, R.S. (eds) Seamounts: Ecology, Conservation and Management. Fish and Aquatic Resources Series, Blackwell, Oxford, UK.
- 30 Clark, M.R., V. I. Vinnichenko, J. D.M. Gordon, G. Z. Beck-Bulat, N. N. Kukharev and A. F. Kakora (2007) Large-scale distant-water trawl fisheries on seamounts. Chapter 17 in Pitcher, T.J., Morato, T., Hart, P.J.B., Clark, M.R., Haggan, N. and Santos, R.S. (eds) Seamounts: Ecology, Conservation and Management. Fish and Aquatic Resources Series, Blackwell, Oxford, UK
- 31 Morato T, Watson R, Pitcher TJ, Pauly D (2006a) Fishing down the deep. *Fish and Fisheries* 7:24–34
- 32 Cheung, W. W. L., Watson, R., Morato, T., Pitcher, T. J. and Pauly, D. 2007. Intrinsic vulnerability in the global fish catch. *Marine Ecology Progress Series* 333: 1–12.
- 33 Cheung, W.W.L., Watson, R., Morato, T., Pitcher, T.J. and Pauly, D. (2007) Intrinsic vulnerability in the global fish catch. *Marine Ecology Progress Series* 333: 1–12.
- 34 Watson, R., A. Kitchingman, W. W. L. Cheung (2007) Catches from World Seamount Fisheries. Chapter 18 in Pitcher, T.J., Morato, T., Hart, P.J.B., Clark, M.R., Haggan, N. and Santos, R.S. (eds) Seamounts: Ecology, Conservation and Management. Fish and Aquatic Resources Series, Blackwell, Oxford, UK. (in press).
- 35 Seamounts and Submarine Canyons. Report from a Census of Marine Life KUU Workshop. Hatfield Marine Science Center, Newport, Oregon, US 22–24 August 2003 Organizers: Karen Stocks, San Diego Supercomputer Center, U. of California San Diego, George Boehlert, Hatfield Marine Science Center, Oregon State University
- 36 Stone, G, L Madin, K Stocks, G Hovermale, P Hoagland, M Schumacher, C Steve-Sotka, and H Tausig (2004). Chapter 2; Seamount Biodiversity, Exploitation and Conservation. *In: Defying Oceans End: an agenda for action*. Edited by Linda K. Glover and Sylvia Earle. Island Press. Pp 43–70

practices such as bottom trawling, and long-lived, slow-growing fish species that are intrinsically vulnerable to fishing.³⁷

The biggest current threat to seamounts comes from fishing activities. Because of the increased productivity associated with some seamounts, seamount ecosystems can be characterized by abundant fisheries resources in comparison to the surrounding open ocean.³⁸ Innovation in fishing technology (i.e., specialized trawl gears for rocky sea bottom, global positioning system for locating seamounts) has enabled exploitation of rich seamount fisheries resources,³⁹ making seamounts the targets of recently developed high-technology fisheries and distant-water fleets,⁴⁰ with serial depletion and reduced genetic diversity the suggested results of exploitation.^{41 42 43} This has made many scientists cautious about the ability of seamount areas to support intensive exploitation.^{44 45 46 47 48} Watson and Morato (2004)⁴⁹ showed that seamount fisheries collapsed faster and recovered more slowly than non-seamount fisheries. Many species associated with seamounts, particularly primary seamount species, such as oreo, orange roughy and Patagonian toothfish, are characterized by slow growth, longevity, late sexual maturity, and restricted distribution, rendering them highly vulnerable to fishing^{50 51}. Over-exploitation of the pelagic armorhead over the Pacific seamounts northwest of Hawaii and the serial depletion of orange roughy stocks between southeastern Australia and New Zealand are examples of fishing as a threat to seamount-associated species.⁵²

Seamount trawl fisheries also have severe impacts on the benthic communities on seamounts, including fragile habitats, such as cold-water corals and other invertebrates.^{53 54 55} Comparative surveys of benthic macrofauna community structure at four seamounts found intact coral cover only on the un-fished and very lightly fished seamounts. The substrate of heavily fished Tasmanian seamounts was predominantly

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- 37 Morato T, Watson R, Pitcher TJ, Pauly D (2006a) Fishing down the deep. *Fish and Fisheries* 7:24–34
- 38 Johnston PA, Santillo D (2004) Conservation of seamount ecosystems: application of a marine protected areas concept. *Archive of Fisheries and Marine Research* 51:305–319
- 39 Clark, M.R. and J. A. Koslow (2007) Impacts of fisheries on seamounts. Chapter 19 in Pitcher, T.J., Morato, T., Hart, P.J.B., Clark, M.R., Haggan, N. and Santos, R.S. (eds) *Seamounts: Ecology, Conservation and Management*. Fish and Aquatic Resources Series, Blackwell, Oxford, UK
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- 50 Morato T, Cheung WWL, Pitcher TJ (2006b) Vulnerability of seamount fish to fishing: fuzzy analysis of life-history attributes. *Journal of Fish Biology* 67:1–13
- 51 Cheung, W. W. L., Watson, R., Morato, T., Pitcher, T. J. and Pauly, D. 2007. Intrinsic vulnerability in the global fish catch. *Marine Ecology Progress Series* 333: 1–12.
- 52 Johnston PA, Santillo D (2004) Conservation of seamount ecosystems: application of a marine protected areas concept. *Archive of Fisheries and Marine Research* 51:305–319
- 53 Clark M and O'Driscoll R (2003) Deepwater fisheries and aspects of their impact on seamount habitat in New Zealand. *J. Northw. Atl. Fish. Sci.* Vol 31: 441–458 (see www.nafo.ca/publications/journal/J31/session1/clark.pdf)
- 54 Clark, M.R. and J. A. Koslow (2007) Impacts of fisheries on seamounts. Chapter 19 in Pitcher, T.J., Morato, T., Hart, P.J.B., Clark, M.R., Haggan, N. and Santos, R.S. (eds) *Seamounts: Ecology, Conservation and Management*. Fish and Aquatic Resources Series, Blackwell, Oxford, UK
- 55 Koslow JA, Gowlett-Holmes K, Lowry JK, Hara TO, Poore GCB, Williams A (2001) Seamount benthic macrofauna off southern Tasmania: community structure and impacts of trawling. *Marine Ecology Progress Series* 213:111–125

bare rock (>90% at most depths), while the existing coral material was either rubble or sand.⁵⁶ Data suggest that virtually all coral aggregate, living or dead, was removed by the fishery, leaving behind bare rock and pulverized coral rubble. The results showed that the impact of trawling on complex coral reefs appears to be dramatic, with the coral substrate and associated community largely removed from the most heavily fished seamounts.

At the present time, deep-sea bottom fishing can reach depths around 2,000m. Thus seamounts that are found shallower than 2,000m may be particularly vulnerable to fishing. At shallow, heavily fished seamounts, most of the shift in community composition was ascribed to the impacts of trawling, which effectively removed the dominant colonial coral, *Solenosmilia variabilis*, and its associated fauna.⁵⁷ Because so few seamounts have been surveyed, it is not possible to say what percentage of all seamounts globally are impacted by fishing and other human activities. Fisheries have been moving faster than scientific research, monitoring and mapping in seamount areas. However, research suggests that many seamounts within fishable depths have already been affected by fishing, and a recent report on seamount biodiversity, exploitation and conservation states that “the authors know of no large, shallow seamounts that are in pristine condition”.⁵⁸

Other threats include the mining of deep-water corals associated with seamounts for the jewelry trade, bioprospecting, potential future seabed mining related to mineral resources of ferromanganese crusts and polymetallic sulphides (from vents, which may occur at some younger seamounts).⁵⁹ Climate change may also present a future threat as seamount community structure may change because of differences in species’ thermal preference and changes in ocean current patterns.

D. FUNCTIONING OF SEAMOUNT ECOSYSTEM AND ECOLOGY OF ASSOCIATED SPECIES

The presence of seamounts can generate ocean current dynamics (e.g., vertical nutrient fluxes) that make them highly productive ecosystems, capable of supporting substantial biodiversity, although the extent and variability of such enhanced productivity may vary.⁶⁰ Surveys in the Tasman Sea and southeast Coral Sea discovered more than 850 macro- and mega-faunal species, of which 29 to 34% are new to science and potential seamount endemics. The data suggested that seamounts that occur in clusters or are positioned along a ridge system might have highly localized species distributions and high endemism.⁶¹ Other studies have found high polychaete diversity⁶² with a decrease in the number of species and the

56 Roberts, S. and M. Hirshfield (2004) Deep-sea corals: out of sight, but no longer out of mind. *Frontiers in Ecology and the Environment* 2: 123–130

57 Koslow JA, Gowlett-Holmes K, Lowry JK, Hara TO, Poore GCB, Williams A (2001) Seamount benthic macrofauna off southern Tasmania: community structure and impacts of trawling. *Marine Ecology Progress Series* 213:111–125

58 Stone, G, L Madin, K Stocks, G Hovermale, P Hoagland, M Schumacher, C Steve-Sotka, and H Tausig (2004). Chapter 2; Seamount Biodiversity, Exploitation and Conservation. In: *Defying Oceans End: an agenda for action*. Edited by Linda K. Glover and Sylvia Earle. Island Press. Pp 43–70

59 Stone, G, L Madin, K Stocks, G Hovermale, P Hoagland, M Schumacher, C Steve-Sotka, and H Tausig (2004). Chapter 2; Seamount Biodiversity, Exploitation and Conservation. In: *Defying Oceans End: an agenda for action*. Edited by Linda K. Glover and Sylvia Earle. Island Press. Pp 43–70

60 White, M., I. Bashmachnikov, J. Aristegui and A. Martins (2007) Physical Processes and Seamount Productivity Chapter 4 in Pitcher, T.J., Morato, T., Hart, P.J.B., Clark, M.R., Haggan, N. and Santos, R.S. (eds) Seamounts: Ecology, Conservation and Management. Fish and Aquatic Resources Series, Blackwell, Oxford, UK

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

62 Gillet P, Dauvin J-C (2000) Polychaetes from the Atlantic seamounts of the southern Azores: biogeographical distribution reproductive patterns. *Journal of the Marine Biological Association of the United Kingdom* 80:651–661

number of individuals with depth,⁶³ suggesting that seamounts may form islands of biodiversity hotspots in the open ocean.

Many seamounts may support a large number of endemic species. Studies on seamounts off Southern Tasmania found that 60% of near-bottom fish species caught had not been previously recorded in the Australian ichthyofauna, or were undescribed. This indicates a specialized fauna restricted to the seamounts, probably containing many endemic species. Number of fish species appeared to diminish both on the deepest seamounts and on the most heavily fished seamounts. Invertebrate samples taken in the same area found that 26 to 44% might be new to science, and 35% appeared to be restricted to the seamount habitat. Approximately 48% were apparently endemic to the region.⁶⁴ Dense and diverse invertebrate communities are found on Tasmanian seamounts dominated by suspension feeders, including reef-forming and gorgonian corals, hydroids, and sponges. Twenty four to 43% of these species are new to science, and 16 to 33% are endemic to the seamount environment.⁶⁵

A review of studies on the biogeography and biodiversity of seamounts found that rates of endemism between 10 and 50% had been reported in medium- and large-scale studies, while the level of seamount biodiversity relative to other habitats in similar environments varied between studies⁶⁶. On the other hand, genetic analysis of several crustaceans and gastropods in Norfolk Ridge seamounts suggests that the genetic structure of some of these species is similar to those found on the New Caledonia slope, and that endemism may be more commonly found in species with limited dispersal ability⁶⁷. Also, in the Tasman and Coral Seas (east and southeast Australia), species diversity and level of endemism of brittle-stars (*Ophiuroidea*) on seamounts appears to be similar to the adjacent continental slopes⁶⁸. Overall, however, the majority of studies support the hypothesis that seamounts are biodiversity hotspots,⁶⁹ at least in areas beyond the limits of national jurisdiction, which are some distance away from continental slopes.

Seamount-aggregating fish are found to be, on average, biologically more vulnerable to fishing than other marine fish. As indicated in the previous section, several studies have focused on the vulnerability of seamount species to fishing, including commercially valuable species found aggregating on or around seamounts. These species include marine top predators, such as bigeye tuna (*Thunnus obesus*) and yellowfin tuna (*Thunnus albacares*) in Hawaii.⁷⁰ Recent estimates suggest that half of the worldwide catches from small-scale fisheries on seamounts are tuna⁷¹. Globally, species diversity of marine predators peaked consistently close to prominent topographic features such as seamounts⁷². Many of these species are

63 Gillet P, Dauvin J-C (2003) Polychaetes from the Irving, Meteor and Plato seamounts, North Atlantic ocean: origin and geographical relationships. *Journal of the Marine Biological Association of the United Kingdom* 83:49–53

64 Koslow JA, Gowlett-Holmes K, Lowry JK, Hara TO, Poore GCB, Williams A (2001) Seamount benthic macrofauna off southern Tasmania: community structure and impacts of trawling. *Marine Ecology Progress Series* 213:111–125

65 Roberts S, Hirshfield M (2004) Deep-sea corals: out of sight, but no longer out of mind. *Frontier in Ecology and Environment* 2:123–130

66 Stocks, K.I. and P. J.B. Hart (2007) Biogeography and biodiversity of seamounts. Chapter 13 in Pitcher, T.J., Morato, T., Hart, P.J.B., Clark, M.R., Haggan, N. and Santos, R.S. (eds) *Seamounts: Ecology, Conservation and Management*. Fish and Aquatic Resources Series, Blackwell, Oxford, UK.

67 Samadi S, Botton L, Macpherson E, Richer De Forges B, Boisselier M-C (2006) Seamount endemism questioned by the geographic distribution and population genetic structure of marine invertebrates. *Marine Biology* 149:1463–1475

68 O'Hara, T.D. (2007) Seamounts: centres of endemism or species richness for ophiuroids? *Global Ecology and Biogeography* (OnlineEarly Articles).

69 Samadi S, Botton L, Macpherson E, Richer De Forges B, Boisselier M-C (2006) Seamount endemism questioned by the geographic distribution and population genetic structure of marine invertebrates. *Marine Biology* 149:1463–1475

70 Itano DG, Holland KN (2000) Movement and vulnerability of bigeye (*Thunnus obesus*) and yellowfin tuna (*Thunnus albacares*) in relation to FADs and natural aggregation points. *Aquatic Living Resources* 13:213–223

71 da Silva, H.M. and M. R. Pinho (2007) Small-scale fishing on seamounts . Chapter 16 in Pitcher, T.J., Morato, T., Hart, P.J.B., Clark, M.R., Haggan, N. and Santos, R.S. (eds) *Seamounts: Ecology, Conservation and Management*. Fish and Aquatic Resources Series, Blackwell, Oxford, UK.

72 Worm, B., H.K. Lotze, and R.A. Myers. 2003. Predator diversity hotspots in the blue ocean. *Proceedings of the National Academy of Science USA*. 100: 9884–9888

large-bodied (a proxy of high intrinsic vulnerability⁷³) and display aggregation behaviour,⁷⁴ rendering them vulnerable to fishing. Particularly, deepwater demersal fish found around seamounts are large-sized, slow growing, late maturing, and undergo extended periods of very low recruitment. These life history characteristics render them less able to withstand fishing mortality^{75 76 77}. Additionally, the localized distribution of many benthic seamount species greatly increases the threat of extinction and may require that conservation and protection of seamount communities be undertaken on a local scale⁷⁸.

In addition to acting as feeding grounds for fishes and marine mammals,⁷⁹ seamounts can also attract seabirds, which feed on prey items concentrated around seamounts. An aggregation of seabirds over Fieberling Guyot, an isolated mid-ocean seamount in the eastern North Pacific Ocean, was found to have seabird density and biomass respectively 2.4 and 8 times higher than the surrounding ocean area. Individual seabird taxa were 2 to 40 times more abundant at the seamount relative to values reported previously from large-scale surveys of deep-ocean regions in the central North Pacific.⁸⁰ A review of seabird associations with seamounts suggests that a wide range of seabird species utilizes marine resources associated with seamounts, although the intensity of such associations is generally not clear⁸¹. Associations of marine mammals with seamounts are widely documented, but direct evidence of seamounts being preferred marine mammal habitat is rare.⁸²

Seamounts may play an important role in understanding patterns of marine biogeography, as hot-spots for the evolution of new species, refuges for ancient species, and stepping-stones for species to spread across ocean basins^{83 84 85}. The degree to which seamounts are genetically isolated is not well understood. Some studies have suggested that there is limited gene flow between seamounts only for those species with limited dispersal abilities, while species with good dispersal abilities are spread throughout a wider area.⁸⁶ Seamounts may be highly productive zones that can support numerous species in small areas and can act as sources of larvae for surrounding areas.⁸⁷ However, the importance of seamount assem-

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- 73 Reynolds, J.D., Dulvey, N.K., Hutchings, J.A. (2005) Biology of extinction risk in marine fishes. *Proc. Royal Soc. Ser. B* 272:2337–2344.
- 74 Cheung, W.W.L., Pitcher, T.J. and Pauly, D. (2005) A fuzzy logic expert system to estimate intrinsic extinction vulnerability of marine fishes to fishing. *Biol. Conserv.* 124: 97–111.
- 75 Morato T, Cheung WWL, Pitcher TJ (2006b) Vulnerability of seamount fish to fishing: fuzzy analysis of life-history attributes. *Journal of Fish Biology* 67:1–13
- 76 Richer de Forges B, Koslow JA, Poore GCB (2000) Diversity and endemism of the benthic seamount fauna in the southwest Pacific. *Nature* 405:944–947
- 77 Cheung, W. W. L., Watson, R., Morato, T., Pitcher, T. J. and Pauly, D. 2007. Intrinsic vulnerability in the global fish catch. *Marine Ecology Progress Series* 333: 1–12.
- 78 Richer de Forges B, Koslow JA, Poore GCB (2000) Diversity and endemism of the benthic seamount fauna in the southwest Pacific. *Nature* 405:944–947
- 79 Johnston PA, Santillo D (2004) Conservation of seamount ecosystems: application of a marine protected areas concept. *Archive of Fisheries and Marine Research* 51:305–319
- 80 Haney JC, Haury LR, Mullineaux LS (1995) Sea-bird aggregation at a deep North Pacific seamount. *Marine Biology* 123:1–9
- 81 Thompson, D.R. (2007) Air-breathing visitors to seamounts: Importance of seamounts to seabirds. Chapter 12C in Pitcher, T.J., Morato, T., Hart, P.J.B., Clark, M.R., Haggan, N. and Santos, R.S. (eds) *Seamounts: Ecology, Conservation and Management*. Fish and Aquatic Resources Series, Blackwell, Oxford, UK.
- 82 Kaschner, K. (2007) Air-breathing visitors to seamounts: marine mammals. Chapter 12 A in Pitcher, T.J., Morato, T., Hart, P.J.B., Clark, M.R., Haggan, N. and Santos, R.S. (eds) *Seamounts: Ecology, Conservation and Management*. Fish and Aquatic Resources Series, Blackwell, Oxford, UK.
- 83 Stone, G, L Madin, K Stocks, G Hovermale, P Hoagland, M Schumacher, C Steve-Sotka, and H Tausig (2004). Chapter 2; Seamount Biodiversity, Exploitation and Conservation. In: *Defying Oceans End: an agenda for action*. Edited by Linda K. Glover and Sylvia Earle. Island Press. Pp 43–70.
- 84 Koslow, J. A., K. Gowlett-Holmes, J. K. Lowry, T. O'Hara, G. C. B. Poore and A. Williams. 2001. Seamount benthic macrofauna off southern Tasmania: community structure and impacts of trawling. *Marine Ecology Progress Series*, 213:111–125.
- 85 Richer de Forges B, JA Koslow, GCB Poore (2000), Diversity and endemism of the benthic seamount macrofauna in the Southwestern Pacific. *Nature*, 405:944–947.
- 86 Samadi S, Bottan L, Macpherson E, Richer De Forges B, Boisselier M-C (2006) Seamount endemism questioned by the geographic distribution and population genetic structure of marine invertebrates. *Marine Biology* 149:1463–1475
- 87 Samadi S, Bottan L, Macpherson E, Richer De Forges B, Boisselier M-C (2006) Seamount endemism questioned by the geographic distribution and population genetic structure of marine invertebrates. *Marine Biology* 149:1463–1475

blages to regional biogeography needs to be confirmed. Patterns of colonization appear to be related to dominant current flows in an area, explaining, for example, similarities between European and African seamount fauna.⁸⁸ Cluster analysis can be used to distinguish groups of seamounts with high percentages of similar species,⁸⁹ potentially leading to the development of a biogeographic classification of seamounts in the future. However, at the present time, this approach is limited by few comparable data between seamounts.

88 Gillet P, Dauvin J-C (2000) Polychaetes from the Atlantic seamounts of the southern Azores: biogeographical distribution reproductive patterns. *Journal of the Marine Biological Association of the United Kingdom* 80:651–661

89 Gillet P, Dauvin J-C (2003) Polychaetes from the Irving, Meteor and Plato seamounts, North Atlantic ocean: origin and geographical relationships. *Journal of the Marine Biological Association of the United Kingdom* 83:49–53

III. COLD-WATER CORALS

A. GLOBAL DISTRIBUTION

Cold-water corals include stony corals (*Scleractinia*), soft corals (*Octocorallia*), black corals (*Antipatharia*), and hydrocorals (*Stylasteridae*). They are widely distributed and have thus far been found in the Atlantic, Mediterranean, Indian, Pacific and Southern oceans⁹⁰. Most of the cold-water corals discovered to date appear to be on the edges of the continental shelf or on seamounts⁹¹. The majority of cold-water coral reefs have been found in the northern Atlantic Ocean (e.g., Norwegian Shelf, Rockall Trough, Darwin Mounds, Porcupine Seabight, Azores, Madeira and Canary Islands, Atlantic Canada, United States, Scotian Shelf). These reefs are usually dominated by the coral genera *Lophelia* and *Madrepora*. One of the largest reef complexes in the world, the Sula Ridge Complex was found off the Norwegian coast. It is over 14 km long and grows to a height of 35 m from the seabed⁹².

Reefs are also found in the Mediterranean Sea and Pacific Ocean. In the Southern hemisphere, extensive cold-water coral reefs and assemblages are found associated with seamounts in the waters off Australia and New Zealand. These reefs are mainly dominated by the genera *Solenosmilia* and *Madrepora*^{93 94 95}.

Our present knowledge about the global distribution of cold-water corals is still incomplete and skewed by the geographically varied levels of research activity and the developed world's bias toward deep-water mapping initiatives⁹⁶. The total area covered by cold-water coral reefs globally is still unknown, although studies indicate that coverage could equal, or exceed, that of warm-water reefs. A conservative estimate of cold-water coral reef coverage is 284,300 km²⁹⁷.

Cold-water coral reefs and mounds tend to cluster in “provinces” where specific hydrodynamic and food-supply conditions favour coral growth⁹⁸. They are largely restricted to sea-water temperatures between 4 and 12°C. They are generally found in shallower waters (~50–1200 m) at high latitudes, and at great depths (up to 4000 m) at low latitudes. For example, in the southern Rockall Trough, living *Lophelia pertusa* is most abundant between 600 and 800m,⁹⁹ and the abundance peak tends to occur in shallower waters towards higher latitudes¹⁰⁰.

There is a strong relationship between the number of cold-water scleractinian coral occurrences and the depth of the aragonite saturation horizon (ASH), which is the depth above which aragonite and calcite

90 Freiward, A. and Roverts, J.M. (eds.) 2005. Cold-water Corals and Ecosystems. Springer-Verlag, Berlin Heidelberg.

91 Roberts S, Hirshfield M (2004) Deep-sea corals: out of sight, but no longer out of mind. *Frontier in Ecology and Environment* 2:123–130

92 The Lophelia.org website at <http://www.lophelia.org> (checked on 14 March 2007)

93 Koslow, J.A., Gowlett-Holmes, K., Lowry, J.K, O'Hara, T.O., G.C.B. Poore and A. Williams (2001) Seamount benthic macrofauna off southern Tasmania: community structure and impacts of trawling. *Marine Ecology Progress Series*: 213: 111–125.

94 Clark M and O'Driscoll R (2003) Deepwater fisheries and aspects of their impact on seamount habitat in New Zealand. *J. Northw. Atl. Fish. Sci.* Vol 31: 441–458 (see www.nafo.ca/publications/journal/J31/session1/clark.pdf)

95 Rogers, A.D. (2004) The Biology, Ecology and Vulnerability of Deep-Water Coral Reefs. Report for the World Conservation Union for the 7th Convention of Parties, Convention for Biodiversity, Kuala Lumpur, February 8th–19th. 8pp. Available at <http://www.iucn.org/themes/marine/pubs/pubs.htm>

96 Roberts JM, Wheeler AJ, Freiwald A (2006) Reefs of the deep: the biology and geology of cold-water coral ecosystems. *Science* 312:543–547

97 Freiwald, A., J.H Fosså, A. Grehan, T. Koslow and J. M. Roberts. 2004. Cold-water Coral Reefs. UNEP-WCMC, Cambridge, UK.

98 Roberts JM, Wheeler AJ, Freiwald A (2006) Reefs of the deep: the biology and geology of cold-water coral ecosystems. *Science* 312:543–547

99 White, M., Mohn, C., de Stigter, H. and Mottram, G. (2005) Deep-water coral development as a function of hydrodynamics and surface productivity around the submarine banks of the Rockall Trough, NE Atlantic. In: Freiwald, A. and Roberts, J.M. (eds.). pp. 503–514. *Cold-water Corals and Ecosystems*. Springer-Verlag Berlin Heidelberg.

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

(carbonate minerals) are saturated and stable. However, aragonite and calcite become more soluble with increasing depth (hence decreasing temperature and increasing pressure). Below the ASH, carbonate becomes under-saturated and structures made of calcium carbonate are vulnerable to being dissolved. Such conditions are unfavourable for the growth of coral.

Cold-water corals are also associated with strong near-seabed currents, which help them maintain food supply, disperse eggs, sperm and larvae, remove waste products and avoid being smothered by sediments. The influence of food supply on distribution is demonstrated by the abundance of *Lophelia pertusa* at depth ranges where bottom water mixing maintains an enhanced flux of particles¹⁰¹.

The global distribution of cold-water coral reefs is not yet well known, and new reefs continue to be discovered¹⁰². A map of known cold-water coral reefs can be seen in figure 3.

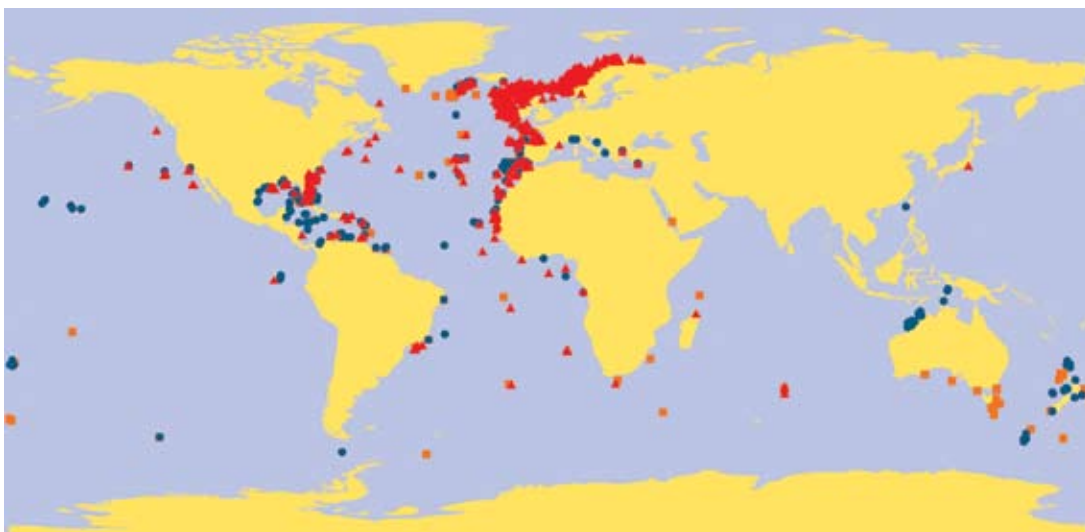


FIGURE 3: Distribution of known cold-water coral areas based on species distributions, *Lophelia pertusa* (red triangles), *Madrepora oculata* (blue circles) and *Solenosmilia varialilis* (orange squares) (UNEP-WCMC sourced from A. Freiwald from various sources)

Several other factors may contribute to the distribution of cold-water coral reefs. For example, distribution and abundance of corals have been found, in some cases, to be related to large-scale topographic features, such as the shelf breaks, ridges and seamounts, as well as to the types of bottom structure, near-bottom temperature and salinity^{103 104}. Corals require hard surface on which to attach,¹⁰⁵ and they are often found in deep salty waters where bacterial activity maintains high oxygen concentrations¹⁰⁶. It has also been proposed that upward seepage of hydrocarbon-charged porewater favours the growth of

101 Frederiksen, R., Jensen, A. and Westerberg, J. (1992) The distribution of the scleractinian coral *Lophelia pertusa* around the Faroes islands and the relation to internal tidal mixing. *Sarsia*, 77: 157–171.

102 Roberts JM, Wheeler AJ, Freiwald A (2006) Reefs of the deep: the biology and geology of cold-water coral ecosystems. *Science* 312:543-547

103 Mortensen PB, Buhl-Mortensen L (2004) Distribution of deep-water gorgonian corals in relation to benthic habitat features in the Northeast Channel (Atlantic Canada). *Marine Biology* 114:1223–1238

104 Rogers, AD (1999) The biology of *Lophelia pertusa* (Linnaeus 1758) and other deep-water reef-forming corals and impacts from human activities. *International Review of Hydrobiology*, 84(4) 315–406

105 Rogers, A.D. (2004) The Biology, Ecology and Vulnerability of Deep-Water Coral Reefs. Report for the World Conservation Union for the 7th Convention of Parties, Convention for Biodiversity, Kuala Lumpur, February 8th–19th. 8pp. Available at Available at <http://www.iucn.org/themes/marine/pubs/pubs.htm>

106 Freiwald, A., Huehnerbach, V., Lindberg, B., Wilson, J.B. and Campbell, J. (2002) The Sula Reef Complex, Norwegian Shelf. *Facies*, 47, 179–200.

bacteria and other micro-organisms, thus providing locally produced nutrients for cold-water corals¹⁰⁷. For instance, relatively high concentrations of light hydrocarbons have been found in the sediment and the base of the *Lophelia pertusa* reef in the Norwegian Sea off mid-Norway, and it has been suggested that seepage is a main factor determining the distribution of *Lophelia pertusa* reefs in Norwegian waters¹⁰⁸. However, based on the available evidence, there is no proof that the Norwegian deep-water coral reefs, or any other of the world's deep-water carbonate mounds and coral reefs, are directly fuelled by seepage.

Observations show that black corals (antipatharians) and horny corals (gorgonians) are more abundant near peaks of seamounts, compared with mid-slope sites at corresponding depths. The abundance of corals also increases on knobs and pinnacles. Physical models and observations, together with direct measurements, suggest that seamount topography affects the local current regime by deflecting and accelerating tidal flow and circulation patterns¹⁰⁹. Corals appear to benefit from flow acceleration, and some of their patterns of distribution can be explained by current flow conditions¹¹⁰. These models and observations support the importance of seamounts and banks as habitat for cold-water corals.

B. STATUS AND TRENDS

There are still large gaps in our understanding of the distribution of cold-water coral reefs, their biology and ecology. These gaps are mainly due to the difficulty of researching these environments, where observation and sampling often require expensive ship time including sophisticated equipment such as submersibles, remotely operated vehicles, underwater video or other ship-based remote sensing equipment. Our current knowledge consists of a series of snapshots of well-studied reefs, most of which are located in the higher latitudes, including the intensively mapped and studied *Lophelia* reefs in Norway. In contrast, although cold-water coral reefs are known to exist on the Mid-Atlantic Ridge, off the coasts of Africa, South America and in the Pacific, these reefs have not generally been subjected to detailed studies and mapping. On-going research projects in a number of countries and the European Community are expected to fill some knowledge gaps¹¹¹. Examples of such research projects include the recent mapping of predicted habitat suitability for seamount stony corals by the Census of Marine Life on Seamounts (CenSeam)¹¹² and Norwegian efforts to identify potential coral areas by analyzing seafloor topography on maps, and to rapidly and reliably ground-truth potential coral areas with simple and inexpensive systems¹¹³. Additionally, NOAA's Undersea Research Programme continues mapping and research of cold-water coral reefs in Hawaii, the Aleutian Islands, off Florida and the Northeast coast of the United States¹¹⁴.

According to currently available knowledge, cold-water corals can exist as small, scattered colonies of no more than a few metres in diameter to vast reef complexes measuring several tens of kilometres across. Radioactive dating techniques have shown that some living banks and reefs are up to 8000 years old, and

107 Hovland M, Thomsen E (1997) Cold-water corals—are they hydrocarbon seep related? *Marine Geology* 137:159–164

108 Hovland M, Risk M (2003) Do Norwegian deep-water coral reefs rely on seeping fluids? *Marine Geology* 198:83–96

109 Mohn, C. and Beckmann, A. 2002. Numerical studies on flow amplification at an isolated shelf break bank, with application to Porcupine Bank. *Cont. Shelf Res.* 22: 1325–1338.

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

111 Freiwald, A., J.H Fosså, A. Grehan, T. Koslow and J. M. Roberts. 2004. Cold-water Coral Reefs. UNEP-WCMC, Cambridge, UK

112 Clark M.R., Tittensor D., Rogers A.D., Brewin P., Schlacher T., Rowden A., Stocks K., Consalvey M. (2006). Seamounts, deep-sea corals and fisheries: vulnerability of deep-sea corals to fishing on seamounts beyond areas of national jurisdiction. UNEP-WCMC, Cambridge, UK.

113 Fosså JH, Lindberg B, Christensen O, Lundälv T, Svellingen I, Mortensen PB, Alvsvåg J 2005. Mapping of *Lophelia* reefs in Norway: experiences and survey methods. In: Freiwald A, Roberts JM (eds) Cold-water Corals and Ecosystems. Springer, Berlin Heidelberg. p 359–391.

114 NOAA's Undersea Research Program (NURP) at <http://www.nurp.noaa.gov/DSCorals.htm>

geological records indicate that cold-water coral reefs have existed for millions of years¹¹⁵. About 20 of the 703 known species of deep-sea stony corals build reef structures. Major reef-forming species include *Lophelia pertusa*, *Madrepora oculata*, *Solenosmilia variabilis* and *Oculina varicosa* (ivory tree coral). It is estimated that more than a hundred deep-sea coral and sponge species live in the North Pacific off Alaska, at least 34 of which are corals. Researchers estimate that roughly 800 species of stony corals alone have yet to be discovered¹¹⁶.

Cold-water coral reefs are associated with rich and diverse assemblages of marine life and are home to thousands of other species, in particular animals like sponges, polychaetes (bristle worms), crustaceans (crabs, lobsters), echinoderms (starfish, sea urchins, brittle stars, feather stars), bryozoans (sea moss) and fish¹¹⁷. More information about species associated with cold-water reefs can be found in section d.

The overall ecological health status of cold-water coral reefs is unknown. Most of the reefs studied thus far show physical damage from trawling activities. Only in a few cases has this damage been quantified. The Norwegian Institute of Marine Research estimated that probably between 30 and 50% of the coral reefs known to exist, or expected to be found, in Norwegian waters had been partially or totally damaged by bottom trawling activities, which had been on-going since the mid-1980s. Widespread trawling damage has been documented on coral reefs at depths between 840 and 1300 m along the West Ireland continental shelf break and at 200m off West Norway¹¹⁸. From 1990 to 2002, the United States federal fishery observer data indicate that approximately 2,176,648 kg of coral and sponge bycatch occurred in the Aleutian Islands, equivalent to 52% of all coral and sponge bycatch in Alaska. Additionally, damage created by trawls and other fishing activities has been documented in many areas, including in the Northeast Atlantic, and in Canadian, United States, New Zealand and Australian waters¹¹⁹. The rate of regeneration and recovery of once-damaged cold-water coral reefs is unknown, but is estimated to be on the scale of decades to centuries for a reef to regain ecological function owing to the very slow growth rate of cold-water coral reefs¹²⁰.

Many countries are undertaking measures for protecting cold-water coral reefs in their national EEZs. For example, Norway was the first country to have implemented protection measures in Europe by closing an area of about 1,000 km² in 1999 to protect *Lophelia* reefs. Protection for cold-water coral reefs is also afforded under the OSPAR Convention (as one of their priority habitats for protection) and under EC regulations¹²¹. The EU closed the Darwin Mounds northwest of Scotland to bottom scraping fishing gear in 2003 to protect the *Lophelia* reef in the area. Other areas closed to bottom fishing to protect cold-water coral habitat include areas off Florida and California (the Davidson Seamount) in the USA, areas off Nova Scotia in Canada, and 19 seamounts in New Zealand waters. Globally, the United Nations General Assembly has adopted recommendations for action in relation to destructive fishing practices including in areas beyond national jurisdiction¹²². No protected area aiming at conserving cold-water corals in the high seas has been established so far.

115 Freiwald, A., J.H Fosså, A. Grehan, T. Koslow and J. M. Roberts. 2004. Cold-water Coral Reefs. UNEP-WCMC, Cambridge, UK.

116 Roberts S, Hirshfield M (2004) Deep-sea corals: out of sight, but no longer out of mind. *Frontier in Ecology and Environment* 2:123–130

117 Freiwald, A., J.H Fosså, A. Grehan, T. Koslow and J. M. Roberts. 2004. Cold-water Coral Reefs. UNEP-WCMC, Cambridge, UK.

118 Hall-Spencer, J., Allain, V. and J. H. Fosså (2001) Trawling damage to Northeast Atlantic ancient coral reefs. *Proceedings of the Royal Society of London*. 269: 507-511.

119 Freiwald, A., J.H Fosså, A. Grehan, T. Koslow and J. M. Roberts. 2004. Cold-water Coral Reefs. UNEP-WCMC, Cambridge, UK.

120 Freiwald, A., J.H Fosså, A. Grehan, T. Koslow and J. M. Roberts. 2004. Cold-water Coral Reefs. UNEP-WCMC, Cambridge, UK.

121 EC Reg. 1568/2005

122 In particular, see resolution 61/105, paragraphs 80–87.

C. THREATS

Major threats to cold-water corals include destructive fishing practices, such as bottom trawling, other bottom-contact fishing (e.g. mid-water trawls may drag the bottom, long lines may snag on corals), hydrocarbon drilling, seabed mining, ocean acidification and direct exploitation. At the present time, bottom trawling is the biggest threat to cold-water coral reefs, causing mechanical breakage of the reef structure. Cold-water corals are also threatened by direct exploitation. For example, corals on Tasmanian seamounts were substantially damaged by bottom trawling for orange roughy and oreos¹²³. The gorgonian coral *Corallium lauuense*, which is found on Hawaiian seamounts, is suffering inbreeding depression (a reduction in fitness and vigor of individuals as a result of increased *homozygosity* through inbreeding) that might have been caused by exploitation of its skeleton for jewelry making¹²⁴. As mentioned in the previous section, widespread trawling damage to cold-water coral reefs has been documented along the West Ireland continental shelf break and off West Norway. Coral bycatch included a diverse array of sessile suspension feeders (e.g., sponges, hydroids, anemones, *serpulids*, barnacles, bivalves, bryozoans, brachiopods, crinoids and tunicates). Coral bycatches from West Ireland had more diverse coral assemblages than those encountered in Norway¹²⁵. Coral bycatch from the South Tasman Rise orange roughy fishery comprised of a large number of species, but was dominated by the reef-forming stony coral *Solenosmilia variabilis*¹²⁶.

Depletion of fisheries resources that are associated with cold-water corals may have an impact on the coral community. Cold-water coral reefs and associated communities on seamounts may be at increased risk from large-scale disturbances due to the localized distribution of seamounts and the limited larval phase in plankton of many species¹²⁷; this may limit their rate of recovery after disturbance. Rich fishery resources associated with seamounts attract fishing efforts and indirectly increase the risk of disturbance to seamount-associated coral reefs.

Ocean acidification presents a potentially serious future threat. Increase in atmospheric carbon dioxide (CO₂) can increase the acidity of seawater through increased CO₂ dissolution. Acidic water de-saturates aragonite in water, making conditions unfavourable for corals to build their carbonate skeletons. Current research predicts that tropical coral calcification would be reduced by up to 54% if atmospheric carbon dioxide doubled. Because of the lowered carbonate saturation state at higher latitudes and in deeper waters, cold-water corals may be even more vulnerable to acidification than their tropical counterparts.¹²⁸ Also, the depth at which aragonite dissolves could become shallower by several hundred metres, thereby raising the prospect that areas once suitable for cold-water coral growth will become inhospitable in the

123 Koslow, J.A. and Gowlet-Holmes, K. 1998. The seamount fauna of southern Tasmania benthic communities: their conservation and impacts of trawling. Final report to Environment Australia and the Fisheries Research Development Corporation, Hobart, Tasmania: CSIRO.

124 Roberts JM, Wheeler AJ, Freiwald A (2006) Reefs of the deep: the biology and geology of cold-water coral ecosystems. *Science* 312:543–547

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

126 Anderson, O.F. and Clark, M.R. (2003) Analysis of bycatch in the fishery for orange roughy, *Hoplostethus atlanticus*, on the South Tasman Rise. *Marine and Freshwater Research* 54: 643–652.

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

128 Orr, J.C., Fabry, V.J., Aumont, O., Bopp, L., Doney, S.C., Feely, R.A., Gnanadesikan, A., Gruber, N., Ishida, A., Joos, F., Key, R.M., Lindsay, K., Maier-Reimer, E., Matear, R., Monfray, P., Mouchet, A., Najjar, R.G., Plattner, G., Rodgers, K.B., Sabine, C.L., Sarmiento, J.L., Schlitzer, R., Slater, R.D., Totterdell, I.J., Weirig, M., Yamanaka, Y. and Yool, A. (2005) Anthropogenic ocean acidification over the twenty-first century and its impact on calcifying organisms. *Nature* 437: 681–686.

future.¹²⁹ It is predicted that 70% of the 410 known locations with deep-sea corals may be in aragonite-undersaturated waters by 2099.¹³⁰

There is little evidence that hydrocarbon exploitation substantially threatens cold-water coral ecosystems¹³¹. The greatest concern is the potential for drill cuttings to smother reef fauna, but such effects would be highly localized compared to the disturbance caused by destructive fishing practices such as bottom trawling. Mining activities risk causing local extinctions of endemic species of cold-water corals and may have regional impacts from benthic disturbance, sediment plumes and nutrient-enriched and potentially toxic wastewater^{132 133}. Corals may live in the vicinity of extinct vents as well as atop seamounts¹³⁴, increasing the risk to them from activities targeting those ecosystems.

In addition to the major threats mentioned above, scientific research and bioprospecting may also be threats to cold-water coral reefs if unsustainably conducted. Besides their ecological importance, deep-sea corals and sponges have potential as pharmaceuticals, nutritional supplements, enzymes, pesticides, cosmetics, and other commercial products^{135 136}. The potential commercial uses of cold-water coral reefs and associated species, if found profitable, may lead to increased sampling and direct exploitation. Such activities, if ineffectively managed, may pose serious threats to cold-water coral reefs and their associated species¹³⁷.

D. FUNCTIONING OF COLD-WATER CORAL ECOSYSTEM AND ECOLOGY OF ASSOCIATED SPECIES

Cold-water coral reefs, like their tropical warm and shallow-water counterparts, are built predominately by stony corals (*Scleractinia*). Unlike tropical reefs, cold-water corals do not have light-dependent symbiotic algae in their tissues, thus they depend solely on current-transported particulate organic matter and zooplankton (animal plankton) for their food. They grow slowly, at only a tenth of the growth rate of warm-water tropical corals. Many of them produce calcium carbonate skeletons that resemble bushes or trees and provide habitat for associated animal communities¹³⁸.

The reproductive biology of cold-water corals is poorly known, and only a limited number of species have had their reproductive histories described¹³⁹. Based on current understanding, unlike the shallow-water hard corals (*scleractinians*), only a few species of cold-water corals are hermaphroditic (mainly solitary corals of the genus *Caryophyllia*). On the other hand, 12 of the 15 species of cold-water corals

129 Roberts JM, Wheeler AJ, Freiwald A (2006) Reefs of the deep: the biology and geology of cold-water coral ecosystems. *Science* 312:543-547

130 Guinotte, J.M., Orr, J., Cairns, S., Freiwald, A., Morgan, L. and George, R. (2006) Will human-induced changes in seawater chemistry alter the distribution of deep-sea scleractinian corals? *Front. Ecol. Environ.* 4(3): 141-146.

131 Roberts JM, Wheeler AJ, Freiwald A (2006) Reefs of the deep: the biology and geology of cold-water coral ecosystems. *Science* 312:543-547

132 Halfar, J. and Fujita, R.M. (2007) Danger of deep-sea mining. *Science*. 316: 987.

133 Schrope, M (2007) Digging deep. *Nature*. 447: 246-247.

134 Stone, G, L Madin, K Stocks, G Hovermale, P Hoagland, M Schumacher, C Steve-Sotka, and H Tausig (2004). Chapter 2; Seamount Biodiversity, Exploitation and Conservation. In: *Defying Oceans End: an agenda for action*. Edited by Linda K. Glover and Sylvia Earle. Island Press. Pp 43-70

135 Roberts S, Hirshfield M (2004) Deep-sea corals: out of sight, but no longer out of mind. *Frontier in Ecology and Environment* 2:123-130

136 Synnes, M. (2006) Bioprospecting of organisms from the deep sea: scientific and environmental aspects.

137 Synnes, M. (2007) Bioprospecting of organisms from the deep sea: scientific and environmental aspects. *Clean Techn Environ Policy* 9: 53-59.

138 Freiwald, A., J.H Fosså, A. Grehan, T. Koslow and J. M. Roberts. 2004. Cold-water Coral Reefs. UNEP-WCMC, Cambridge, UK.

139 Waller, R.G. and Tyler, P.A. (2005) The reproductive biology of two deep-water, reef-building scleractinians from the NE Atlantic Ocean. *Coral Reefs* 24: 514-522.

are gonochoric (having unique gender)¹⁴⁰. Only a few brooding species of cold-water corals have been observed from the deep Antarctic continental shelf. Knowledge about the larval ecology of these corals is also limited, with only *Oculina varicosa* studied in depth^{141 142}. Broader scale (in terms of species and areas) understanding of the reproductive biology of cold-water corals is required to enable an adequate assessment of conservation potential¹⁴³.

Development of cold-water coral reefs starts from an initial settlement of coral larva on hard substratum. As a coral grows, polyps in older portions die, and the skeleton becomes increasingly vulnerable to bio-eroders (notably, clionid sponges) and mechanical breakage. Bio-eroded skeletons may break, fall to the seabed, and extend the perimeter of the reef patch. These processes are fundamental in creating the reef framework that, over time, baffles and traps mobile sediment, further building the reef¹⁴⁴.

There is no doubt that cold-water coral reefs support diverse communities of unique species. Species diversity on cold-water coral mounds has been found to be much higher than in the surrounding sea bottom habitat¹⁴⁵ and cold-water coral reefs are frequently reported on seamounts where their associated species may have high endemism¹⁴⁶. More than 1300 species have been recorded living on or in *L. pertusa* reefs in the northeast Atlantic, a diversity that is three times higher than on surrounding soft bottoms. Thus, cold-water coral reefs may be considered biodiversity hotspots in the open ocean. A study of 25 blocks of the coral *Lophelia pertusa* collected from the Faroes, weighing a total of 18.5 kg, found 4,626 individuals belonging to 256 species. Of the 298 species found, 97 were recorded for the first time from the area around the Faroes. When these findings were compared with studies of *Lophelia* banks in Norway and the Bay of Biscay, there were very few overlaps in the associated species, indicating potentially large differences between sites¹⁴⁷ and high endemism of cold-water coral reef-associated assemblages.

Other species associated with cold-water coral reefs include economically important rockfish, shrimp and crabs, which often hide among the branches of red tree corals (*Primnoa resedaeformis*). Crinoids, basket stars, anemones and sponges attach themselves to branches so that they may better filter food from the currents. Other animals, such as sea stars and snails, feed directly on the corals themselves. Most species found on cold-water corals are facultative symbionts (a relationship in which one partner may, but does not have to, live with another in order to survive). Some deep-water coral reefs seem to have richer and more abundant crustacean fauna than similar tropical reefs¹⁴⁸. Factors affecting the community structure of species associated with cold-water coral reefs include time needed for community development, frequency of external disturbance and variability of nutrient supply.

140 Waller, R.G. and Tyler, P.A. (2005) The reproductive biology of two deep-water, reef-building scleractinians from the NE Atlantic Ocean. *Coral Reefs* 24: 514–522.

141 Brooke, S. and Young, C.M. (2003) Reproductive ecology of a deep-water scleractinian coral, *Oculina varicosa*, from the southeast Florida shelf. *Cont Shelf Res* 23: 847–858.

142 Brooke, S. and Young, C.M. (2005) Embryogenesis and larval biology of the ahermatypic scleractinian *oculina varicosa*. *Marine Biology* 146: 665–675.

143 Waller, R.G. and Tyler, P.A. (2005) The reproductive biology of two deep-water, reef-building scleractinians from the NE Atlantic Ocean. *Coral Reefs* 24: 514–522.

144 Roberts JM, Wheeler AJ, Freiwald A (2006) Reefs of the deep: the biology and geology of cold-water coral ecosystems. *Science* 312:543–547

145 Henry L-A, Roberts JM (2007) Biodiversity and ecological composition of macrobenthos on cold-water coral mounds and adjacent off-mound habitat in the bathyal Porcupine Seabight, NE Atlantic. *Deep-sea research I*

146 Roberts JM, Wheeler AJ, Freiwald A (2006) Reefs of the deep: the biology and geology of cold-water coral ecosystems. *Science* 312:543–547

147 Jensen A, Frederiksen R (1992) The fauna associated with the bank-forming deepwater coral *Lophelia pertusa* (Scleractinaria) on the Faroe shelf. *Sarsia* 77:53–69

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

Fish often aggregate on deep-sea reefs¹⁴⁹, though the specific functional relationship between species present on a cold-water coral reef and the importance of that reef as fish habitat is not well understood¹⁵⁰. Studies of the *Lophelia* reef in the Northeast Atlantic recorded 25 species of fish of which 17 were commercially important¹⁵¹. Depth was found to be the most significant parameter influencing the fish species found associated with reefs. Species assemblages appeared to be largely different above and below 400 to 600 m depth. Fish species richness and abundance were greater on the reef than around the surrounding seabed. In the Gulf of Alaska, large rockfish (*Sebastes* spp.) were found mainly associated with boulders with *Primnoa* corals¹⁵². On the other hand, comparisons of fish communities between sites with and without dense cold-water corals in the Gulf of Maine suggest that communities in habitats dominated by dense corals and epifauna may be functionally equivalent when compared with other less complex habitats (e.g., boulders with sparse coral cover)¹⁵³. Further understanding of cold-water coral reef ecosystems is needed to fully understand the function of the reefs and their associated fauna.

Cold-water corals, reefs and mounds generally occur in areas of fast currents and internal waves, where particle flow rates are fast¹⁵⁴. Given their high species diversity and longevity, and their occurrence in areas of fast current flow, cold-water coral reefs may be major centres of speciation¹⁵⁵.

Recent DNA studies have revealed that some cold-water corals species, such as *Lophelia*, show high genetic variability across the Atlantic Ocean. Sequences obtained from samples of *Lophelia* from the northeast Atlantic were very different from those obtained from samples collected in the southwest Atlantic. *Lophelia* samples collected in Scandinavian fjords appeared to be genetically different from those distributed along the European continental margin. Results suggest that continental margin reefs might originate from migrants dispersed out of the fjords in the past. Understanding such relationships may be important for the development of conservation and management strategies¹⁵⁶.

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- 149 Roberts S, Hirshfield M (2004) Deep-sea corals: out of sight, but no longer out of mind. *Frontier in Ecology and Environment* 2:123–130
- 150 Roberts JM, Wheeler AJ, Freiwald A (2006) Reefs of the deep: the biology and geology of cold-water coral ecosystems. *Science* 312:543–547
- 151 Costello M, McCrea M, Freiwald A, Lundälv T, Jonsson L, Bett B, van Weering T, de Hass H, Roberts J, Allen D. 2005. Role of cold-water *Lophelia pertusa* coral reefs as fish habitat in the NE Atlantic. . In: Freiwald A, Roberts JM (eds) *Cold-water Corals and Ecosystems*. Springer, Berlin Heidelberg. p 771–805.
- 152 Krieger, K.J. and Wing, B.L. (2002) Megafauna associations with deepwater corals (*Primnoa* spp.) in the Gulf of Alaska. *Hydrobiologia* 471: 83–90.
- 153 Auster, P.J. (2005) Are deep-water corals important habitats for fishes? In: Freiwald, A. and Roberts, J.M. (eds.). pp. 747–760. *Cold-water Corals and Ecosystems*. Springer-Verlag Berlin Heidelberg.
- 154 Henry L-A, Roberts JM (2007) Biodiversity and ecological composition of macrobenthos on cold-water coral mounds and adjacent off-mound habitat in the bathyal Porcupine Seabight, NE Atlantic. *Deep-sea research I*
- 155 Roberts JM, Wheeler AJ, Freiwald A (2006) Reefs of the deep: the biology and geology of cold-water coral ecosystems. *Science* 312:543–547
- 156 www.lophelia.org and Le Goff-Vitry, M. C., O. G. Pybus and A. D. Rogers (2004). “Genetic structure of the deep-sea coral *Lophelia pertusa* in the northeast Atlantic revealed by microsatellites and internal transcribed spacer sequences.” *Molecular Ecology* 13(3): 537–549.

IV. HYDROTHERMAL VENTS

A. GLOBAL DISTRIBUTION

The discovery of hydrothermal vents along the Galapagos Rift in the eastern Pacific in 1977 arguably represented one of the most important findings in biological science in the latter quarter of the twentieth century¹⁵⁷. Hydrothermal vents were the first ecosystem on Earth found to be independent from the sun as an original source of energy, relying instead on chemosynthesis. Hydrothermal vents are now known to occur along all active mid-ocean ridges and back-arc spreading centres. The InterRidge Hydrothermal Vent Database currently lists 212 separate vent sites¹⁵⁸, though more are likely to exist. The map in figure 4 has been produced by the ChEss project, which is a global study of the distribution, abundance and diversity of species in deep-water hydrothermal vents, cold seeps and other chemosynthetic ecosystems for the Census of Marine Life initiative.¹⁵⁹

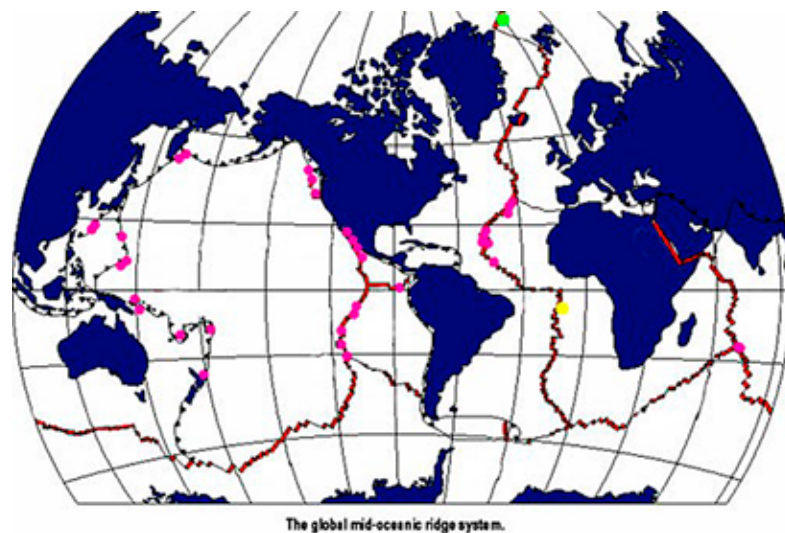


FIGURE 4: Global distribution of known hydrothermal vents. The locations of those vents that have already been studied are marked on the map as pink dots. Two new vent sites were discovered in 2005—one on the south Mid-Atlantic Ridge (yellow dot) and one on the Arctic Ridge system (green dot). The latter contains the northern most vent fields found in the world to date (map courtesy of ChEss office at NOC, UK, P.Tyler, C.German, M.Baker & E.Ramirez).

As mentioned above, hydrothermal vents are associated with mid-ocean ridges, where they are formed by interactions between molten rock and seawater as the tectonic plates spread apart. The recent discovery of a new type of hydrothermal vent, a so-called off-axis vent, indicates that ocean-bottom hydrothermal activity may be much more widespread than previously thought. The off-axis vents have been found up to a few tens of kilometres away from the mid-ocean ridge, on near-ridge seamounts. Instead of being formed by volcanism, the off-axis vents appear to be formed by a heat-generating chemical reaction taking place when the seamount's eroded rocks interact with seawater¹⁶⁰.

157 Glowka, L. (2003) Putting marine scientific research on a sustainable footing at hydrothermal vents. *Marine Policy*: 27: 303–312.

158 The InterRidge website: <http://www.interridge.org/> (checked on 13 March 2007)

159 The ChEss Study website: <http://www.noc.soton.ac.uk/chess/> (checked on 13 March 2007)

160 Kelley, D.S. Karson, J.A., Blackman, D.K., Früh-Green, G.L., Butterfield, D.A., Lilley, M.D., Olson, E.J., Schrenk, M.O., Roe, K.K., Lebon, G.T. and Rivizzigno, P. (2001) An Off-Axis Hydrothermal Vent Field Near the Mid-Atlantic Ridge at 30°N. *Nature* 412: 145–149.

Some studies suggest that vents associated with mid-ocean ridges may be more frequent than originally thought. Initially it was hypothesized that vents occurred only in areas where the ridge is spreading at fast rates. However, recent studies have found the presence of vents at ridge locations characterized by a variety of spreading rates, from relatively slow to fast¹⁶¹. This does not necessarily imply that vents are common. Other research suggests that less than 1% of mid-ocean and back-arc basin ridge areas contain active vents¹⁶².

B. STATUS AND TRENDS

As is evident from the previous section, our knowledge about where hydrothermal vents occur, and how extensive they are, is far from complete. Hydrothermal activity does not take place everywhere along mid-ocean ridge systems. Since the 1990s, there have been large-scale, systematic searches for undiscovered vent sites. Many of these searches rely on inferring the presence of vents from water column observations by measuring optical properties, temperature and particle anomalies, as well as chemical tracers that distinguish hydrothermal plumes from the surrounding seawater. The known vent sites have, in the past, reflected historic funding priorities for research, with majority of the known or inferred ridge vent sites occurring on the heavily surveyed eastern Pacific ridges¹⁶³. However, recent research has revealed a substantial number of vent sites in the southern hemisphere¹⁶⁴.

There are also knowledge gaps in regards to the biodiversity and ecology of hydrothermal vent ecosystems, and their interactions with surrounding communities. Generally, biomass of hydrothermal vent communities is high but biodiversity is low¹⁶⁵. This is typical of habitats with high energy availability and extreme environmental conditions. However, vent sites support exceptionally productive biological communities in the deep sea, and vent fauna range from tiny chemosynthetic bacteria to tube worms, giant clams, and ghostly white crabs. At the present time, 471 species have been described from vents and their immediate vicinity, from which 91% are endemic. Of these species, 29% were mollusks, 33% crustaceans and 17% polychaetes¹⁶⁶. More species are likely to be discovered, as only a relatively small proportion (10% in 2004) of the ocean ridge system has been explored for hydrothermal activity¹⁶⁷. It is estimated that the average rate of discovery of new species over the past three decades is approximately two new species per month¹⁶⁸. Many species are exclusive to these ecosystems and would be unable to exist outside them¹⁶⁹. These animals are discussed in more detail in section D.

161 Michael, P.J., Langmuir, C.H., Dick, H.J.B, Snow, J.E., Goldstein, S.L., Graham, D.W., Lehnert, K, Kurras, G., Mühe, R. and Edmonds, H.N. (2003) Magmatic and Amagmatic Seafloor Spreading at the Slowest Mid-Ocean Ridge: Gakkel Ridge, Arctic Ocean, *Nature* 423: 956–961.

162 Margaret Tivey on behalf of InterRidge (2007) presentation to the United Nations Informal Consultative Process on Oceans and Law of the Sea, June 27, 2007.

163 Edward T. Baker, E.T. and German, C.R. (2004) On the Global Distribution of Hydrothermal Vent Fields. In: *Mid-Ocean Ridges: Hydrothermal Interactions Between the Lithosphere and Oceans, Geophysical Monograph Series 148*, C.R. German, J. Lin, and L.M. Parson (eds.), 245–266. See: http://www.pmel.noaa.gov/pubs/outstand/bake2544/global_vent.shtml

164 IFREMER personal communication. At the time of time of the writing of this document, 31 vent sites had been found in the Southern Hemisphere.

165 Ramirez-Llodra, E., Shank, T. M. and German, C. R. (2007) Biodiversity and biogeography of hydrothermal vent species. *Oceanography*, 20(1): 30–41.

166 Desbruyères, D., M. Segonzac, et al. (2006). *Handbook of deep-sea hydrothermal vent fauna*. Linz, Landesmuseum, 544pp

167 Edward T. Baker, E.T. and German, C.R. (2004) On the Global Distribution of Hydrothermal Vent Fields. In: *Mid-Ocean Ridges: Hydrothermal Interactions Between the Lithosphere and Oceans, Geophysical Monograph Series 148*, C.R. German, J. Lin, and L.M. Parson (eds.), 245–266. See: http://www.pmel.noaa.gov/pubs/outstand/bake2544/global_vent.shtml

168 Fisher, C. R., Takai, K. and Le Bris, N. (2007) Hydrothermal vent ecosystems. *Oceanography*, 20(1); 15–23.

169 Tunnicliffe V, McArthur AG, McHuge D (1998) A biogeographical perspective of the deep-sea hydrothermal vent fauna. *Advances in Marine Biology* 34:353–492

Individual hydrothermal vent sites are intrinsically unstable and ephemeral on geological time scales, lasting on the order of years to hundreds or thousands of years^{170 171}. Volcanic eruptions, or the ceasing of vent fluids can generate extinctions, re-colonizations and changes in community structure. Though the age of vent systems varies, the transient nature of some vent sites, and its consequences on vent fauna, is discussed further in section D.

Human impacts on hydrothermal vent ecosystems have, to date, been limited to those vent sites subject to intensive scientific studies. Although some human impacts have been documented on heavily visited sites (see section C), the high natural variability of vent systems may make it more difficult to accurately assess the effects of human activities¹⁷².

C. THREATS

The only currently documented anthropogenic impacts to hydrothermal vent ecosystems in areas beyond the limits of national jurisdiction result from marine scientific research. However, the mining of polymetallic sulphides presents a potentially much more serious and urgent threat to vent ecosystems (see the next paragraph). Scientific research may entail physical disturbance or disruption, or the introduction of light into an ecosystem that is naturally deprived of it. Some evidence of disturbance caused by scientific research already exists, although such impacts are very localized. For example, the use of floodlights on manned submersibles may have irretrievably damaged the eyes of decapod shrimps (family *Bresiliidae*) that dominate the fauna at vents on the Mid-Atlantic Ridge.¹⁷³ The scientific community is aware of this threat and has begun to consider preventive action. InterRidge (a non-profit organization concerned with promoting all aspects of mid-ocean ridge research) issued in 2006 a statement of commitment to responsible research practices at deep-sea hydrothermal vents. This statement contains guidelines for responsible research practices, which InterRidge encourages scientists to abide by¹⁷⁴. A Code of Conduct for the Scientific Study of Marine Hydrothermal Vent Sites is under development. It should be noted, though, that both the guidelines and the Code are voluntary measures.

Mining of polymetallic sulphide deposits associated with vent systems poses a future threat, which is moving closer to becoming a reality, at least within national EEZs. Because the extraction of polymetallic sulphide deposits will be relying on new technologies and methods, its impacts are as of yet unknown. It is expected that the drifting particles produced by deep-sea sulphide mining have the potential to smother, clog, and contaminate nearby vent communities. Organisms surviving these perturbations would be subject to a radical change in habitat conditions with hard substrata being replaced by soft particles settling from the mining plume. Mining could also potentially alter hydrologic patterns that supply vent communities with essential nutrients and hot water. A further problem may arise during dewatering of ores on mining platforms, resulting in discharge of highly nutrient enriched deep-water into oligotrophic surface waters, which can drift to nearby shelf areas. These impacts may extend beyond national EEZs into international waters^{175 176}. Because most invertebrate diversity at vents is found in rare species, habitat destruction by mining can be potentially devastating to local and regional populations¹⁷⁷.

170 Micheli, F., Peterson, H. and G.A. Johnson (2002) Predation structures communities at deep-sea hydrothermal vents. *Ecological Monographs* 72: 365–382.

171 Van Dover 2000 the Ecology of Deep-Sea Hydrothermal Vents (Princeton University Press)

172 Tunnicliffe, V. and Thomson, R. (1999) Oceans Background Report. The Endeavour Hot Vents Area: A Pilot Marine Protected Area In Canada's Pacific Ocean. Prepared for Fisheries and Oceans Canada, Sidney, British Columbia, January, 1999. See: http://www.pac.dfo-mpo.gc.ca/Oceans/mpa/backgrnd-report_e.htm#_Toc441476668

173 Herring P, Gaten E, Shelton PMJ (1999) Are vent shrimps blinded by science? *Nature* 398:116

174 <http://www.interridge.org/>

175 Halfar, J. and Fujita, R.M. (2007) Danger of deep-sea mining. *Science*. 316: 987.

176 Schrope, M (2007) Digging deep. *Nature*. 447: 246–247.

177 Cindy Van Dover, personal communication.

Bioprospecting of hydrothermal vent organisms is already taking place, and some organisms have been used for the purposes of biotechnology. Hydrothermal vent organisms possess novel adaptations that make them capable of surviving in extreme environments. These same adaptations make the organisms of potential use to biotechnology. A number of patents have been filed relating to inventions based on hydrothermal vent organisms, ranging from skin care products to industrial applications¹⁷⁸. For example, the California-based biotechnology company Verenium (formerly Diversa) has developed the Valley “Ultra-Thin™” product from genes recovered from a deepsea hydrothermal vent organism within national jurisdiction. This product is currently marketed by Valley Research for use in starch liquefaction for the production of ethanol¹⁷⁹.

High-end tourism presents another potential future threat to vent ecosystems. Submarine-based marine tourism and marine scientific research may disturb the fragile vent ecosystem⁸², such as the retinal damage to deep-sea crustaceans mentioned above⁹⁴.

D. FUNCTIONING OF HYDROTHERMAL VENT ECOSYSTEMS AND ECOLOGY OF ASSOCIATED SPECIES

Hydrothermal vents are mostly found along mid-ocean ridges, where magma from deep parts of the earth emerges. A vent is typically formed when seawater penetrates the crust, is heated by the magma, and surges back into the ocean through a hot vent, bringing with it mineral substances, including sulfide, hydrogen, methane, manganese and metals. Chemoautotrophic bacteria use the sulfur-rich water for primary production. The energy produced by the bacteria supports the nutritional requirements of other organisms in the vent community.¹⁸⁰ For example, giant tubeworms (*Riftia*), which can reach up to 3m in length, survive only as a result of the symbiotic relationship they have with chemoautotrophic bacteria.

Because of their independence from sunlight as an energy source, hydrothermal vent systems are thought to have played an important role in the development of life on Earth, and the differentiation of a common ancestor into Bacteria and *Archaea* (an evolutionary branch that is separate from those of Bacteria and Eukarya). There is evidence that life has existed around hydrothermal vents for more than 3 billion years. However, subsequent studies have found limited support for the hypothesis that modern vent fauna are Palaeozoic relics. Instead, molecular evidence suggests that these fauna evolved from relatively recent radiations (or re-radiations) of vent and seep taxa. This implies that deep-sea chemosynthetic environments are not immune from global extinction events affecting diversity in the photic zone.¹⁸¹ Similarly, the hypothesis that life arose in hydrothermal vents has not been proven¹⁸².

The heat of volcanic processes creates and sustains hydrothermal plumes, formed through the interaction of seawater with rock. These plumes are often black or white, with the colour coming from mineral particles that precipitate rapidly as hot hydrothermal fluids (with temperatures as high as 340°C) mix with cold seawater (usually about 1–2°C) at or just below the vent orifice. As mentioned in section b, scientists search for evidence of hydrothermal plumes in seawater to discover the presence of hydrothermal activity below. Hydrothermal plumes are likely to be very important for the transport and distribution of marine organisms, especially thermophile or hyperthermophile bacteria that live under the seafloor and have

178 UNU-IAS (2005) Bioprospecting of Genetic Resources in the Deep Seabed: Scientific, Legal and Policy Aspects. *UNU-IAS Report*. 72pp.

179 The Diversa website: <http://www.verenium.com/index.html> (checked on 8 October 2007)

180 Tyler PA, Young CM (2003) Dispersal at hydrothermal vents: a summary of recent progress. *Hydrobiologia* 503:9–19

181 Little CTS, Vrijenhoek RC (2003) Are hydrothermal vent animals living fossils. *Trends in Ecology and Evolution* 18:582–588

182 Miller SL, Bada JL (1988) Submarine hot springs and the origin of life. *Nature* 334:609–611

been released into the ocean in plumes resulting from recent volcanic events¹⁸³. The chemosynthetic bacteria, re-suspended detritus from the upper ocean, and other biological products carried upward by the plumes also appear to support a wide range of biological activity in the overlying water column, in particular zooplankton communities consisting of both deep- and shallow-water species, though these interactions are not well known. Similarly, the links between hydrothermal vents and surrounding communities are not well understood. Studies at the Endeavour vent field suggest that substantial carnivore biomass outside the vents, including deep-sea crabs, octopus and fish may be dependent upon localized production¹⁸⁴.

Deep-sea hydrothermal vent communities are characterized by three important environmental attributes, which govern community composition, distribution and dynamics: (1) the harsh physical and chemical conditions experienced by the vent fauna, (2) the patchy distribution of vent sites over oceanic ridges, where distances between vents within a given field range from a few metres to hundreds of metres, and the distances between vent fields range from hundreds to thousands of kilometres; and (3) the high temporal variability of hydrothermal activity due to tectonic events and heat convection through the oceanic crust, which induces a high site turnover that may vary in duration from years to decades on fast-spreading ridges.¹⁸⁵

The first of these attributes has caused hydrothermal vent animals to develop a rich variety of novel biochemical and physiological features that allow them to survive in the extreme environmental conditions within a vent field.¹⁸⁶ The harsh vent environment has also resulted in a high degree of endemism. Studies have shown that vent communities contain remarkable taxonomic novelty, and over 80% of vent species appear to be endemic¹⁸⁷. Many species found in studies are new to science¹⁸⁸.

Although most of the species diversity at hydrothermal vents can be attributed to taxonomic groups that comprise small, inconspicuous individuals (e.g. polychaete worms, gastropods, copepod crustaceans and nematodes), most of the biomass is formed by a few large and visually striking species. These include vestimentiferan tube worms (*Siboglinidae*), vent clams (*Vesicomysidae*), vent mussels (*Bahtymodiolinae*) and the blind vent shrimp, all of which harbour chemoautotrophic bacterial symbionts. These organisms exploit the reduced chemical compounds in vents either directly, by way of symbiotic chemoautotrophic bacteria, or indirectly, by grazing and filtering free-living *chemoautotrophs*¹⁸⁹. The trophic structures seem to be relatively simple, with few steps. Most animals appear to feed directly on microbial production¹⁹⁰.

Giant tubeworms are perhaps the most spectacular fauna that have adapted to living near hydrothermal vents. The Pompeii worm (*Alvinella pompejana*) inhabits active deep-sea hydrothermal vents, which form thick, heavily channelled structures along the outer walls of the vent 'chimneys' created by an accumula-

183 NOAA-VENTS Plume Studies Group, see: <http://dwb.unl.edu/Teacher/NSF/C11/C11Links/www.pmel.noaa.gov/vents/PlumeStudies/PlumeStudies1.html>

184 Tunnicliffe, V. and Thomson, R. (1999) Oceans Background Report. The Endeavour Hot Vents Area: A Pilot Marine Protected Area In Canada's Pacific Ocean. Prepared for Fisheries and Oceans Canada, Sidney, British Columbia, January, 1999. See: http://www.pac.dfo-mpo.gc.ca/Oceans/mpa/backgrnd-report_e.htm#_Toc441476668

185 Thiebaut E, Huther X, Shillito B, Jollivet D, Gaill F (2002) Spatial and temporal variations of recruitment in the tube worm *Riftia pachyptila* on the East Pacific Rise (9o50' N and 13o N). *Marine Ecology Progress Series* 234:147–157

186 Childress JJ, Fisher CR (1992) The biology of hydrothermal vent animals: physiology, biochemistry and autotrophic symbioses. *Oceanography and Marine Biology Annual Review* 30:337–441

187 Little CTS, Vrijenhoek RC (2003) Are hydrothermal vent animals living fossils. *Trends in Ecology and Evolution* 18:582–588

188 Tsurumi M, Tunnicliffe V (2001) Characteristics of a hydrothermal vent assemblage on a volcanically active segment of Juan de Fuca Ridge, northeast Pacific. *Canadian Journal of Fisheries and Aquatic Science* 58:530–542

189 Little CTS, Vrijenhoek RC (2003) Are hydrothermal vent animals living fossils. *Trends in Ecology and Evolution* 18:582–588

190 Tunnicliffe, V. and Thomson, R. (1999) Oceans Background Report. The Endeavour Hot Vents Area: A Pilot Marine Protected Area In Canada's Pacific Ocean. Prepared for Fisheries and Oceans Canada, Sidney, British Columbia, January, 1999. See: http://www.pac.dfo-mpo.gc.ca/Oceans/mpa/backgrnd-report_e.htm#_Toc441476668

tion of metal sulphides. The worm is tolerant of extreme temperatures, inhabiting an environment with a temperature gradient of up to 60°C and an absolute temperature of up to 81°C.¹⁹¹

The distribution of animals within a vent community exhibits a pattern of zonation, an example of which has been documented at the Broken Spur vent (in the Mid-Atlantic Ridge). Bresiliid shrimp were present close to black smokers, brittle stars were found on solid surfaces of chimneys and mounds, peak densities of anemones occurred at the base of sulphide mounds, and peak densities of brachyuran crabs were found at platform structures¹⁹². However, there are large differences in population structure between vent sites, likely in response to local variations in time of larval supply and/or reproductive activity¹⁹³. A majority of vent species occur at only one site, and none occur at all studied sites¹⁹⁴. The results tend to support the hypothesis of a lack of consequent long-distance transport of larvae.¹⁹⁵

Genetic diversity of communities inhabiting deep-sea hydrothermal vent environments is affected by the extreme environment, the biology and ecology of the species, and ocean circulation. Genetic studies on deep-sea hydrothermal vent communities suggest that some micro-organisms of novel phylotypes (genomic uniqueness) were likely present in deep-sea vent environments¹⁹⁶–¹⁹⁷. Additionally, a high diversity among vent communities capable of anaerobic oxidation of methane can be observed¹⁹⁸. The deep-sea hydrothermal vent endemic amphipod *Ventiella sulfuris*—an amphipod that broods its young and has no larval stage—is found to have high genetic divergence between populations on disjunct ridge axes in the East Pacific Rise and Galapagos Rift. This suggests that migration and gene flow between major subpopulations may be limited by the island-like arrangement of the vent habitats and the low dispersal ability of the species¹⁹⁹. In contrast, species that produce pelagic larvae (e.g., vent mussels, clams, limpets, tubeworms, and polychaetes) have high rates of gene flow across thousands of kilometres in disjunct East Pacific Rise²⁰⁰. In addition, the overall abundance, reproductive output of a species and ocean circulation pattern play significant roles in dispersal and retention of genetic diversity in deep-sea hydrothermal vents²⁰¹. Detailed understanding of the worldwide distribution of vent and seep environments, as well as deep-ocean circulation patterns and the role of sea floor topography as barriers or filters to dispersal is needed to fully understand the dispersal and gene flow of populations in deep-sea hydrothermal vent environments. Understanding gene flow and genetic diversity can help in designing conservation measures²⁰².

191 Cary SC, Shank TM, Stein J (1998) Worms bask in extreme temperatures. *Nature* 391:545–546

192 Copley JTP, Tyler PA, Murton BJ, Van Dover CL (1997) Spatial and interannual variation in the faunal distribution at Broken Spur vent field (29°N, Mid-Atlantic Ridge). *Marine Biology* 129:723–733

193 Thiebaut E, Huther X, Shillito B, Jollivet D, Gaill F (2002) Spatial and temporal variations of recruitment in the tube worm *Riftia pachyptila* on the East Pacific Rise (9°50' N and 13° N). *Marine Ecology Progress Series* 234:147–157

194 Tunnicliffe V, McArthur AG, McHuge D (1998) A biogeographical perspective of the deep-sea hydrothermal vent fauna. *Advances in Marine Biology* 34:353–492

195 Thiebaut E, Huther X, Shillito B, Jollivet D, Gaill F (2002) Spatial and temporal variations of recruitment in the tube worm *Riftia pachyptila* on the East Pacific Rise (9°50' N and 13° N). *Marine Ecology Progress Series* 234:147–157

196 Takai, K. and Horikoshi, K. 1999. Genetic diversity of Archaea in deep-sea hydrothermal vent environments. *Genetics* 152: 1285–1297.

197 Orphan, V.J., House, C.H., Hinrichs, K., McKeegan, K.D. and Delong, E.F. 2002. Multiple archaeal groups mediate methane oxidation in anoxic cold seep sediments. *PNAS* 99: 7663–7668.

198 Teske, A., Hinrichs, K., Edgcomb, V., Gomez, A.V., Kysela, D., Sylva, S.P., Sogin, M.L. and Jannasch, H. W. 2002. Microbial diversity of hydrothermal sediments in the Guaymas Basin: evidence for anaerobic methanotrophic communities. *Applied and Environmental Microbiology* 68: 1994–2007.

199 France, S.C., Hessler, R.R. and Vrijenhoek, R.C. 1992. Genetic differentiation between spatially-disjunct populations of the deep-sea, hydrothermal vent-endemic amphipod *Ventiella sulfuris*. *Marine Biology* 114: 551–559.

200 Vrijenhoek, R.C., 1997. Gene flow and genetic diversity in naturally fragmented metapopulations of deep-sea hydrothermal vent animals. *Journal of Heredity* 88(4): 285–293.

France, S.C., Hessler, R.R. and Vrijenhoek, R.C. 1992. Genetic differentiation between spatially-disjunct populations of the deep-sea, hydrothermal vent-endemic amphipod *Ventiella sulfuris*. *Marine Biology* 114: 551–559

201 Van Dover 2000 *The Ecology of Deep-Sea Hydrothermal Vents* (Princeton University Press)

202 Palumbi, S.R. 2003. Population genetics, demographic connectivity, and the design of marine reserves. *Ecological Applications* 13(1) Supplement: S146–S158.

Some hydrothermal vent sites can be ephemeral, and their activity is highly variable due to the dynamic nature of the oceanic crust. Other vents, specifically those on slowly spreading ridges, have an unknown dynamic and are likely more stable and long-lived. Human impacts on these more stable vents may be much higher, particularly in the context of their attractiveness as sites for mining activity²⁰³. The age of vent systems varies, depending on the locale. In general, it is thought that vents on the East Pacific Rise, a fast-spreading ridge system, are short-lived for any given habitat, on the order of a decade or two at most, often much less. At intermediate spreading ridges, vent systems are active for longer periods (several tens of years or more), though any given surface of sulfide is subject to failure, collapse, clogging, or other events that change the chemical milieu. At large vent systems like the TAG site on the slow-spreading Mid-Atlantic Ridge, vents are active for hundreds to thousands of years, with little or no change in fauna²⁰⁴.

As the ephemeral vents wane, organismal associations can be observed slowly transitioning as they gain greater similarity to background communities²⁰⁵. Mobile inhabitants may be able to escape from fading vent sites and establish populations on neighbouring vents or on new vent sites, but the large aggregations of sessile organisms die if fluids cease to flow²⁰⁶. There is a successional pattern following disturbances, as demonstrated by vent-animal colonization following an eruption on a segment of the Juan de Fuca Ridge, where it took five years for the species pool to reach pre-disturbance characteristics. The environmental unpredictability and transient nature of short-lived vent sites, as well as the high biological production of hydrothermal systems, also favours continuing reproduction, rapid recruitment, accelerated growth and a tolerance to environmental perturbations, though the cumulative impacts of environmental disturbance and potential anthropogenic stresses may pose a threat to vent communities. In addition, long-lived vent sites, which are not subject to similar unpredictability, may be at added risk from human disturbance. An example of accelerated growth rates of vent animals is demonstrated by the giant tube worm *Riftia pachyptila*, which can grow almost 2.5 cm in 10 days. This is the fastest rate reported to date for any species of marine invertebrates.²⁰⁷

Inactive vent sites may also contain important biodiversity, especially as habitat for corals and little-known bacteria. These 'inactive' sulfides support chemoautotrophic bacteria, and are often colonized by filter-feeding invertebrates—corals, barnacles, brachiopods—but the extent to which these organisms might rely on chemoautotrophic production is largely unexplored²⁰⁸.

Studies relating to fish diversity on and around hydrothermal vents found a low specific diversity of fish, but a high degree of endemism. In general, fishes can be separated into two groups: (1) species living within the vent and seep environments, including the so-called vent-endemic species, and (2) species pertaining to the surrounding deep water environment, but recorded from a close proximity to vents and seeps. Their high degree of endemism is demonstrated by a study of the order Anguilliformes (comprising eels and other elongated fishes) living inside active vent fields. Of the 21 species found, 11 species (52%) have been described and five (24%) were new to science. The remaining five (24%) could only be identified to the genus or family level. Vent-living fishes were found at only 20 of some 50 active vent

203 IFREMER personal communication

204 Van Dover 2000 the Ecology of Deep-Sea Hydrothermal Vents (Princeton University Press)

205 Tunnicliffe, V. and Thomson, R. (1999) Oceans Background Report. The Endeavour Hot Vents Area: A Pilot Marine Protected Area In Canada's Pacific Ocean. Prepared for Fisheries and Oceans Canada, Sidney, British Columbia, January, 1999. See: http://www.pac.dfo-mpo.gc.ca/Oceans/mpa/backgrnd-report_e.htm#_Toc441476668

206 CSA Discovery Guides; Hydrothermal Vents. See: <http://www.csa.com/discoveryguides/vent/review.php>

207 Lutz RA, Shank TM, Fornari DJ, Haymon RM, Lilley MD, Von Damm KL, Desbruyeres D (1994) Rapid growth at deep-sea vents. *Nature* 371

208 Van Dover, C. L., Grassle, J. F. & Boudrias, M. 1990. Hydrothermal vent fauna of Escanaba Trough (Gorda Ridge). In: McMurray, G. R. (ed.) *Gorda Ridge*. Springer-Verlag, 285-287.

fields discovered at the time of the study. Species diversity in the Atlantic appears to be slightly higher than in the Pacific. This may be partly attributed to the differences in depth range of the vents²⁰⁹.

The patchiness of vent sites has resulted in the delineation of a number of vent biogeographic provinces. On a large scale, the vent sites at different ocean basins differ somewhat. The vents in the East Pacific are dominated by giant tubeworms (*Riftia*), large white clams (*Calyptogena magnifica*) and mussels (*Bathymodiolus*). The Atlantic vent communities differ considerably from those in the Pacific, notably in the absence of vestimentiferan tube worms.²¹⁰ Instead, the Atlantic vents are dominated by dense aggregations of bresilioid shrimp (six species belonging to five genera) and mussel beds. Most of the Indian Ocean vent fauna is related to the animals in the Pacific, presenting evidence in support of a connection between Indian Ocean vents and those in the Pacific. There has also been speculation in regards to a connection between the Indian Ocean and the Atlantic Ocean, due to the Atlantic shrimp *Rimicaris* having been reported from the Indian Ocean²¹¹. However, later studies suggest that this shrimp may, instead, have been a new species (*Mirocaris indica*), and thus the connection with the Atlantic remains unproven²¹².

Because of these differences between vent fields, the following biogeographic provinces of hydrothermal vents can be identified: (1) East Pacific Rise and Galápagos Rift; (2) Northeast Pacific; (3) Western Pacific; (4) Atlantic (Azores); (5) Mid-Atlantic ridge between Azores Triple Junction and Equator; and (6) Indian Ocean (Central Indian Ridge)^{213 214}. It is likely that the regional species pool affects local vent diversity.²¹⁵

There are also differences within these biogeographic provinces. A comparison of the fauna between Lucky Strike, Menez Gwen and Rainbow vent fields on the Mid-Atlantic ridge between the Equator and the Azores archipelago showed that the Lucky Strike and Menez Gwen sites are dominated by mussels (*Bathymodiolus azoricus*) while the Snake Pit and TAG sites are dominated by shrimps (particularly *R. exoculata*). It could be argued that these sites do not belong to a single biogeographic province, but are rather a succession of several distinct biogeographic islands having different associations and habitats. There was also a decrease in the number of non-endemic species with depth²¹⁶. Thus, vent communities in deeper water may contain a higher proportion of endemic species. A separate study considered that the Lucky Strike fauna was sufficiently unique to be a separate biogeographic hydrothermal province, in addition to the eastern Pacific (East Pacific Rise and Galapagos Spreading Center), northeastern Pacific (Gorda, Juan de Fuca, Explorer ridges), western Pacific (Back-Arc) and Mid-Atlantic Ridge (TAG and

209 Biscoito M, Segonzac M, Almeida AJ, Desbruyeres D, Geistdoerfer P, Turnipseed M, Van Dover C (2002) Fishes from the hydrothermal vents and cold seeps—An update. *Cahier de Biologie marine* 38:140–141

210 Gebruk AV, Galkin GV, Vereshchaka AL, Moskalev LI, Southward AJ (1997) Ecology and biogeography of the hydrothermal vent fauna of the mid-Atlantic ridge. *Advances in Marine Biology* 32:93–144

211 Van Dover CL, Humphris SE, Fornari D, Cavanaugh CM, Collier R, Goffredi SK, Hashimoto J, Lilley mD, Reysenbach AL, Shank TM, Von Damm KL, Banta A, Gallant RM, Gotz D, Green D, Hall J, Harmer TL, Hurtado LA, Johnson P, Mckiness ZP, Meredith C, Olson E, Pan IL, Turnipseed M, Won Y, Young III CR, Vrijenhoek RC (2001) Biogeography and ecological setting of Indian Ocean hydrothermal vents. *Science* 294:818–823

212 Komai, T., Martin, J., Zala, K., Tsuchida, S., & Hashimoto, J. (2006) A new species of *Mirocaris* (Crustacea: Decapoda: Caridea: Alvinocarididae) associated with hydrothermal vents on the Central Indian Ridge, Indian Ocean. *Scientia Marina* [Online] 70 (1): 109–119. Available: <http://scientiamarina.revistas.csic.es/index.php/scientiamarina/article/view/188>

213 Tyler PA, Young CM (2003) Dispersal at hydrothermal vents: a summary of recent progress. *Hydrobiologia* 503:9–19

214 Ramirez-Llodra, E., Shank, T. M. and German, C. R. (2007) Biodiversity and biogeography of hydrothermal vent species. *Oceanography*, 20(1): 30–41.

215 Tsurumi M (2003) Diversity at hydrothermal vents. *Global Ecology and Biogeography* 12:181–190

216 Desbruyeres D, Biscoito M, Caprais JC, Colaco A, Comtet T, Crassous P, Fouquest Y, Khripunoff A, Bris NL, Olu K, Riso R, Sarrafin PM, Segonzac M, Vangriesheim A (2001) Variations in deep-sea hydrothermal vent communities on the Mid-Atlantic Ridge near the Azores plateau. *Deep-sea research* 48:1325–1346

Snake Pit) provinces.²¹⁷ This demonstrates that biogeographic differences exist between sites, but that they are not yet well documented. Table 1 provides a summary of biogeographic provinces of hydrothermal vents and their dominant fauna as proposed by Ramirez-Llodra et al. (2007)²¹⁸. Such differences are important for any initiatives to conserve representative areas consisting of hydrothermal vent sites.

| BIOGEOGRAPHIC PROVINCE | DOMINANT FAUNA |
|---|---|
| East Pacific Rise and Galápagos Rift | Vestimentiferan tubeworms, bathymodiolid mussels, vesicomid clams, alvinellid polychaetes, amphipods, and crabs |
| Northeast Pacific | Vestimentiferan tubeworms (except Riftiidae, polychaetes and gastropods) |
| Western Pacific | Barnacles, limpets, bathymodiolid mussels, “hairy” gastropod, vesicomid clams, and shrimp. |
| Atlantic (Azores) | Bathymodiolid mussels, amphipods, and caridean shrimp |
| Mid-Atlantic ridge between Azores Triple Junction and Equator | Caridean shrimp and bathymodiolid mussels |
| Indian Ocean (Central Indian Ridge) | Caridean shrimp and mussels, gastropods and anemones |

TABLE 1. Main biogeographical provinces of hydrothermal vents and their dominant fauna²¹⁹

217 Van Dover CL, Humphris SE, Fornari D, Cavanaugh CM, Collier R, Goffredi SK, Hashimoto J, Lilley mD, Reysenbach AL, Shank TM, Von Damm KL, Banta A, Gallant RM, Gotz D, Green D, Hall J, Harmer TL, Hurtado LA, Johnson P, Mckiness ZP, Meredith C, Olson E, Pan IL, Turnipseed M, Won Y, Young III CR, Vrijenhoek RC (2001) Biogeography and ecological setting of Indian Ocean hydrothermal vents. *Science* 294:818–823

218 Ramirez-Llodra, E., Shank, T. M. and German, C. R. (2007) Biodiversity and biogeography of hydrothermal vent species. *Oceanography*, 20(1): 30–41.

219 Ramirez-Llodra, E., Shank, T. M. and German, C. R. (2007) Biodiversity and biogeography of hydrothermal vent species. *Oceanography*, 20(1): 30–41.

V. OTHER ECOSYSTEMS IN MARINE AREAS BEYOND THE LIMITS OF NATIONAL JURISDICTION

This section provides descriptions of selected other ecosystems in marine areas beyond the limits of national jurisdiction, and includes both pelagic and benthic habitats. The benthic habitats described in detail are sponge reefs and fields, and cold seeps. Detailed descriptions of these ecosystems are provided due to their interest to the Conference of the Parties to the Convention on Biological Diversity (decision VIII/21 paragraph 1). In addition, a very brief overview of abyssal plains and submarine canyons is provided.

A. PELAGIC HABITATS

1. Introduction

The pelagic realm can be divided into three parts based on depth: the epipelagic zone (surface to approximately 150-200m), the mesopelagic zone and (approximately 200m to 1000m), and the bathypelagic zone (1000m to the bottom of the sea). The epipelagic zone has sufficient light for photosynthesis, with the highest overall species diversity in the subtropics, followed by the equatorial belt. Deep-water production depends on this thin photosynthetic layer at the surface. The mesopelagic zone is home to communities of animals that undergo daily migrations to the surface to feed at night, returning to deeper water during the day to avoid predators. The bathypelagic zone is the least studied and least understood part of the pelagic realm. The animals differ from those in the mesopelagic zone, but are not well studied²²⁰.

Distributions of pelagic species assemblages match the patterns of large-scale circulation as characterized by the distribution of waters and topographic features²²¹. Bathymetric and hydrographic features in the oceans create diverse pelagic habitats, which form areas of high productivity²²² and biodiversity^{223 224}. As discussed in the previous section, heterogeneity in pelagic habitats is caused by bathymetric or topographic features such as seamounts and banks. Heterogeneity is also caused by hydrographic features. These features include upwelling at divergences, fronts at convergence zones between water masses and eddies spun off from ocean currents creating large scale nutrient patterns, primary production and temperature fronts^{225 226}. These features affect global patterns of pelagic species diversity.

Based on an analysis of similarities and differences in ecosystem structure and function and general considerations of algal blooms, shelf morphology and nutrient dynamics, Longhurst (1995²²⁷; 1998²²⁸) subdivided the oceans into four biomes (the coastal boundary zone, trade-winds, westerlies, and polar) and 57 “biogeochemical provinces” with distinct seasonal patterns of surface nutrient enrichment,

220 Document A/60/63/Add.1 presented to the 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. See: <http://daccessdds.un.org/doc/UNDOC/GEN/N05/425/11/PDF/N0542511.pdf?OpenElement>.

221 Angel, M.V. 1993. Biodiversity of the pelagic ocean. *Conservation Biology* 7: 760-772.

222 Polovina, J.J., Kobayashi, D.R., Parker, D.M., Seki, M.P. and Balazs, G.H. 2000. Turtles on the edge: movement of loggerhead turtles (*Caretta caretta*) along oceanic fronts spanning longline fishing grounds in the central North Pacific, 1997-1998. *Fisheries Oceanography* 9: 71-82.

223 Myers RA, Worm B (2003) Rapid worldwide depletion of predatory fish communities. *Nature* 423:280-283

224 Worm, B., Sandow, M., Oschlies, A., Lotze, H.K. and Myers, R.A. 2005. Global patterns of predator diversity in the open oceans. *Science* 309: 1365-1369.

225 Hyrenbach KD, Forney KA, Dayton PK (2000) Marine protected areas and ocean basin management. *Aquatic Conservation: Marine and Freshwater Ecosystems* 10:437-458

226 Dugdale RC (1976). Nutrients cycles. In: Cushing DH, Walsh JJ (eds). *The Ecology of the Seas*. Blackwell Scientific Publications, Oxford. p. 141-172.

227 Longhurst, A.R. (1995) Seasonal cycles of pelagic production and consumption. *Progress in Oceanography* 36, 77-167

228 Longhurst, A.R., 1998. *Ecological geography of the sea*. Academic Press., San Diego

which determine primary production levels and, ultimately, fisheries yield. This pelagic bioregional classification is widely accepted, and has been used as a basis for global assessments²²⁹ and further work on bioregionalization²³⁰.

Hydrographic features affecting the distribution of pelagic species can be classified into persistent and ephemeral²³¹. Persistent features are regions of elevated biological activity in continental shelves, where seabirds, marine mammals and tunas aggregate to exploit prey concentrations. For example, in the North Pacific, a narrow (40°–44°) region of strong temperature and salinity gradients, termed the Transition Domain, is of particular biological importance. Frontal zones contain the highest standing stocks of micronekton (small but actively swimming organisms, such as jellyfish, crustaceans and small fish) in the North Pacific during the boreal spring and summer, and represent a vital foraging habitat and migratory route for many species including salmonids, albacore tuna, albatrosses, shearwaters, sharks and turtles.

Ephemeral features are defined by short-lived gradients in water properties. Highly mobile pelagic species find and exploit ephemeral fronts while they persist. Upwelling is a major process that can create ephemeral enhancement of primary production in the pelagic zones. In addition, short-lived fronts created along the edges of eddies enhance and retrain primary and secondary production. Pelagic predators (e.g. seabirds, marine mammals, tunas) feed on the plankton aggregated in these regions²³². Wind forcing, deep convection and buoyancy fluxes can also create small-scale fronts and convergence zones which may provide important nurseries and foraging habitats for pelagic species.

2. Status and Trends

The epipelagic zone (the top 200 m of the water column) is relatively better understood than other habitats in the high seas. Sea surface primary productivity is monitored by remote sensing and ship-based sampling. Taxonomic diversity of micronekton and macrozooplankton is well documented, with no great expectations of finding new species with the exception of gelatinous groups (e.g. jellyfish)²³³. However, recent genetic studies have questioned whether the wide-spread zooplankton and micronekton species are one highly variable species or a species complex. Species richness of pelagic fish predators and zooplankton are suggested to be correlated with sea surface temperature (SST), SST gradients and dissolved oxygen concentration²³⁴. The diversity of pelagic fish predators and zooplankton consistently peaks at intermediate latitudes (20–30°N and S), where ranges of tropical and temperate species overlap^{235 236}. Species richness of pelagic seabirds and marine mammals peaks at higher latitudes, between 30 and 60°S in the southern hemisphere^{237 238}.

229 E.g. The Millennium Ecosystem Assessment chapter on Marine Fisheries Systems.

230 E.g. Spalding, M.D., Fox, H.E., Allen, G.R., Davidson, N, Ferdana, Z.A., Finlayson, M., Halpern, B.S., Jorge, M.A., Lombana, A., Lourie, S.A., Martin, K.D., McManus, E., Molnar, J., Recchia, C.A., and Robertson, J. (2007) Marine ecoregions of the world: a bioregionalization of coastal and shelf areas. *Bioscience* 57(7):573–582.

231 Hyrenbach KD, Forney KA, Dayton PK (2000) Marine protected areas and ocean basin management. *Aquatic Conservation: Marine and Freshwater Ecosystems* 10:437–458

232 Hyrenbach KD, Forney KA, Dayton PK (2000) Marine protected areas and ocean basin management. *Aquatic Conservation: Marine and Freshwater Ecosystems* 10:437–458

233 Pierrot-Bults, A.C. and van der Spoel, S. 2003. Macrozooplankton diversity: how much do we really know? *Zoo. Verh. Leiden* 345: 297–312.

234 Worm, B., Sandow, M., Oschlies, A., Lotze, H.K. and Myers, R.A. 2005. Global patterns of predator diversity in the open oceans. *Science* 309: 1365–1369.

235 Myers RA, Worm B (2003) Rapid worldwide depletion of predatory fish communities. *Nature* 423:280–283

236 Angel MV (2003) The pelagic environment of the open ocean. *Ecosystems of the World* 28: 39–80.

237 Chown, S.L., Gaston, K.J. and Williams, P.H. 1998. Global patterns in species richness of pelagic seabirds: the Procellariiformes. *Ecography* 21: 342–350.

238 Cheung, W.W.L., Pitcher, T.J. and Pauly, D. (2005) A fuzzy logic expert system to estimate intrinsic extinction vulnerability of marine fishes to fishing. *Biol. Conserv.* 124: 97–111.

Mesopelagic species are important components of oceanic ecosystems²³⁹. This is due in part to their commonness and abundance worldwide (except in the Arctic). Mesopelagic fishes are the main consumers of zooplankton, larval and juvenile fishes, and are important prey for the higher producers, such as tunas, squids and marine mammals. At least 160 fish genera in 30 families were recognized as important components of the mesopelagic fauna²⁴⁰. Mesopelagic fishes are generally not exploited by fisheries, owing to their extreme dispersion (density of about 1g m³)²⁴¹. The biomass of mesopelagic fishes globally is estimated to be approximately 999 million tonnes. Western Indian Ocean, and in particular the northern Arabian sea, contains the most biomass (263.2 million tonnes in total)²⁴².

The bathypelagic zone is the least-known of the three depth zones in terms of taxonomic diversity. This is due in part to the insufficiency and difficulty of sampling. Faunal composition includes squid and octopus (cephalopods), deep-sea fishes (viperfishes, anglerfishes) and whales. It is expected that new species will be discovered in this region.

3. Threats

Many pelagic species are threatened directly or indirectly by commercial fishing. Pelagic fishes are caught as target species and as bycatch. Following a long history of intensive exploitation of large pelagic fish, and particularly, the global expansion of longline fisheries since the 1950s, predators such as sharks and tunas may have declined by over 90% in 50 years²⁴³, although the magnitude of the decline is still being debated²⁴⁴. For example, in the tropical Pacific Ocean, the largest and most abundant predators, such as sharks and large tunas, showed large reductions in mean body mass and abundance. The mean mass of blue shark (*Prionace glauca*) was 52 kg in the 1950s compared to 22 kg in the 1990s, while abundance was only 13% of that in the 1950s²⁴⁵. In the Gulf of Mexico, oceanic whitetip and silky sharks have declined by over 99% and 90%, respectively²⁴⁶. Such depletions of pelagic predators contribute to a reduction in species diversity and changes in community structure of pelagic systems. It is estimated that pelagic predator diversity declined between 10% and 50% in all oceans; this decline coincided with increased fishing pressure and El Niño–Southern Oscillation²⁴⁷.

In addition to fishes, other pelagic megafauna are also threatened directly or indirectly by fishing. Past whaling activities have driven many marine mammals to endangered levels²⁴⁸. Prior to commercial whaling, the abundance of whales was estimated to have been 42 x 106 tonnes globally²⁴⁹. By the 1960s, when a near-global moratorium on whaling began, their abundance was estimated to have been reduced

239 Cornejo R and Koppelman R (2006) Distribution patterns of mesopelagic fishes with special reference to *Vinciguerra lucetia* Garman 1899 (Phosichthyidae: Pisces) in the Humboldt Current Region off Peru. *Marine Biology* 149: 1519–1537.

240 Gjosaeter, J. and Kawaguchi, K. 1980. A review of the world resources of mesopelagic fish. *FAO Fisheries Technical Paper*, 193, 151 pp.

241 Lam, V. and Pauly, D. 2005. Mapping the global biomass of mesopelagic fishes. *Sea Around Us Project Newsletter* July/August (30): 4.

242 Lam, V. and Pauly, D. 2005. Mapping the global biomass of mesopelagic fishes. *Sea Around Us Project Newsletter* July/August (30): 4.

243 Myers RA, Worm B (2003) Rapid worldwide depletion of predatory fish communities. *Nature* 423:280–283

244 Sibert J, Hampton J, Kleiber P, Maunder M (2006) Biomass, size and trophic status of top predators in the Pacific Ocean. *Science* 314:1773–1776

245 Ward, P. and Myers, R.A., 2005. Shifts in open-ocean fish communities coinciding with the commencement of commercial fishing. *Ecology* 86(4): 835–847.

246 Baum, J.K. and R. A. Myers (2004) Shifting baselines and the decline of pelagic sharks in the Gulf of Mexico. *Ecology Letters* 7 (2), 135–145.

247 Worm, B., Sandow, M., Oschlies, A., Lotze, H.K. and Myers, R.A. (2005) Global patterns of predator diversity in the open oceans. *Science* 309: 1365–1369.

248 Clapham, P.J., Young, S.B. and Brownell, R.L. Jr. (1999) Baleen whales conservation issues and the status of the most endangered populations. *Mammal Review* 29: 35–60.

249 Valiela, I. 1995. *Marine Ecological Processes*. Second edition. New York, USA: Springer-Verlag: 686 pp.

by approximately 80%. The decline of marine mammals has caused changes in ecosystem dynamics in some regions²⁵⁰.

Bycatch remains a serious problem. Bycatch by pelagic gillnet and longline fishing continues to kill marine mammals, seabirds and sea turtles, and the following examples highlight the extent of the threat. It is estimated that more than 200,000 loggerhead and 50,000 leatherback turtles were likely taken as pelagic longline bycatch in 2000, a level that is not sustainable²⁵¹. In the central North Pacific, as many as 10,000 Black-footed albatross individuals per year might be killed as longline bycatch²⁵², and monitored high seas fishing vessels off northern and central Patagonian coast caught 97 mammals as bycatch during a total of 5761 fishing days²⁵³. Bycatch in longline fisheries can be greatly reduced by using appropriately sized circle hooks with whole finfish, while at the same time maintaining target catch rates. In 2003, the Inter-American Tropical Tuna Commission (IATTC) launched an initiative among its member states to run experiments toward the replacement of traditional j-hooks with circle hooks in longlines of the Eastern Pacific with the intention to reduce mortality from bycatch.

Bioaccumulation of chemical contaminants poses threats to the health of pelagic animals, particularly top predators. Organochlorine pesticides, such as DDT, and industrial pollutants, such as polychlorinated biphenyls (PCBs), are resistant to degradation and can bioaccumulate and biomagnify in food webs^{254 255}. These chemicals have been shown to be associated with reproductive problems in marine mammals²⁵⁶. On the other hand, organochlorine and metal contaminants in baleen whales appeared low. Therefore, firm conclusions on the effect of these contaminants on the baleen whale populations could not be drawn. This suggests that research and management actions should focus on reducing direct human-induced mortality (e.g., bycatch, ship strikes) and on increasing habitat carrying capacity for these species^{257 258}.

Climate change may have a potentially large impact on pelagic systems in the high seas. Dynamics of pelagic systems depend largely on sea water temperature and current flow patterns, which affect the magnitude and temporal and spatial distribution of primary productivity. These factors, in turn, affect the distribution of zooplankton, pelagic fishes and other pelagic megafauna²⁵⁹. The dissolution of CO₂ has already lowered the average pH of the oceans by about 0.1 units from pre-industrial levels²⁶⁰, and ocean acidification is likely to affect calcification of foraminifera and pteropods (plankton with calcareous

250 Verity, P.G., Smetacek, V. and Smayda, T.J. (2002) Status, trends and the future of the marine pelagic ecosystem. *Environmental Conservation* 29(2): 207–237.

251 Lewison, R.L., Freeman, S.A. and Crowder, L.B. (2004) Quantifying the effects of fisheries on threatened species: the impact of pelagic longlines on loggerhead and leatherback sea turtles. *Ecology Letters* 7: 221–231.

252 Lewison, R. L. and Crowder, L.B. 2002. Estimating fishery bycatch and effects on a vulnerable seabird population. *Ecological Applications* 13: 743–753.

253 Crespo EA, Pedraza SN, Dans SL, Alonso MK, Reyes LM, Garcia NA, Coscarella M, Schiavini ACM (1997) Direct and indirect effects of the highseas fisheries on the marine mammal populations in the northern and central Patagonian coast. *Journal of Northwest Atlantic Fisheries Science* 22:189–207.

254 Ronald K, Frank RJ, Dougan J, Frank R and Braun HE (1984) Pollutants in harp seals (*Phoca groenlandica*). I. Organochlorines. *The Science of the total environment* 38: 153–166

255 Becker PR, Krahn MM, Mackey EA, Demiralp R, Schantz MM, Epstein MS, Donais MK, Porter BJ, Muir DCG, Wise SA (2000) Concentrations of polychlorinated biphenyls (PCBs), chlorinated pesticides, and heavy metals and other elements in tissues of Belugas, *Delphinapterus leucas*, from Cook Inlet, Alaska. *Marine Fisheries Review* 62(3): 81–98.

256 Aguilar, A. and Jover, L. (1982) DDT and PCB residues in the fin whale, *Balaenoptera physalus*, of the North Atlantic. *Reports of the International Whaling Commission* 32: 299–301.

257 Clapham, P.J., Young, S.B. and Brownell, R.L. Jr. (1999) Baleen whales conservation issues and the status of the most endangered populations. *Mammal Review* 29: 35–60.

258 O'Shea, T.J. and Brownell, R.L., Jr. (1994) Organochlorine and metal contaminants in baleen whales: a review and evaluation of conservation implications. *The Science of the Total Environment* 154: 179–200.

259 Hobday, A. J., Okey, T. A., Poloczanska, E. S., Kunz, T. J. & Richardson, A. J. (eds) (2006) Impacts of climate change on Australian marine life: Part C. Literature Review. Report to the Australian Greenhouse Office, Canberra, Australia. September 2006.

260 Caldeira, K., Wickett, M.E. (2003) Anthropogenic carbon and ocean pH. *Nature* 425, 365.

shells), which produce CaCO_3 in its aragonite form²⁶¹. However, the extent to which climate change may threaten species in the pelagic systems requires further research.

Carbon sequestration may present a related future threat. It has been suggested that one strategy for combating climate change is to enhance the ocean's natural capacity to absorb and store atmospheric carbon dioxide, either by inducing and enhancing the growth of carbon-fixing plants in the surface ocean, or by speeding up the natural, surface-to-deep-water transfer of dissolved carbon dioxide by directly injecting it into the deep ocean. The environmental consequences of this activity are unknown, and the carbon dioxide dumped in the oceans will eventually percolate to the surface and back into the atmosphere²⁶².

4. Functioning of this Ecosystem and Ecology of Associated Species

Species diversity in the pelagic environment is generally lower than in the benthic environment despite the far greater volume of the pelagic environment²⁶³. The lower diversity in pelagic systems may be a result of their openness, which allows for rapid and widespread gene flow through pelagic communities. Of the 28 phyla of animals that inhabit the ocean, one phylum, the Ctenophora, is endemic to the pelagic realm. The number of pelagic species recorded within a single locality can be very high, however. For example, 200 phytoplankton species were recorded in the epipelagic zone of the central Pacific, while 175 species of copepod were recorded in the upper 500 m of the North Atlantic. Similarly, 320 species from four taxa (fish, decapods, euphausiids, and ostracods) were recorded in one locality, a count which could have reached 1,000 species if all sampled taxa had been identified²⁶⁴.

In general, pelagic fish diversity declines rapidly with increasing depth²⁶⁵. For instance, in an analysis of the relationship between species richness and depth for pelagic marine fishes between 40°N and 50°N in the north-east Pacific Ocean, species richness declined from around 300 species on the upper 200 m to below 150 species at around 1,000 m depth, and less than 30 species at around 3,000 m depth²⁶⁶. In contrast to the pattern found in fish diversity, maximum richness of planktonic ostracods is generally approximately 1,000 m²⁶⁷. These studies indicate differences in taxonomic groups' relationships between depth and species richness. Alternatively, these observed patterns may be a result of sampling biases.

The pelagic ecosystem is fueled by phytoplankton primary production. Herbivorous zooplankton graze on phytoplankton, and in turn support predators including planktivores and piscivores. However, the open ocean is largely oligotrophic (nutrient poor) as nutrient mixing from deep water to the surface layers is prevented by a thermal and density boundary called the thermocline, leading to low primary productivity. It is because of this generally nutrient-poor status of oceans that oceanographic features bringing nutrient-rich deep water to the surface greatly enhance primary productivity. As mentioned in the section above, these may be static bathymetric features such as reefs, shelf breaks and seamounts, or they may be hydrographic features, such as ocean fronts, which alter water flow and promote upwelling of deeper, nutrient-rich waters. The nutrient rich zones aggregate animals along the food chain from mesopelagic fishes to predators such as tuna and billfish, marine mammals and seabirds.

261 Feely, R.A., Sabine, C.L., Lee, K., Berelson, W., Kleypas, J., Fabry, V.J., Millero, F.J. (2004) Impact of anthropogenic CO₂ on the CaCO₂ system in the ocean. *Science* 305, 362–366.

262 IOC of UNESCO. <http://ioc.unesco.org/iocweb/co2panel/sequestration.htm>

263 Angel, M.V. 1993. Biodiversity of the pelagic ocean. *Conservation Biology* 7: 760–772.

264 Angel, M.V. 1991. Variations in time and space: Is biogeography relevant to studies of long-time scale change? *Journal of the Marine Biological Association of the United Kingdom* 71: 191–206.

265 Smith and Brown 2002. Patterns of diversity, depth range and body size among pelagic fishes along a gradient of depth. *Global Ecology & Biogeography* 11: 313–322.

266 Smith and Brown 2002. Patterns of diversity, depth range and body size among pelagic fishes along a gradient of depth. *Global Ecology & Biogeography* 11: 313–322.

267 Angel, M.V. 1993. Biodiversity of the pelagic ocean. *Conservation Biology* 7: 760–772.

The microbial loop is also an important component of the food chain in pelagic systems^{268 269}. Dissolved organic matter produced by phytoplankton and zooplankton can be a food source for bacteria. These bacteria, in turn, provide food for protozoan and metazoan plankton, while the organic matter they produce goes back to the dissolved organic matter pathway that supports the bacteria. Because microbes are the base of the food web in most oceanic environments, the trophic efficiency of the microbial loop has an important impact on productivity of fisheries and the amount of carbon exported to the ocean floor.

Understanding the relationship between physical and oceanographic attributes and the distribution of pelagic species allows areas of high productivity and diversity to be predicted²⁷⁰. In particular, numerous species of conservation concerns (including marine turtles, marine mammals, seabirds, and pelagic fish predators) inhabit the open ocean. These species are not evenly distributed across the open ocean, but may be concentrated temporally or spatially for feeding, reproduction or migration. The location of species concentrations are generally correlated with physical and oceanographic features²⁷¹. For example, the diversity of planktonic foraminifera peaks in the middle latitudes in all oceans and is strongly correlated with sea surface temperature²⁷². Sea surface temperature also correlates with the diversity of pelagic predators (tunas and billfishes)²⁷³.

Many pelagic species, ranging from krill to tunas and marine mammals, migrate during different stages of their different life history²⁷⁴. These migrations may be linked to predation avoidance in early life stages, maintaining preferred conditions (e.g. temperature, food supplies) in the seasonally varying pelagic environment, and for reproduction. For example, long-distance movement of loggerhead turtles between the western and eastern Mediterranean basins follows a seasonal pattern and seems to be triggered by temperature and food availability²⁷⁵. Leatherback turtles follow at least two main patterns of migration: some disperse north, broadly towards the Gulf Stream area, and others disperse to the east and remain in tropical waters²⁷⁶. It is suggested that mammals and seabirds in the Gulf of Alaska may respond in a similar manner to broad-scale environmental factors, such as changes in ocean productivity²⁷⁷.

268 Pomeroy, L.R. (1974) The ocean's food web: a changing paradigm. *Bioscience* 24: 542–544.

269 Azam, F., Fenchel, T., Field, J.G., Gray, J.S., Meyer-Reil, L.A. and Thingstad, F. (1983) The ecological role of water-column microbes in the sea. *Marine Ecology Progress Series* 10: 257–263.

270 Worm, B., Sandow, M., Oschlies, A., Lotze, H.K. and Myers, R.A. (2005) Global patterns of predator diversity in the open oceans. *Science* 309: 1365–1369.

271 Hyrenbach KD, Forney KA, Dayton PK (2000) Marine protected areas and ocean basin management. *Aquatic Conservation: Marine and Freshwater Ecosystems* 10:437–458

272 Rutherford S, D'Hondt S, Prell W (1999) Environmental controls on the geographic distribution of zooplankton diversity. *Nature* 400:749–753

273 Worm, B., H.K. Lotze, and R.A. Myers. 2003. Predator diversity hotspots in the blue ocean. *Proceedings of the National Academy of Science USA*. 100: 9884–9888

274 Angel, M.V. 1993. Biodiversity of the pelagic ocean. *Conservation Biology* 7: 760–772.

275 Bentivegna, F. (2002) Intro-Mediterranean migrations of loggerhead sea turtles (*Caretta caretta*) monitored by satellite telemetry. *Marine Biology* 141:795–800.

276 Ferraroli S, Georges J-Y, Gaspar II P, Maho YL (2004) Where leatherback turtles meet fisheries. *Nature* 429:521

277 Yen PPW, Sydeman WJ, Morgan KH, Whitney FA (2005) Top predator distribution and abundance across the eastern Gulf of Alaska: Temporal variability and ocean habitat associations. *Deep-Sea Research II* 52:799–822

B. BENTHIC HABITATS

1. Sponge Reefs and Fields

a. Global distribution

Sponge reefs, which are formed by glass sponges with three-dimensional silica skeletons, are built in a manner similar to coral reefs, by new generations growing on previous ones. Sponge stalk communities can be found on the soft mud bottom of the deep sea throughout the world's oceans between the depths of 500 and 3,000m²⁷⁸. Despite their worldwide distribution, the main occurrences of sponge reefs are in cold waters associated with bathymetric and topographic structures, such as seamounts, continental slopes and underwater canyons, where fast-flowing, nutrient-rich deepwater currents can be found^{279 280 281}.

Our current knowledge of the global distribution of sponge reefs is incomplete and biased by insufficient sampling. Sponge fields and communities have been found on Tasmanian seamounts²⁸² in the continental margin canyons off southeastern Australia²⁸³; and at depths greater than 3.5 km on the Blake Spur, a rocky cliff-dominated feature on the western Atlantic continental margin²⁸⁴. In the North Atlantic, large sponge fields exist in deeper waters off East Greenland, around Iceland and along the Reykjanes Ridge, around the Faroes, off northern Norway, in the Barents Sea and off Svalbard. In the Mediterranean, 30 species of sponges have been recorded in association with a coral bank situated off Cape S. Maria di Leuca (southern Italy) at depths of 430 to 1,160 m²⁸⁵. In the Queen Charlotte Sound and Hecate Strait off British Columbia, Canada, sponge reefs discontinuously cover approximately 1,000 km² of seafloor.

b. Status and trends

Our knowledge of the distribution, status and trends of sponge reefs is limited, though something can be said about their biodiversity. Based on a map of sponge (demospongiae) species richness in 35 marine biogeographic provinces²⁸⁶, the region with the highest observed species richness is the Asia-Pacific region (965 species), followed by southwest Africa (683 species), west central Atlantic (640 species), Central Atlantic (640 species), the Mediterranean (552 species), off Northwest Africa (445 species) and Tasmania (436 species). Similar species richness was observed in the south central Pacific (354 species), Northeast Atlantic (348 species), Arctic (360 species) and Antarctic (337 species). These estimates include both shallow and deep-sea sponges. However, current knowledge about the species richness of sponge reefs and fields is incomplete and biased by insufficient sampling and poor taxonomic knowledge, particularly

278 Beaulieu, S.E. (2001) Life on glass houses: sponge stalk communities in the deep sea. *Marine Biology* 138: 803–817.

279 Genin, A., Paull, C.K. and Dillon, W.P. (1992) Anomalous abundances of deep sea fauna on a rocky bottom exposed to strong currents. *Deep-Sea Research* 39: 293–302.

280 Rice, A.L. and Lamshead, P.J.D. (1994) Patch dynamics in the deep-sea benthos: the role of a heterogeneous supply of organic matter. In *Aquatic Ecology Scale pattern and Process*. Giller P.S., Hildrew, A.G., Raffaelli, D.G. (eds.). pp. 469–497. Blackwell Science: Oxford.

281 Schlacher, T.A., Schlacher-Hoenlinger, M.A., Williams, A., Althaus, F., Hooper, J.N.A. and Kloser, R. (2007) Richness and distribution of sponge megabenthos in continental margin canyons off southeastern Australia. *Marine Ecology Progress Series* 340: 73–88.

282 Roberts S, Hirshfield M (2004) Deep-sea corals: out of sight, but no longer out of mind. *Frontiers in Ecology and the Environment* 2: 123–130.

283 Schlacher, T.A., Schlacher-Hoenlinger, M.A., Williams, A., Althaus, F., Hooper, J.N.A. and Kloser, R. (2007) Richness and distribution of sponge megabenthos in continental margin canyons off southeastern Australia. *Marine Ecology Progress Series* 340: 73–88.

284 Genin, A., Paull, C.K. and Dillon, W.P. (1992) Anomalous abundances of deep sea fauna on a rocky bottom exposed to strong currents. *Deep-sea Research* 39: 293–302.

285 Longo, C., Mastrototaro, F. and Corriero, G. (2005) Sponge fauna associated with a Mediterranean deep-sea coral bank. *Journal of Marine Biological Association U.K.* 8: 1341–1352

286 McClintock, J.B., Amsler, C.D., Baker, B.J. and van Soest, R.W.M. (2005) Ecology of Antarctic marine sponges: An overview. *Integr. Comp. Biol.* 45: 359–368.

in regards to deep-sea sponge species. For instance, the species richness in the deep sea of the Atlantic, central Pacific and southern Pacific is unknown²⁸⁷.

Many sponge reefs show impact of bottom fishing activities, and sponges are common as bycatch from fishing operations²⁸⁸. The global extent of fishing impact on sponge reefs has not been documented.

c. Threats

The threats facing sponge reefs are similar to those facing cold-water coral reefs. Sponge reefs resemble cold-water coral reefs in terms of the area of potential occurrence (e.g., association with deepwater topographic features and with strong flow of nutrient rich waters) and their function as living physical structure for their associated species. Like corals, sponges are generally slow-growing and sensitive to changes in their environment. Major threats to sponge reefs and fields include destructive fishing practices such as bottom trawling, other bottom-contact fishing (e.g., mid-water trawls, long lines), hydrocarbon drilling, seabed mining and direct exploitation. Currently, bottom trawling is the biggest threat to sponge reefs and fields, causing mechanical breakage of their structure. Moreover, bottom trawling creates a sediment cloud that can clog the filter-feeding sponges.

Given the large number of shallow-water tropical sponges that have been found to be of actual and potential use for biotechnology, in particular in the field of pharmaceuticals, deep-sea sponges may be of similar future interest to bioprospectors.

d. Functioning of sponge-reef ecosystems and ecology of associated species

Sponge reefs are slow-growing and long-lived. Their growth rate is generally two to seven centimetres per year, and they can live to be up to 6,000 years old (estimated from a 5-m thick sponge reef in the Queen Charlotte Sound of British Columbia)²⁸⁹.

Sponges play a functional role in the marine benthos. They can modify the physical properties of the seafloor and influence the composition, abundance, and distribution of fauna²⁹⁰. Sponges can also act as structure-forming invertebrates, adding structural complexity and providing habitat for many species, including invertebrates and commercially important fish^{291 292 293}.

A great diversity of invertebrates can be found associated with sponges. For example, in the Faroese waters, more than 250 species of invertebrates were found associated with sponge reefs²⁹⁴. In general, twice as many species of invertebrates can be found in sponge reefs or fields than the surrounding seabed.

287 McClintock, J.B., Amsler, C.D., Baker, B.J. and van Soest, R.W.M. (2005) Ecology of Antarctic marine sponges: An overview. *Integr. Comp. Biol.* 45: 359–368.

288 Freiwald, A., J.H Fosså, A. Grehan, T. Koslow and J. M. Roberts. 2004. Cold-water Coral Reefs. UNEP-WCMC, Cambridge, UK.

289 CBD (2005) Status and trends of, and threats to, deep seabed genetic resources beyond national jurisdiction, and identification of technical options for their conservation and sustainable use (UNEP/CBD/SBSTTA/11/11). See: <http://www.biodiv.org/doc/meetings/sbstta/sbstta-11/official/sbstta-11-11-en.doc>

290 Bett, B.J. and Rice, A.L. (1992) The influence of hexactinellid sponge (*Pheronema carpenleri*) spicules on the patchy distribution on macrobenthos in the Porcupine Seabight (Bathyal NE Atlantic). *Ophelia* 36: 217–226.

291 UNEP (2006) Ecosystems and biodiversity in deep waters and high seas. UNEP Regional Seas Reports and Studies No. 178. UNEP/IUCN Switzerland 2006.

292 Beaulieu SE (2001) Life on glass houses: sponge stalk communities in the deep sea. *Marine Biology* 138:803–817

293 Tissot, B.N., Yoklavich, M.M., Love, M.S., York, K. and Amend, M. (2006) Benthic invertebrates that form habitat on deep banks off southern California, with species reference to deep sea coral. *Fish. Bull.* 104: 167–181.

294 Klitgaard, A.B. and Tendal, O.S. (2004) Distribution and species composition of mass occurrences of large-sized sponges in the northeast Atlantic. *Progress in Oceanography* 61: 57–98.

Stalks of sponges offer vertical living space, extending several tens of centimetres above the sediment surface into the turbulent benthic boundary layer flow with its drifting food particles.

Studies off the coast of California found that the most abundant taxa living on glass sponges included the calcareous *foraminiferan* *Cibicides lobatulus*, followed by the most abundant metazoan, the *serpulid polychaete* *Bathyvermilia* sp.²⁹⁵. The number of taxa in sponge stalk communities ranged from four to 44 per stalk, with a mean of 22 taxa and 272 individuals. Sponge stalk communities appear to be based on detritus collected on stalk branches, which supports detritivores such as copepods and polychaetes. Mobile predators may feed on the detritivores, or on the cnidarian colonies present in the stalk communities. Vertical species zonation can be found on stalks, with large suspension feeders, such as cnidarian colonies, living at the top and smaller solitary epifauna and encrusting foraminifera living at the base of the stalks. This vertical zonation appears to be controlled by biological interactions among species. Sponges both in shallow and deep water are considered islands for cryptofauna, organisms dwelling in cavities²⁹⁶.

Sponges can modify their surrounding environment through current baffling, enhancement of bacterial biomass, and by the formation of a biogenic layer and structure. They play a key role in benthic-pelagic coupling and benthic metabolism in deep-sea environments^{297 298}. When the sponges die, large amounts of sponge skeletal structures called spicules are released. These can form a local spicule mat on the sea bottom, or be transported by bottom currents to other locations. Spicule mats have been observed in the Faroe Islands, Iceland, off East Greenland, the Porcupine Seabight (NE Atlantic), off Morocco and around Antarctica^{299 300 301 302 303}. Spicule mats can change the sediment composition and structure as well as the composition of the benthic fauna.

2. Cold seeps

a. Distribution

Cold seeps are deep soft-bottom areas where oil or gases seep out of the sediments. "Seepage" encompasses everything from vigorous bubbling of gas from the seabed to the small-scale emanation of microscopic bubbles or hydrocarbon compounds in solution. Seep fluids contain a high concentration of methane. This methane can have a biological origin from the decomposition of organic matter by microbial activity in anoxic sediments, or a thermogenic origin from fast transformation of organic matter caused by high temperatures. Another important factor in some cold seeps is a high concentration of sulfide in the sediments, produced by the reduction of sulfates. Both methane and sulfide play a major role in sustaining highly productive cold seep communities.

295 Beaulieu SE (2001) Life on glass houses: sponge stalk communities in the deep sea. *Marine Biology* 138:803–817

296 Beaulieu SE (2001) Life on glass houses: sponge stalk communities in the deep sea. *Marine Biology* 138:803–817

297 Witte, U. and Graf, G. (1996) Metabolism of deep-sea sponges in the Greenland-Norwegian Sea. *J. Exp. Mar. Biol. Ecol.* 198: 223–235

298 Schlacher, T.A., Schlacher-Hoenlinger, M.A., Williams, A., Althaus, F., Hooper, J.N.A. and Kloser, R. (2007) Richness and distribution of sponge megabenthos in continental margin canyons off southeastern Australia. *Marine Ecology Progress Series* 340: 73–88.

299 Bett, B.J. and Rice, A.L. (1992) The influence of hexactinellid sponge (*Pheronema carpenteri*) spicules on the patchy distribution on macrobenthos in the Porcupine Seabight (Bathyal NE Atlantic). *Ophelia* 36: 217–226.

300 Rice AL, Thurston MH, New AL (1990) Dense aggregations of a hexactinellid sponge, *Pheronema carpenteri* in the Porcupine Seabight (Northeast Atlantic Ocean) and possible causes. *Progress in Oceanography* 24: 197–206.

301 Barthel D (1992) Do hexactinellids structure Antarctic sponge associations? *Ophelia* 36: 111–118

302 Barthel D and Tendal OS (1994) Antarctic Hexactinellida. Synopses of the Antarctic benthos. Koeltz, Koenigstein

303 Barthel D, Tendal OS and Thiel H (1996) A wandering population of the hexactinellid sponge *Pheronema carpenteri* on the continental slope off Morocco, Northwest Africa. *Marine Ecology* 17: 603–616.

Cold seeps are found along the world's passive and active continental margins at depths extending from 400 m to over 7000 m^{304 305}. On passive margin settings, such as along the Gulf of Mexico, fluids are expelled in cold seeps. Active seeps have been observed in all oceans of the world except in the polar regions³⁰⁶. Sibuet and Olu (1998)³⁰⁷ presented a map of known cold seeps globally on both passive and active margins. Known locations of cold seeps include the Atlantic, Eastern and Western Pacific oceans and the Mediterranean Sea. Well-studied seeps are mainly in waters within national jurisdiction, and include the seeps in Nankai Trough and Sagami Bay off Japan, The Aleutian Trench, Hydrate Ridge off Oregon, the Eel River margin and Monterey Bay in northern California, the Costa Rica Prism, the Peru margin, the Barbados Prism, and the Florida Escarpment in the Gulf of Mexico³⁰⁸. Cold seeps can be classified by their geological constructs, features and fluid flux rate³⁰⁹.

b. Status and trends

There are still knowledge gaps relating to the distribution, biodiversity and ecology of cold seeps. Cold seeps are known to support relatively high diversity. Over 210 species have been reported from cold seeps. This is very likely an under-estimate because of insufficient samples and poor taxonomic identification of cold-seep assemblages^{310 311}. From the total reported species, 147 species were non-symbiont-containing species, and only 26 were described and named. The dominant macro-fauna include clams, mussels and tubeworms^{312 313}. New species from cold seeps are still being described. For example, in the Gulf of Mexico, a new species called "ice worm" (*Hesiocaeca methanicola*) was discovered in 1997. This species excavates seafloor deposits of gas hydrates and grazes on the hydrate surfaces.

Cold seeps also support endemic species. Symbiont-containing species (those species that rely on sulphide or methane oxidation, or both, via chemoautotrophic endosymbiotic bacteria) appear to be mostly endemic to a seep site^{314 315}. Each of these species is only known to one or two cold seeps, though exceptions exist in the form of species found in both Pacific and Atlantic oceans. Surveys have found that only 13 out of 211 cold-seep-associated species occur at both seeps and hydrothermal vents^{316 317}. Similarly, surveyed *mytilidae* (mussel) species were found only at one cold seep area, while each of the

304 Levin, L. A. (2005) Ecology of cold seep sediments: interactions of fauna with flow, chemistry and microbes. *Oceanography and Marine Biology: An Annual Review* 43: 1–46.

305 Sibuet, M. and Olu, K. (1998) Biogeography, biodiversity and fluid dependence of deep-sea cold-seep communities at active and passive margins. *Deep-Sea Research II* 45: 517–567

306 Levin, L. A. (2005) Ecology of cold seep sediments: interactions of fauna with flow, chemistry and microbes. *Oceanography and Marine Biology: An Annual Review* 43: 1–46.

307 Sibuet, M. and Olu, K. (1998) Biogeography, biodiversity and fluid dependence of deep-sea cold-seep communities at active and passive margins. *Deep-Sea Research II* 45: 517–567

308 Levin, L. A. (2005) Ecology of cold seep sediments: interactions of fauna with flow, chemistry and microbes. *Oceanography and Marine Biology: An Annual Review* 43: 1–46.

309 Levin, L. A. (2005) Ecology of cold seep sediments: interactions of fauna with flow, chemistry and microbes. *Oceanography and Marine Biology: An Annual Review* 43: 1–46.

310 Sibuet, M. and Olu, K. (1998) Biogeography, biodiversity and fluid dependence of deep-sea cold-seep communities at active and passive margins. *Deep-Sea Research II* 45: 517–567

311 Sibuet, M. and Olu, K. (1998) Biogeography, biodiversity and fluid dependence of deep-sea cold-seep communities at active and passive margins. *Deep-Sea Research II* 45: 517–567

312 ChEss website: http://www.noc.soton.ac.uk/chess/education/edu_cs_animals.php

313 ChEss website: http://www.noc.soton.ac.uk/chess/education/edu_cs_animals.php

314 Bischoff M, Segonzac M, Almeida AJ, Desbruyeres D, Geistdoerfer P, Turnipseed M, Van Dover C (2002) Fishes from the hydrothermal vents and cold seeps—An update. *Cahier de Biologie marine* 38:140–141

315 Bischoff M, Segonzac M, Almeida AJ, Desbruyeres D, Geistdoerfer P, Turnipseed M, Van Dover C (2002) Fishes from the hydrothermal vents and cold seeps—An update. *Cahier de Biologie marine* 38:140–141

316 CBD (2005) Status and trends of, and threats to, deep seabed genetic resources beyond national jurisdiction, and identification of technical options for their conservation and sustainable use (UNEP/CBD/SBSTTA/11/11). See: <http://www.biodiv.org/doc/meetings/sbstta/sbstta-11/official/sbstta-11-11-en.doc>

317 CBD (2005) Status and trends of, and threats to, deep seabed genetic resources beyond national jurisdiction, and identification of technical options for their conservation and sustainable use (UNEP/CBD/SBSTTA/11/11). See: <http://www.biodiv.org/doc/meetings/sbstta/sbstta-11/official/sbstta-11-11-en.doc>

Vesicomysidae (bivalve mollusc) species were known only from one or two closely located seeps^{318 319}. These surveys indicate high endemism of symbiont-containing cold seep species. However, recent taxonomic and phylogenetic investigations report complexes of amphi-atlantic *Bathymodiolus* species, suggesting long-distance exchanges between mytilid populations^{320 321}.

The ecological status of cold seeps is not well documented, though there is some evidence of impact from fishing activities (see section C).

c. Threats

Threats to cold seeps include bottom fishing activities. Recent research reports from New Zealand record evidence of trawl damage, including extensive areas of coral rubble, as well as lost fishing gear on cold seeps³²².

Oil, gas and mineral exploration are potential threats to cold seep biodiversity. At the present time, such exploration occurs mainly on the continental shelf. However, the rich oil, gas and mineral reserves at or near cold seeps beyond national jurisdiction may attract exploration in the future, thus threatening their associated communities.

d. Functioning of cold-seep ecosystems and ecology of associated species

Cold seeps support abundant biological populations, fuelled by chemosynthesis. The chemoautotrophic bacteria of cold seeps are found both free-living and in symbiotic associations with seep-associated organisms. The symbiont-associated species are mostly sessile taxa such as clams, mussels and vestimentiferan tubeworms, clustering in areas where fluids rich in reduced chemicals exit from the seafloor^{323 324}. For example, the ecosystem-structuring, extremely slow-growing vestimentiferan tubeworm, *Lamellibrachia* sp., was found around hydrocarbon seeps on the Louisiana continental slope. Symbiont-associated mussels (*Mytilidae*) are found in cold seeps where natural gas (primarily methane) is released.

The chemosynthetic bacteria greatly enhance the productivity in and around cold seeps in an otherwise oligotrophic deepsea environment. Thus the seep systems can support biomass much greater than the surrounding deep sea. Moreover, biological production at cold seeps is related to the intensity of the fluid flow^{325 326}. Specifically, spatial variation in the fluid supply is an important factor explaining the distribution of cold-seep communities within a single site. The high productivity in cold seeps attracts

318 Sibuet, M. and Olu, K. (1998) Biogeography, biodiversity and fluid dependence of deep-sea cold-seep communities at active and passive margins. *Deep-Sea Research II* 45: 517–567

319 Sibuet, M. and Olu, K. (1998) Biogeography, biodiversity and fluid dependence of deep-sea cold-seep communities at active and passive margins. *Deep-Sea Research II* 45: 517–567

320 Cordes EE, Carney SL, Hourdez S, Carney RS, Brooks JM, Fisher CR (2007) Cold seeps of the deep Gulf of Mexico: Community structure and biogeographic comparisons to Atlantic equatorial belt seep communities. *Deep-Sea Research I* 54:637–653

321 Olu-Le Roy K, Cosel Rv, Hourdez S, Carney SL, Jollivet D (2007) Amphi-Atlantic cold-seep *Bathymodiolus* species complexes across the equatorial belt. *Deep Sea Research Part I: Oceanographic Research Papers* 54:1890–1911.

322 See, for example, NOAA Ocean Explorer at <http://www.oceanexplorer.noaa.gov/explorations/06newzealand/welcome.html> and UnderwaterTimes.com at http://www.underwatertimes.com/news.php?article_id=23807910461

323 Bergquist, D.C., Ward, T., Cordes, E.E., McNelis, T., Howlett, S., Kosoff, R., Hourdez, S., Carney, R. and Fisher, C.R. (2003) Community structure of vestimentiferan-generated habitat islands from Gulf of Mexico cold seeps. *Journal of Experimental Marine Biology and Ecology* 289: 197–222.

324 Bergquist, D.C., Ward, T., Cordes, E.E., McNelis, T., Howlett, S., Kosoff, R., Hourdez, S., Carney, R. and Fisher, C.R. (2003) Community structure of vestimentiferan-generated habitat islands from Gulf of Mexico cold seeps. *Journal of Experimental Marine Biology and Ecology* 289: 197–222.

325 Sibuet, M. and Olu, K. (1998) Biogeography, biodiversity and fluid dependence of deep-sea cold-seep communities at active and passive margins. *Deep-Sea Research II* 45: 517–567

326 Sibuet, M. and Olu, K. (1998) Biogeography, biodiversity and fluid dependence of deep-sea cold-seep communities at active and passive margins. *Deep-Sea Research II* 45: 517–567

organisms without chemosynthetic symbiotic bacteria. These species may feed on free bacteria present in the fluid or on bacterial mats, while some are carnivorous on other seep-associated species. Although the seep ecosystems support communities that are phylogenetically and physiologically quite similar to those at the hydrothermal vents, the latter experience rapidly fluctuating and ephemeral environments that stimulate their biological growth and development at rates far exceeding those of other deep-sea communities^{327 328}.

Populations of cold-seep communities may be connected between the Atlantic and eastern Pacific through the Isthmus of Panama^{329 330 331 332}, with the exception of seep-associated sponges, which are known only in the Atlantic Ocean, and the genus *Bathymodiolus*, which is absent from the eastern Pacific. Non-symbiont-containing species generally occur in both cold seeps and the surrounding deep sea, although they may show restricted geographic distributions when only cold-seep communities are compared³³³. Diversity of fish fauna associated with cold seeps is generally low. Of the approximately 20 known cold-seeps, only four revealed the presence of seep-living fishes, which had low diversity but high endemism¹⁶⁵. Additional studies of seep communities and their surrounding area are needed to better understand the global biogeography of cold-seep organisms.

Generally, the species richness of symbiont-containing species decreases with depth. Only one symbiont-containing species occurs at the Japan and Kurile trenches at 6,000 m depth, while 15 and 10 species were recorded at the Louisiana upper slope and Sagami Bay cold seeps, respectively. The lower species richness at greater depths may be a result of the limited larval dispersal in deep waters. Within similar depths, cold seeps on sediment substrates have higher species diversity than those on hard substrates^{334 335}. The characteristics of seepage fluids (duration of seepage, fluid flow rate, methane and sulphide concentrations in the fluid) may also affect species richness of cold-seep assemblages. The stability of the seep habitats might provide more opportunity for local diversification and speciation^{336 337}.

C. OTHER BENTHIC HABITATS

The ecosystems above have been singled out for attention by the Conference of the Parties to the Convention on Biological Diversity (decision VIII/21), and are thus described in detail. However, other important ecosystems also exist in the deep seabed. Our knowledge of these ecosystems is limited, as vast areas of the ocean bottom have never been surveyed. For example, mid-ocean ridges away from vent

327 Bergquist DC, Williams FM, Fisher CR (2000) Longevity record for deep-sea invertebrate. *Nature* 403:499–500

328 Bergquist DC, Williams FM, Fisher CR (2000) Longevity record for deep-sea invertebrate. *Nature* 403:499–500

329 Sibuet, M. and Olu, K. (1998) Biogeography, biodiversity and fluid dependence of deep-sea cold-seep communities at active and passive margins. *Deep-Sea Research II* 45: 517–567

330 Tunnicliffe, V., C. M. R. Fowler and A. McArthur (1996) Plate tectonic history and hot vent biogeography, In *Tectonic, Magmatic, Hydrothermal and Biological Segmentation of Mid-Ocean Ridges*, MacLeod, C. J., P. Tyler & C. L. Walker (eds). Geological Society Special Publication No. 118, pp. 225–238.

331 Sibuet, M. and Olu, K. (1998) Biogeography, biodiversity and fluid dependence of deep-sea cold-seep communities at active and passive margins. *Deep-Sea Research II* 45: 517–567

332 Tunnicliffe, V., C. M. R. Fowler and A. McArthur (1996) Plate tectonic history and hot vent biogeography, In *Tectonic, Magmatic, Hydrothermal and Biological Segmentation of Mid-Ocean Ridges*, MacLeod, C. J., P. Tyler & C. L. Walker (eds). Geological Society Special Publication No. 118, pp. 225–238.

333 Sibuet, M. and Olu, K. (1998) Biogeography, biodiversity and fluid dependence of deep-sea cold-seep communities at active and passive margins. *Deep-Sea Research II* 45: 517–567

334 Sibuet, M. and Olu, K. (1998) Biogeography, biodiversity and fluid dependence of deep-sea cold-seep communities at active and passive margins. *Deep-Sea Research II* 45: 517–567

335 Sibuet, M. and Olu, K. (1998) Biogeography, biodiversity and fluid dependence of deep-sea cold-seep communities at active and passive margins. *Deep-Sea Research II* 45: 517–567

336 Craddock, C., Hoeh, W.R., Gustafson, R.G., Lutz, R.A., Hashimoto, J., Vrijenhoek, R.J. (1995) Evolutionary relationships among deep-sea mytilids (Bivalvia: Mytilidae) from hydrothermal vents and cold-water methane/sulfide seeps. *Marine Biology* 121: 477–485.

337 Sibuet, M. and Olu, K. (1998) Biogeography, biodiversity and fluid dependence of deep-sea cold-seep communities at active and passive margins. *Deep-Sea Research II* 45: 517–567

sites, fracture zones, plateaus, escarpments and abyssal hills have hardly been studied by ecologists³³⁸. Two unique deep seabed benthic habitats, abyssal plains and canyons, are briefly described here.

1. Abyssal plains

Abyssal plains cover almost 50% of the deep-seabed, and are comprised mainly of mud flats. There is a relatively high diversity of animals living in and on deep-sea sediments, including bottom-dwelling fishes, sea cucumbers, star fishes, brittle stars, anemones, glass sponges, sea pens, stalked barnacles, mollusks, worms and small crustaceans³³⁹. However, despite the large number of rare animals, a few species make up the individuals in deep-sea samples. The most diverse species are macrofauna, small animals of up to 1mm in size³⁴⁰.

Not all areas of the abyssal plain have similar species diversity. Species diversity of both macro- and megafauna increases with depth below the continental shelf, reaching a maximum at mid to lower bathyal regions (bathyal regions correspond to the continental slope, between the depths of 200 and 2000m). Diversity also decreases with increasing distance seaward on the abyssal plain. While deep-sea benthic fauna is less patchily distributed than shallow-water fauna, significant aggregations of different taxa have been detected on scales ranging from centimetres to metres and kilometres. The most pronounced depth-related change in faunal composition occurs at the transition from continental shelf to continental slope (shelf-slope transition), and is probably due to differential adaptation by species to increasing environmental predictability on the upper slope. Rates of species replacement are more gradual below the shelf-slope break. The rate of environmental change is high at bathyal depths and lessens at abyssal depths³⁴¹.

Some large-scale biogeographic patterns of species diversity can also be found. Local species richness in the central equatorial Pacific abyss was found to be higher than that recorded at abyssal depths in the North Atlantic³⁴². Moreover, species diversity appears to decrease toward the poles³⁴³. For instance, deep-sea isopods, gastropods, and bivalves in the North Atlantic exhibit poleward decreases in species richness. It has been suggested that the decreased diversity at the poles may be due to greater seasonality in these regions, which produces seasonal pulses in phytoplankton production and thus in nutrients sinking to the deep-sea³⁴⁴. However, a recent study has found high levels of biodiversity new to science in the deep benthos of the Southern Ocean, challenging the suggestion that deep sea biodiversity is depressed in these areas³⁴⁵.

338 Peter Harris, Geoscience Australia, personal communication

339 UNEP (2006) Ecosystems and biodiversity in deep waters and high seas. UNEP Regional Seas Reports and Studies No. 178. UNEP/IUCN Switzerland 2006.

340 Document A/60/63/Add.1 presented to the 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. See: <http://daccessdds.un.org/doc/UNDOC/GEN/N05/425/11/PDF/N0542511.pdf?OpenElement>.

341 Rex MA (1981) Community structure in the deep-sea benthos. *Annual Review in Ecology and Systematics* 12:331–353

342 Glover AG, Smith CR, Paterson GLJ, Wilson GDF, Hawkins L, Shearer M (2002) Polychaete species diversity in the central Pacific abyss: local and regional patterns, and relationships with productivity. *Marine Ecology Progress Series* 240:157–170

343 Rex MA, Stuart CT, Coyne G (2000) Latitudinal gradient of species richness in the deep-sea benthos of the North Atlantic. *PNAS* 97:4082–4085

344 Rex MA, Stuart CT, Coyne G (2000) Latitudinal gradient of species richness in the deep-sea benthos of the North Atlantic. *PNAS* 97:4082–4085

345 Brandt, A.; Gooday, A.J.; Brandao, S.N.; Brix, S.; Brokeland, W.; Cedhagen, T.; Choudhury, M.; Cornelius, N.; Danis, B.; De Mesel, I.; Diaz, R.J.; Gillian, D.C.; Ebbe, B.; Howe, J.A.; Janussen, D.; Kaiser, S.; Linse, K.; Malyutina, M.; Pawlowski, J.; Raupach, M.; Vanreusel, A. (2007) First insights into the biodiversity and biogeography of the Southern Ocean deep sea. *Nature* 447: 307–311

2. Canyons

Canyons dissect continental margins in many places. They are biologically productive because they receive organic matter from the continental shelf and are characterized by currents driven by internal waves and upwelling. Canyons can be rich in species and differ from the surrounding continental slope. The biological communities are variable in composition. An abundance of predators, such as cetaceans, are attracted to these locations^{346 347 348}.

346 Document A/60/63/Add.1 presented to the 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. See: <http://daccessdds.un.org/doc/UNDOC/GEN/N05/425/11/PDF/N0542511.pdf?OpenElement>.

347 Yen PPW, Sydeman WJ, Hyrenbach KD (2004) Marine bird and cetacean associations with bathymetric habitats and shallow-water topographies: implications for trophic transfer and conservation. *Journal of Marine Systems* 50:79–99

348 Hyrenbach KD, Forney KA, Dayton PK (2000) Marine protected areas and ocean basin management. *Aquatic Conservation: Marine and Freshwater Ecosystems* 10:437–458

VI. PRIORITY AREAS FOR CONSERVATION

A. INTRODUCTION

The previous section discussed the state of knowledge related to specific ecosystems beyond the limits of national jurisdiction. This section will review a number of efforts to identify priority areas for conservation in marine areas beyond the limits of national jurisdiction. Each of the five studies reviewed here was undertaken for a slightly different purpose, which is reflected in its individual approach; four are global and one is regional. The purpose of the review is not to endorse any one of these studies, but to present a variety of approaches with goals, rationales, methods and results that hold both differences and similarities. Collectively, these studies provide lessons that can be applied and that can serve as a starting point for practical efforts to protect priority areas beyond the limits of national jurisdiction.

The method for identifying priority areas for conservation in marine areas beyond the limits of national jurisdiction will depend on the objectives of that conservation action (for example, habitat representation and protection of threatened species). Once those objectives have been determined, criteria for site selection can be developed. At the present time, discussions relating to criteria for identifying priority areas for protection in areas beyond the limits of national jurisdiction are being undertaken in the context of the United Nations, including the Convention on Biological Diversity^{349 350 351}. Without pre-empting these important discussions, the studies reviewed here demonstrate how priority areas might be selected if areas of high species richness are of primary conservation interest (see studies 1 and 2); if the challenge is to protect a network of sites that represent the full spectrum of life (see studies 3 and 4); or if the protection of threatened species is of primary importance (see study 5). It should be noted that most countries and international organizations (such as the International Maritime Organization criteria for Particularly Sensitive Sea Areas) apply multiple selection criteria that are not mutually exclusive, and which go beyond those listed here³⁵².

Regardless of the type of criteria chosen, an important challenge in marine areas beyond the limits of national jurisdiction is that conservation measures will need to address both fixed (for example seamounts, cold-water corals and hydrothermal vents) and mobile (currents, areas of upwelling, convergence zones) features, as well as migratory species³⁵³. Such measures will also need to address the three-dimensional nature of the oceans, and may, in some cases, need to consider the benthic and pelagic environments separately. If area-based measures are to be employed, they may need to be mobile, applied on a large enough scale to encompass important oceanographic features³⁵⁴, and address the breeding, feeding and nursery grounds of migratory species³⁵⁵. The maintenance of ecological connectivity between protected

349 CBD (2006) Summary of existing ecological criteria for identification of potential marine areas for protection and biogeographical classification systems (UNEP/CBD/COP/8/1/INF/16). See: <http://www.biodiv.org/doc/meetings/cop/cop-08/information/cop-08-inf-16-en.doc>.

350 CBD (2006) Report of the Scientific Experts' Workshop on Criteria for Identifying Ecologically or Biologically Significant Areas beyond National Jurisdiction 6-8 December 2005, Ottawa, Canada (UNEP/CBD/COP/8/INF/39). See: <http://www.cbd.int/doc/meetings/cop/cop-08/information/cop-08-inf-39-en.pdf>

351 Expert Workshop on ecological criteria and biogeographic classification systems for marine areas in need of protection, 2-4 October 2007—S.Miguel Island, Azores, Portugal. See: <http://www.cbd.int/doc/meeting.aspx?mtg=EWSEBM-01&tab=1>

352 CBD (2006) Summary of existing ecological criteria for identification of potential marine areas for protection and biogeographical classification systems (UNEP/CBD/COP/8/1/INF/16). See: <http://www.biodiv.org/doc/meetings/cop/cop-08/information/cop-08-inf-16-en.doc>.

353 Hyrenbach KD, Forney KA, Dayton PK (2000) Marine protected areas and ocean basin management. *Aquatic Conservation: Marine and Freshwater Ecosystems* 10:437-458

354 Roberts, C.M., L. Mason and J.P. Hawkins (2006) Roadmap to recovery: A global network of marine reserves. A Greenpeace publication. See: <http://oceans.greenpeace.org/raw/content/en/documents-reports/roadmap-to-recovery.pdf>

355 Norse, E.A., L.B. Crowder, K. Gjerde, D. Hyrenbach, C.M. Roberts, C. Safina and M.E. Soule. (2005) Place-based ecosystem management in the open ocean. Pages 302-327 in E. Norse & L. Crowder, eds. *Marine Conservation Biology: The Science of Maintaining the Sea's Biodiversity*. Island Press, Washington DC, USA.

sites requires that species movement and dispersal be taken into account through the area covered by the protected sites, replication of representative elements in sites, and the size and spacing of individual sites³⁵⁶.

The amount of available data may also influence the approach chosen. As is evident from the review above, more is known about some species and habitats than others, and many knowledge gaps still exist. While it is possible, and indeed important, to protect some well-known habitats and species because of their high diversity, rarity, endemism, threatened status, etc., our incomplete knowledge about marine areas beyond the limits of national jurisdiction would seem to require the application of a precautionary approach. This can be done through the protection of a wide, representative range of biodiversity and ecosystem processes, which will ensure that important but poorly understood ecological processes, or poorly studied areas, are protected³⁵⁷.

Using the representative areas approach will eventually require the development of a detailed biogeographic classification of marine areas beyond national jurisdiction, although it is not essential in the early stages, where each new area adds a different element of representativeness. An agreed-upon biogeographic classification for marine areas beyond national jurisdiction does not exist as of yet, though it is being contemplated at the Convention on Biological Diversity and at other fora. Work towards developing a biogeography of various marine ecosystems beyond national jurisdiction has been undertaken for hydrothermal vents³⁵⁸ and the pelagic realm^{359 360 361}. A rough classification also exists for seeps³⁶². A global biogeography of seamounts has not yet been developed, though classification of the physical environment of seamounts has been undertaken for the region surrounding New Zealand³⁶³. The recent Scientific Experts' Workshop on Biogeographic Classification Systems in Open Ocean and Deep Seabed Areas beyond National Jurisdiction, which was held at the National University of Mexico (UNAM) in Mexico City, Mexico, from 22 to 24 January 2007, has already made considerable progress on this topic³⁶⁴. Similar efforts are underway in some regions, for example in regards to the Southern Ocean³⁶⁵.

The data and information available globally on the distribution of ecosystems, habitats and species of the deep sea and open ocean, though limited, is improving and has already been put to use, including in some of the studies to identify priority conservation areas presented below. Large-scale initiatives, such as the Census of Marine Life will result in an improved informational basis for conservation action. The Census of Marine Life is a growing global 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. A number of field programmes relevant to areas beyond national

356 Roberts, C.M., L. Mason and J.P. Hawkins (2006) Roadmap to recovery: A global network of marine reserves. A Greenpeace publication. See: <http://oceans.greenpeace.org/raw/content/en/documents-reports/roadmap-to-recovery.pdf>

357 CBD (2006) Report of the Scientific Experts' Workshop on Criteria for Identifying Ecologically or Biologically Significant Areas beyond National Jurisdiction 6-8 December 2005, Ottawa, Canada (UNEP/CBD/COP/8/INF/39). See: <http://www.cbd.int/doc/meetings/cop/cop-08/information/cop-08-inf-39-en.pdf>

358 Ramirez-Llodra, E., Shank, T. M. and German, C. R. (2007) Biodiversity and biogeography of hydrothermal vent species. *Oceanography*, 20(1): 30–41.

359 Longhurst A (1998) *Ecological Geography of the Sea*. Academic Press, San Diego

360 Sherman K, Alexander LM (1989) *Biomass Yields and Geography of Large Marine Ecosystems*. Westview Press, Boulder

361 Hyrenbach KD, Forney KA, Dayton PK (2000) Marine protected areas and ocean basin management. *Aquatic Conservation: Marine and Freshwater Ecosystems* 10:437–458

362 CenSeam, personal communication

363 Rowden, A.A., Clark, M.R. and I.C. Wright (2005) Physical characterisation and a biologically focused classification of "seamounts" in the New Zealand region. *New Zealand Journal of Marine and Freshwater Research*, Vol. 39: 1039–1059

364 UNICPOLOS (2007) An update on work related to biogeographic criteria for the classification of open and deep ocean areas. United Nations Informal Consultative Process on Oceans and the Law of the Sea. Side event background paper. 8th Meeting. New York, June 2007.

365 Grant et al (2007) Bioregionalisation of the Southern Ocean. Report of Experts Workshop (Hobart, September 2006). WWF-Australia and ACE CRC.

jurisdiction exist within the Census, for example CenSeam (Global Census of Marine Life on Seamounts), ChEss (biogeography of deep-water chemosynthetic ecosystems) and CeDaMar (Census of Diversity of Abyssal Marine Life)³⁶⁶.

At the present time, the following databases contain information about the global distribution of ecosystems and species in marine areas beyond the limits of national jurisdiction. It should be noted that the list is not exhaustive.

- The Ocean Biogeographic Information System (OBIS), which was developed as part of the Census of Marine Life. The database focuses on marine biodiversity (see <http://www.iobis.org/>)
- The *Sea Around Us Project* database, which provides fisheries and biodiversity information by area (see <http://www.seaaroundus.org/>)
- SeamountsOnline, which is an information system for seamount biology (see <http://seamounts.sdsc.edu/>)
- The InterRidge databases, which provide information about the known (i.e., ground-truthed) and suspected (i.e., plumes observed, vents not yet ground-truthed) vents, and about taxonomical, biological, ecological and distributional data of all species described from deep-water chemosynthetic ecosystems (see <http://www.interridge.org/>)
- OBIS-SEAMAP (Ocean Biogeographic Information System—Spatial Ecological Analysis of Megavertebrate Populations), which provides spatially referenced data about the distribution of marine mammals, seabirds and sea turtles (see <http://seamap.env.duke.edu/>)
- The Global Cold-water Coral Reef Data Base and GIS. This internet-based interactive tool was created by the UNEP Coral Reef Unit in collaboration with UNEP-WCMC. Launched publicly in October 2006, this comprehensive cold-water coral GIS incorporates datasets by experts such as Andre Freiwald and others. The GIS allows the user to combine the location of cold-water corals (as a group or as individual species) with other information/data, e.g., location of seamounts, MPAs, maritime boundaries (i.e., to see which locations are in areas beyond national jurisdiction) etc. It also includes a predicted distribution of scleractinian corals (see <http://bure.unep-wcmc.org/marine/coldcoral/viewer.htm>).
- ChessBase, a database providing taxonomical, biological, ecological and distributional data of all species described from deep-water chemosynthetic ecosystems, as well as bibliography and information on the habitats (see <http://www.noc.soton.ac.uk/chess/database/database.html>).
- FishBase, which is a global information database on fishes (see <http://www.fishbase.org/home.htm>)
- CephBase, which is a database-driven web site on all living cephalopods (octopus, squid, cuttlefish and nautilus) (see <http://www.cephbase.utmb.edu/>)
- Sealifebase, which is a global information database and portal on all marine organisms (see <http://www.sealifebase.org>)
- Global Biodiversity Information Facility (GBIF), which provides access to millions of data records shared via the GBIF network (see <http://data.gbif.org>).

The text below reviews previous and ongoing efforts to identify priority areas for conservation in marine areas beyond the limits of national jurisdiction, including through the identification of: (i) patterns of species diversity and distribution; (ii) representative areas; and (iii) areas with high concentrations of endangered, threatened, rare and endemic species. For each of the studies presented, the goal, rationale, data and methods used, and results are reviewed.

³⁶⁶ <http://www.coml.org/>

B. PATTERNS OF SPECIES DIVERSITY AND DISTRIBUTION

The first two studies presented here examine patterns of species diversity and distribution in the high seas. The first study focuses on the diversity of large fish predators, while the second one includes in its analysis a broad range of species from invertebrates to marine mammals. The two analyses concentrate on “hotspots” of species richness and diversity, an approach which is widely used and is argued to maximize the number of protected species. The approach has been criticized for failing to take into account species outside hotspots, which may include endemic and threatened species³⁶⁷. Nor are productivity and biodiversity always closely coupled, and areas of high productivity may need to be considered separately³⁶⁸. Though possibly not sufficient on its own, this approach has value when considered together with other approaches for selecting priority areas for conservation.

STUDY 1: Global predator diversity hotspots

The goal and rationale

This study by Worm et al. (2005)³⁶⁹ derived worldwide patterns of tuna and billfish diversity over the past 50 years, revealing distinct hotspots. The study focused on large predators because many of them, such as tunas, sharks, billfishes, and sea turtles are of current conservation concern due to their vulnerability to overfishing, or in the case of sea turtles, to incidental capture, loss of nesting beach habitat, poaching, illegal wildlife trade, etc. In addition, all of these predators are important for their role in the ecosystem.

The study looked at pelagic diversity hotspots in terms of species richness (number of species) and species density (number of species per unit area). The hotspots were deemed to represent an important conservation option because many species benefit concurrently, and the resulting maintenance of high biodiversity may also be critical for the sustainability of fishing³⁷⁰. The study argued that knowledge of global diversity patterns, when merged with fine-scale information on habitat use, spawning areas, migration patterns, and fishing mortality could be used to define priority areas for ocean conservation.

Data and methods

The study used Japanese longlining data from 1990 to 1999 to analyse contemporary patterns of tuna and billfish diversity. These results were checked using independent scientific observer data from longline fisheries in the Atlantic and Pacific Oceans.

In addition, the effects of remotely sensed sea surface temperatures (SST) (mean and spatial gradients), dissolved oxygen levels, eddy kinetic energy (calculated from sea surface height anomalies), chlorophyll a (mean and spatial gradients), and depth (mean and spatial gradients) on diversity, were examined using spatial regression models.

367 G, Ceballos and P. R. Ehrlich (2006) Global mammal distributions, biodiversity hotspots, and conservation. *PNAS* 103: 19374-19379

368 Roberts, C.M., L. Mason and J.P. Hawkins (2006) Roadmap to recovery: A global network of marine reserves. A Greenpeace publication. See: <http://oceans.greenpeace.org/raw/content/en/documents-reports/roadmap-to-recovery.pdf>

369 Worm, B., M. Sandow, A. Oschlies, H.K. Lotze, and R.A. Myers. 2005. Global patterns of predator diversity in the open oceans. *Science*. 309: 1365-1369.

370 Worm, B., H.K. Lotze, and R.A. Myers. 2003. Predator diversity hotspots in the blue ocean. *Proceedings of the National Academy of Science USA*. 100: 9884-9888

Results

The study concluded that predator diversity shows a predictable yet eroding pattern signaling ecosystem-wide changes linked to climate and fishing. The worldwide patterns of tuna and billfish diversity over the past 50 years revealed distinct subtropical “hotspots” that appeared to hold generally for other predators and zooplankton. Diversity was positively correlated with thermal fronts and dissolved oxygen and a nonlinear function of temperature (~25°C optimum). A similar correlation between sea surface temperature and diversity of planktonic foraminifera has also been previously documented³⁷¹.

Examples of biodiversity hotspots were clustered mostly in the subtropics, namely off the U.S. and Australian east coasts, south of the Hawaiian Islands chain, east of Sri Lanka, and most prominently in the southeastern Pacific. Not surprisingly, some of these hotspots coincided with regions of high productivity due to oceanographic features such as convergence zones and eddies.

It should be noted that the findings of this study were used to help design a global network of marine reserves by Roberts et al. (2006)³⁶⁸ (see study 4).

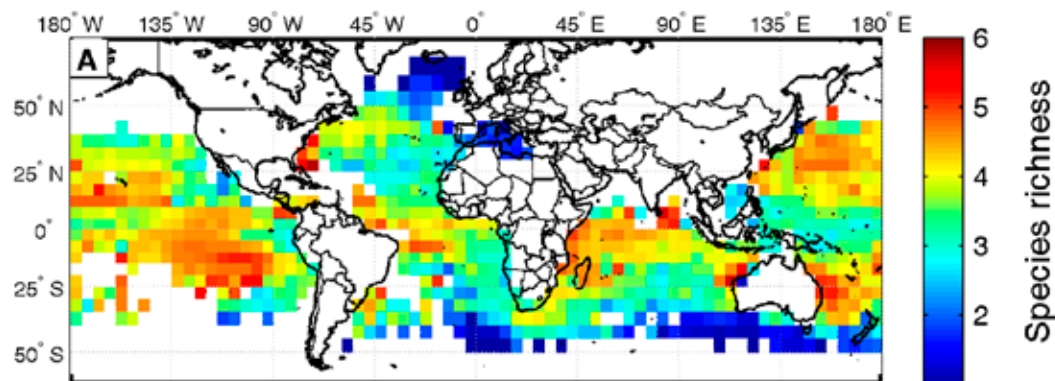


FIGURE 5: Map showing the species richness of tunas and billfish (number of species per 50 fish caught). From Worm et al.³⁶⁹ as reproduced in Roberts et al.³⁶⁸

STUDY 2: Patterns of species richness in the high seas

The goal and rationale

A study undertaken by Cheung et al. (2005) and commissioned by the CBD Secretariat, with funding from the European Union, created maps of species richness in the high seas. This study was presented at the first meeting of the Ad Hoc Open-ended Working Group on Protected Areas, which took place in Montecatini, Italy, from 13 to 17 June 2005, and was later published as CBD Technical Series No. 20³⁷², while a policy summary can be found in document UNEP/CBD/WG-PA/1/INF/1 (Scientific Information on Biodiversity in Marine Areas beyond the Limits of National Jurisdiction)³⁷³.

371 S. Rutherford, S. D'Hondt and W. Prell, Environmental controls on the geographic distribution of zooplankton diversity, *Nature* 400 (1999), pp. 749–752.

372 This report is available on the CBD website at <http://www.biodiv.org/doc/publications/cbd-ts-20.pdf>.

373 This document is available on the CBD website at <http://www.biodiv.org/doc/meetings/pa/pawg-01/information/pawg-01-inf-01-en.doc>.

Data and methods

Whereas the study by Worm et al. (2005) (see study 1) concentrated on predator diversity, the species data used in this analysis included marine invertebrates (305 species of crustaceans, 115 species of mollusks, 119 species of cephalopods and 438 species of other invertebrates), fish (463 high seas species), marine reptiles (7 species of sea turtle, 79 species of sea snakes, 1 saltwater crocodile and 1 marine iguana), seabirds (351 species), and marine mammals (100 species).

The study compiled geographic information systems (GIS) maps of distributions of individual species occurring in the high seas obtained from published maps or from depth and latitudinal range data and other information. These data were used to infer ranges of species. Maps of known locations of cold-water corals and seamounts were also presented. The maps were considered individually and in combination to discern patterns of species richness in the high seas. The combined maps showed areas of high species richness (so called “hotspots”) that might be targeted for conservation action. Additionally, threats to biodiversity in marine areas beyond national jurisdiction were explored through maps of distribution of red-listed non-fish vertebrates.

It should be noted that the maps were based on a 200 nm exclusive economic zone, and do not take into account extended continental shelf areas under national jurisdiction and control.

Results

Based on the species richness patterns, a preliminary set of priority sites for conservation beyond national jurisdiction were identified as follows:

- (a) Marine areas beyond national jurisdiction of the Indo-Pacific region, specifically centred on South-East Asia, northern Australia and the Tasman Sea;
- (b) Seamounts beyond national jurisdiction in the north and south Atlantic, and the Southern Ocean convergence zone; and
- (c) Marine areas beyond national jurisdiction adjacent to islands in the southern ocean.

Figures 6 and 7 show the results of the GIS analysis for all analysed species (figure 5) and for marine fish and higher vertebrates (figure 6).

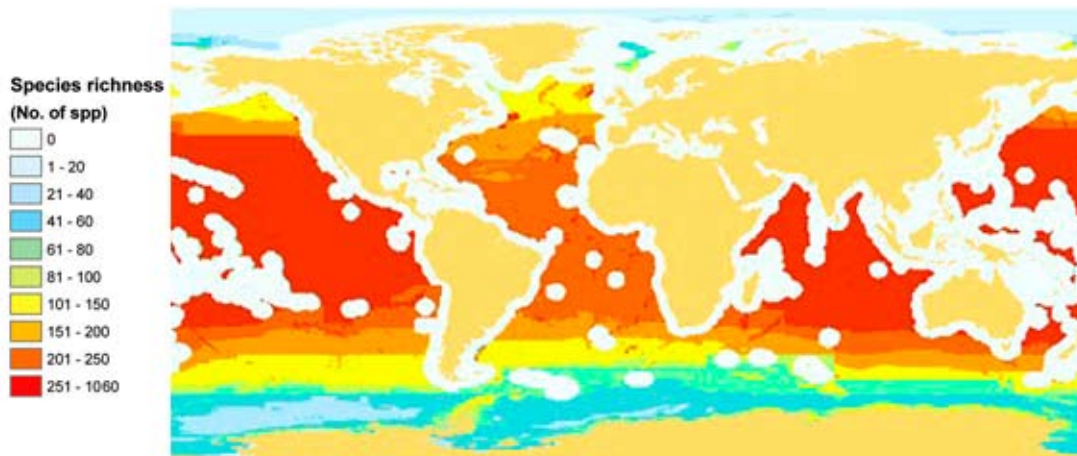


FIGURE 6: Map of marine species richness in areas beyond the limits of national jurisdiction (based on the ranges of exploited invertebrates and fish, and of reptiles, birds, and marine mammal species).

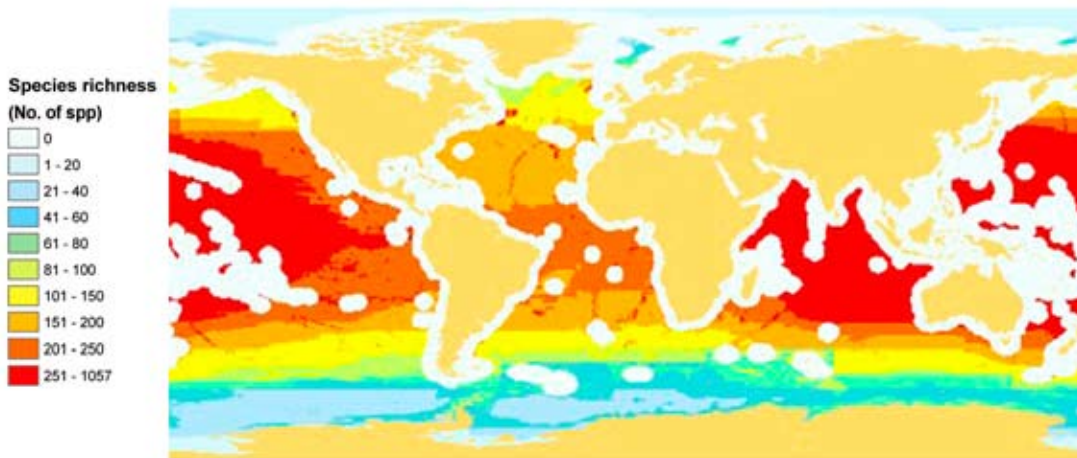


FIGURE 7: Map of marine fish and higher vertebrates' species richness in the high seas. Note the relatively high species richness of seamounts in the Atlantic.

C. REPRESENTATIVE AREAS

The next two studies focus on identifying for protection examples of the entire range of ecosystems, habitats and species found in marine areas beyond the limits of national jurisdiction. This approach aims to maintain the health and resilience of these ocean areas in their entirety in the long term, and aims to do so via networks of marine protected areas (MPAs). The first study (study 3) focuses on finding representative pelagic areas for protection, and proposes ways to employ MPAs in the highly dynamic context of pelagic systems. The second study (study 4) uses a broad range of oceanographic, physical and species data to generate a representative global network of MPAs in marine areas beyond the limits of national jurisdiction. Because of their data poor nature, selecting a representative range of habitats and species for protection may be a viable approach for marine areas beyond jurisdiction, keeping in mind that MPAs would need to be applied in the context of the ecosystem approach, and that other tools and approaches for protection may also need to be employed.

STUDY 3: Designing representative pelagic marine protected areas

The goal and rationale

A study undertaken by Hyrenbach et al. (2000)³⁷⁴ aims to facilitate the design of representative pelagic marine protected areas. The study argues that differences in scale and predictability differentiate highly dynamic pelagic systems from terrestrial and nearshore ecosystems. Yet, as in static systems, many pelagic species use predictable habitats to breed and forage. MPAs could be designed to protect these foraging and breeding aggregations. Understanding the physical mechanisms that influence the formation and persistence of these aggregations is essential in order to define and implement pelagic protected areas. Many important pelagic habitats are neither fixed nor predictable. Thus, pelagic protected areas will require dynamic boundaries and extensive buffers. In addition, the protection of far-ranging pelagic vertebrates will require dynamic MPAs defined by the extent and location of large-scale oceanographic features.

The study classified pelagic habitats according to their dynamics and predictability into three categories: static, persistent and ephemeral features:

- (1) Static bathymetric features, which include reefs, shelf breaks, submarine canyons, seamounts and the lee (downstream) of islands, where primary production is often enhanced and many pelagic predators aggregate for foraging.
- (2) Persistent hydrographic features, which include currents and frontal systems. These features are recognized as regions of elevated biological activity, where seabirds, marine mammals and tunas aggregate to exploit prey concentrations. Frontal zones, with their high productivity, represent vital foraging habitat and migratory routes for many species including salmonids, albacore tuna, albatrosses, shearwaters, sharks and turtles.
- (3) The ephemeral hydrographic features, which are defined by short-lived gradients in water properties. Highly mobile pelagic species find and exploit these ephemeral fronts while they persist (e.g., west coast of North America, where large volumes of upwelled water are transported offshore by high-speed jets of cool and productive water).

Data and methods

In contrast to the quantitative analyses presented in Worm et al. (2005) (study 1) and Cheung et al. (2005) (study 2), this study reviewed existing literature on different bathymetric and oceanographic features that affect the pelagic system. It categorized these features into three types (see above), and discussed the characteristics of each feature, including their importance to the ecology and biogeography of the associated species. Specific examples, such as the North Pacific Transition Domain, were used to explain the need for different types of designs of pelagic MPAs and to suggest that ocean temperature should be a useful proxy to delineate boundaries of dynamic hydrographic features for protection. The study also proposed that static bathymetric features (e.g. seamounts) and temporally consistent hydrographic features (e.g. water mass boundaries) could be used to delineate “core” areas defined by the average extent of potential habitats, while “buffers” could be defined by the variability about those mean conditions.

374 Hyrenbach KD, Forney KA, Dayton PK (2000) Marine protected areas and ocean basin management. *Aquatic Conservation: Marine and Freshwater Ecosystems* 10:437-458

Results

Instead of listing all the potential areas of pelagic systems for protection, this study proposed a scheme to identify and delineate pelagic MPAs, many of which can occur in marine areas beyond national jurisdiction. The study argued that a network of isolated MPAs may not be the best approach to protect oceanic systems because of the highly dynamic and uncertain nature of migration routes, large variability between species, and the difficulty in mitigating impacts outside of protected areas. Thus, the study suggests the need to scale up pelagic MPA designs for the effective protection of isolated habitat features and large-scale features of the ocean globally. Based on the reviewed literature, the study uses the North Pacific Transition Domain as an example of protecting large-scale features. This area has strong temperature and salinity gradients, is home to many migratory species, and is identified as an ecologically important persistent hydrographic feature. The study suggested setting up a single ring-shaped protected area encompassing the mid-section of the currents forming the North Pacific gyre, offering protection to species throughout their migratory ranges³⁷⁵.

STUDY 4: A global network of marine reserves

The goal and rationale

A report undertaken by Roberts et al. (2006) and commissioned by Greenpeace presented a design for a global network of high seas marine reserves. This network design was based on the following principles: that a network (1) should be representative of the full range of biodiversity, (2) should replicate habitats in different marine reserves, (3) should be designed so that populations in different marine reserves can interact and be mutually supporting, (4) should be sufficiently large to ensure long-term persistence of species, habitats, ecological processes and services, and (5) should be based on the best available scientific, local and traditional information.

The authors of the report emphasized that a central objective for a network is to ensure ecological connectivity among protected area units. In areas beyond national jurisdiction, there are various scales of ecological linkages based on the movements of juveniles and adult organisms, dispersal of their offspring, and transport of materials. These scales extend from metres to thousands of kilometres. Seamount invertebrates, for example, may disperse only metres, while migratory tunas can undertake journeys of 20,000 kilometres in a year. To ensure ecological connectivity in the network, marine reserves with similar habitats should generally be spaced from a few hundreds to a few thousand kilometres apart.

The report was based on the goal of establishing a network of marine reserves to protect 40% of all habitats in marine areas beyond the limits of national jurisdiction. The 40% figure was based on a review study that concluded that between 20 and 50% of the sea should be protected to achieve the conservation of viable populations, support fisheries management, secure ecosystem processes and assure sufficient connectivity between marine reserves in networks³⁷⁶. Because of the large scales of oceanic processes and species' movements on the high seas, the authors argued that a high level of protection is warranted.

Data and methods

The data layers included in the GIS analysis were oceanographic features (upwellings and downwellings, sea surface temperature gradients), physical features (bathymetry, bathymetric complexity, seamounts,

³⁷⁵ Ibid.

³⁷⁶ Gell F.R. and C.M. Roberts (2003). Benefits beyond boundaries: the fishery effects of marine reserves. *Trends in Ecology and Evolution* 18: 448-455

bottom sediments, ocean trenches), biological features (at sea movements of albatrosses, turtles, pinnipeds and penguins; biodiversity distribution of cetaceans; billfish and tuna species richness; billfish and tuna species density; and marine biomes). Twelve marine biogeographic zones were used. Expert consultation was also taken into account in the analysis.

Results

The set of priority sites was generated using Marxan, the most commonly applied computer programme for developing networks of marine protected areas, originally developed and applied for the rezoning process of the Great Barrier Reef Marine Park. The resulting map can be seen in Figure 8 below³⁷⁷. The design included 29 separate marine reserves that together encompass 40.8% of the area of the world's oceans. The report also listed 41 smaller scale areas identified by a wide variety of experts as conservation priorities. These areas may warrant further study.



FIGURE 8: A proposal for a global network of marine reserves, which incorporates the following priority areas: (1) Greenland Sea (2) North Atlantic (3) Azores/Mid-Atlantic Ridge (4) Eastern Mediterranean (5) Central Mediterranean (6) Sargasso Sea/Western Atlantic (7) South-Central Atlantic (8) Antarctic-Patagonia (9) Vema Seamount-Benguela (10) South Africa—Agulhas Current (11) Southern Ocean (12) Southern Ocean—Australia/New Zealand (13) Central Indian Ocean—Arabian Sea (14) Bay of Bengal (15) Northwestern Australia (16) South Australia (17) Lord Howe Rise and Norfolk Ridge (18) Coral Sea (19) Northern New Guinea (20) Western Pacific (21) Kuroshio-Oyashio Confluence (22) Sea of Okhotsk (23) Gulf of Alaska (24) Northeastern Pacific (25) Southeastern Pacific (R) Representative Areas.

D. AREAS WITH HIGH CONCENTRATIONS OF ENDANGERED, THREATENED, RARE AND ENDEMIC SPECIES

Conserving areas with high concentrations of endangered, threatened, rare and endemic species will ideally prevent such species from declining, and where decline has occurred, will assist in restoring their populations. The study by OSPAR presented below is still a work in progress, but it highlights a systematic effort of collaboration by member countries to identify and map threatened and declining species for conservation and management. This effort may well have applications for marine areas beyond national

377 Roberts, C.M., L. Mason and J.P. Hawkins (2006) Roadmap to recovery: A global network of marine reserves. A Greenpeace publication. See: <http://oceans.greenpeace.org/raw/content/en/documents-reports/roadmap-to-recovery.pdf>

jurisdiction on a broader scale. It should be noted that the OSPAR maritime area contains areas that are both within and beyond national jurisdiction.

STUDY 5: OSPAR mapping of threatened and declining species

The goal and rationale

Work to comprehensively map threatened and declining species in the North-East Atlantic has been undertaken by the OSPAR Commission for the Protection of the Marine Environment of the North-East Atlantic. In 2003, the OSPAR Commission adopted an initial list of threatened and/or declining species and habitats, with further species and habitats added in 2004. At its Biodiversity Committee (BDC) meeting in 2003, OSPAR agreed to proceed with a programme to collate existing data on the distribution of the 14 habitats on this list, as part of a wider programme to develop measures for their protection and conservation. Each OSPAR Contracting Party agreed to compile the relevant data for its own marine waters and submit these to the lead country (UK) for collation into composite maps on the distribution of each habitat type across the whole OSPAR area. The work has been coordinated by the Joint Nature Conservation Committee (JNCC). A web-mapping application has been developed to disseminate the data collated through the OSPAR mapping programme³⁷⁸.

Data used

The data available to date provide an initial indication of the distribution of each OSPAR priority habitat type; further data will be added as it becomes available. The maps are not yet considered to be comprehensive for the OSPAR area as a whole and may not be comprehensive within any given Contracting Party's waters. Figure 9 shows a map of seamount habitat data in the OSPAR area, while Figure 10 shows *Lophelia pertusa* cold-water coral distributions. Other habitat types often found beyond national jurisdiction, and covered by the OSPAR maps, include, *inter alia*, carbonate mounds, deep-sea sponge aggregations, oceanic ridges with hydrothermal vents/fields and *Sabellaria spinulosa* reefs.³⁷⁹

Results

This work is still ongoing and will guide OSPAR in setting priorities for further work on the conservation and protection of marine biodiversity, including developing programmes and measures for the protection of priority habitats and species. This work is additional, but complementary, to measures underway to develop an ecologically coherent network of well managed marine protected areas. This work also highlights the importance of developing the best possible informational basis to support conservation measures.

378 The OSPAR Commission website: <http://www.ospar.org/> (checked 14 March 2007)

379 The OSPAR Commission website: <http://www.ospar.org/> (checked 14 March 2007)



FIGURE 9: The distribution of seamounts in the OSPAR area (red dots). National maritime boundaries can be seen in dark blue. It should be noted that as the maps are work in progress, they may not yet be comprehensive or inclusive of all seamounts in the area (map courtesy of UK Joint Nature Conservation Committee, OSPARmapping@jncc.gov.uk).

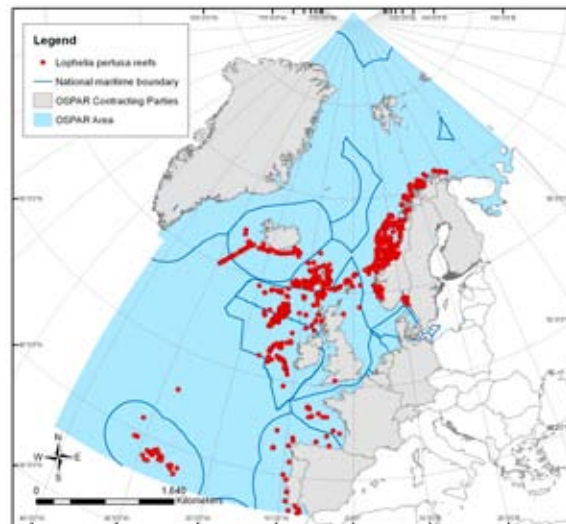


FIGURE 10: The distribution of *Lophelia pertusa* records in the OSPAR area (red dots). Country maritime boundaries are seen in dark blue (map courtesy of UK Joint Nature Conservation Committee, OSPARmapping@jncc.gov.uk).

VII. CONCLUSIONS

There is clear evidence of detrimental human impacts to cold-water coral reefs, sponge reefs, seamounts and pelagic habitats, supporting the need for undertaking conservation action on the basis of the precautionary approach, even if our scientific understanding of these ecosystems is still imperfect. Major existing and potential anthropogenic threats include destructive fishing practices, such as bottom trawling, as well as climate change, pollution, mining, research, bioprospecting, and carbon sequestration. Urgent research efforts are needed to identify the potential impacts of ocean acidification, which could be a potentially serious threat, particularly to cold-water corals.

Knowledge gaps exist in regards to our understanding of these ecosystems. These gaps include basic information about their extent and global distribution, as well as their functioning, ecology and biogeography. Improved maps of the coverage of cold-water coral reefs, sponge reefs, seamounts and hydrothermal vents, as well as pelagic species and processes, would greatly assist in the design of management regimes, including marine protected areas. In the absence of data, models for habitat suitability and for predicting species and habitat distributions may serve to improve the information basis^{380 381}. Additionally, better knowledge of the biogeography, reproductive strategies and vulnerabilities of these ecosystems, as well as the life history and ecology of their associated species would assist in making such management regimes more effective.

The literature reviewed here indicates that each of the ecosystems discussed—seamounts, cold-water coral and sponge reefs, hydrothermal vents, pelagic habitats, cold seeps, abyssal plains and canyons—has characteristics that would qualify them as priority areas for conservation. Of these, at least seamounts, cold-water coral and sponge reefs and pelagic habitats face current threats from human activities. Our knowledge of hydrothermal vent communities is good enough to know that they have high levels of endemism and rarity, and that the habitat area occupied by them is relatively small. Knowledge about the other ecosystems is still limited, though the studies reviewed here indicate that seamounts may be biological hotspots, that cold-water coral and sponge reefs support highly diverse communities, and that pelagic regions have distinct hotspots of species richness and productivity that include feeding grounds of predators such as tunas, sharks, seabirds and cetaceans. Each of these ecosystems will need to be considered in conservation and management schemes for marine areas beyond the limits of national jurisdiction. In addition, such management regimes would need to address the requirements of migratory species throughout their life history.

The studies to identify priority conservation areas discussed here have commonalities, but also differences in approaches and results. The differences may be due to the variety of approaches taken, the different objectives in selecting priority areas, and the fact that global patterns of species richness and diversity are not completely understood, nor are they necessarily similar for different taxa. The lists of priority areas generated by these studies will be worth examining as part of global efforts to conserve biodiversity beyond national jurisdiction. Equally valuable is an examination of the methods employed by these studies, which range from the identification of species richness patterns to novel ways of implementing marine protected areas in oceanic environments. In particular, conserving representative examples of the entire range of ecosystems, habitats and species found in marine areas beyond the limits of national jurisdiction may be a viable, precautionary approach due to the limits of our scientific knowledge. However, repre-

380 Fosså JH, Lindberg B, Christensen O, Lundälv T, Svellingen I, Mortensen PB, Alvsvåg J 2005. Mapping of Lophelia reefs in Norway: experiences and survey methods. In: Freiwald A, Roberts JM (eds) *Cold-water Corals and Ecosystems*. Springer, Berlin Heidelberg. p 359–391.

381 Clark M.R., Tittensor D., Rogers A.D., Brewin P., Schlacher T., Rowden A., Stocks K., Consalvey M. (2006). *Seamounts, deep-sea corals and fisheries: vulnerability of deep-sea corals to fishing on seamounts beyond areas of national jurisdiction*. UNEP-WCMC, Cambridge, UK.

sentative areas alone may not be enough, and other types of areas (e.g., those that are highly biodiverse, threatened, unique, or hold other important attributes) as well as areas important for migratory species may also require special protection measures.

A number of management options to deliver on conservation objectives exist for selected priority areas. Such options include the use of area-based management tools, such as marine protected³⁸², are applied in the context of the ecosystem approach, as well as limitations on specific activities and gear types. A discussion of these management options is beyond the scope of this study, but whichever approaches and tools are chosen, it would seem important that they are applied through a comprehensive and participatory conservation planning process.

382 Johnston PA, Santillo D (2004) Conservation of seamount ecosystems: application of a marine protected areas concept. *Archive of Fisheries and Marine Research* 51:305–319