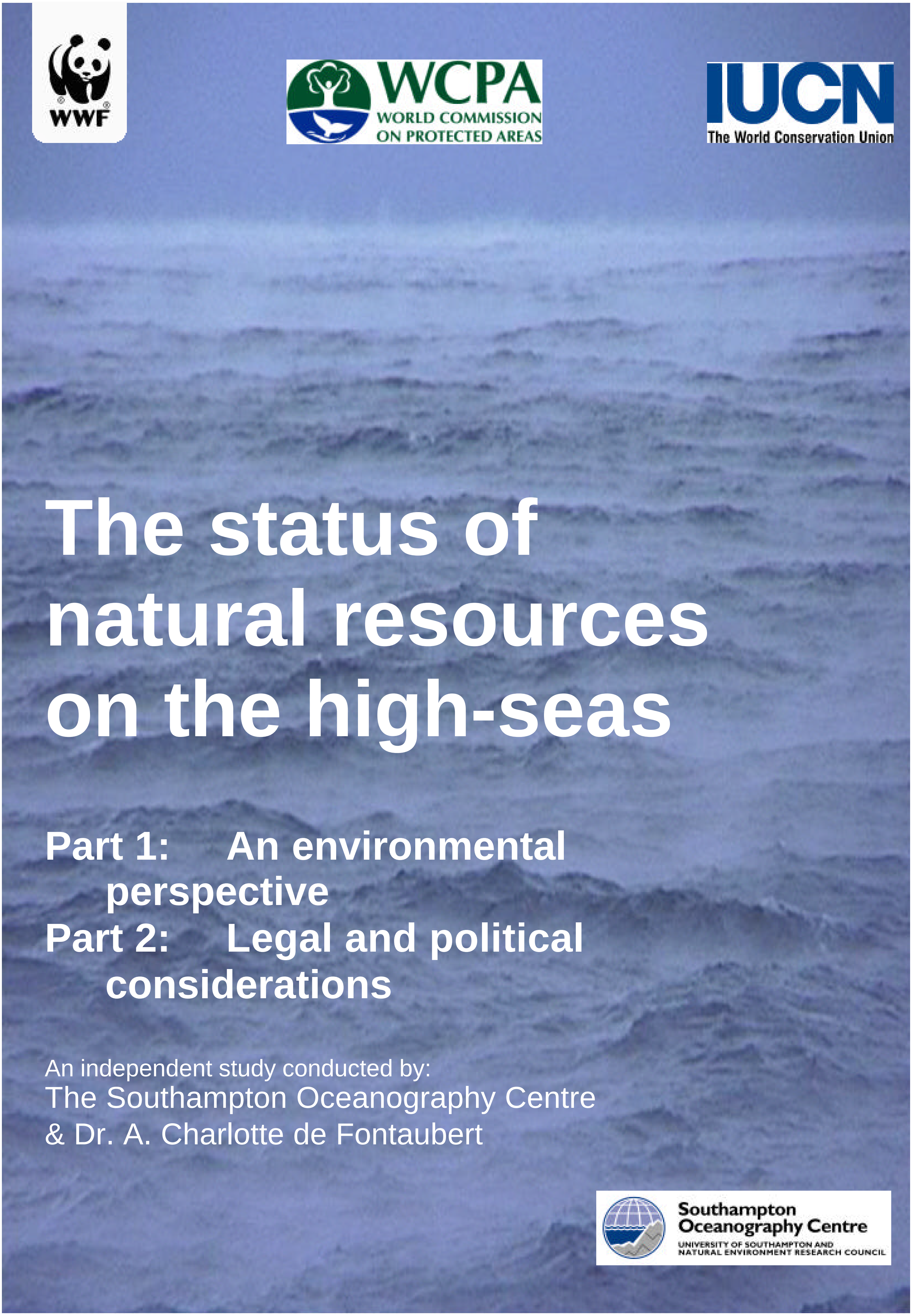

The status of natural resources on the high-seas

Part 1: An environmental perspective
Part 2: Legal and political considerations

An independent study conducted by:
The Southampton Oceanography Centre
& Dr. A. Charlotte de Fontaubert

The status of natural resources on the high-seas

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TABLE OF CONTENTS

iv

Preface

The value of creating Marine Protected Areas (MPAs) as a tool for conserving areas of high, valuable, sensitive or rare biodiversity that are potentially threatened is well established. WWF and IUCN have both adopted a strategy of facilitating the establishment of networks of representative MPAs. Experience from managing MPAs around the world indicates that political will, legal security and stakeholder support is necessary to establish, manage and enforce the protected area status. As a necessity, MPAs have been located close to the coasts of nations where there is sufficient political will and where they can be nested within the legislation of those states. In recent years, there has been an increasing awareness amongst States and NGOs that little protection is currently afforded to marine areas outside of 200 mile Exclusive Economic Zones.

WWF and IUCN have commissioned an independent study, by leading specialists in the field, of high-seas habitats, resources, threats and legal status. A definition of the resources, either biodiversity and/or exploitable reserves, that occur beyond national jurisdiction, and potential for any threats to these resources has two main benefits: the need for, and extent of, protection can be better estimated; the types of legislation and governance that would be required to afford real protection and/or management can be determined and focused. It is expected that there will not be a single solution suitable for all potential protected areas. In formulating transparent mechanisms for protection, the rights of legitimate users of the high-seas must be respected, so that the protected status has a chance of being respected.

This study is an independent, objective, scientific and legislative review of published evidence that will contribute to:

- a listing of the natural resources, primarily biodiversity related, that occur in areas outside of the jurisdiction of coastal states;
- identification of the types of threats or potential threats that are, or may, impact on those resources;
- an indication of the types of areas, if any, that would seem to be potential candidates because of location, natural resource, or biodiversity, but that would in practice be unlikely, perhaps for reasons of politics, biodiversity or legislation;
- an informed opinion as to the current legal status of various forms of protected areas on the high-seas;
- an interpretation of the potential for adapting current legal institutional arrangements to afford protection.

In short, this study objectively examines if there are any areas on the high-seas that are of conservation value but are being, or expected to be threatened. If that is the case, the study further examines if there are currently any legislative instruments that could be used in order to afford those areas the protection they deserve.

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vi

The status of natural resources on the high-seas

- Part 1 - an environmental perspective -

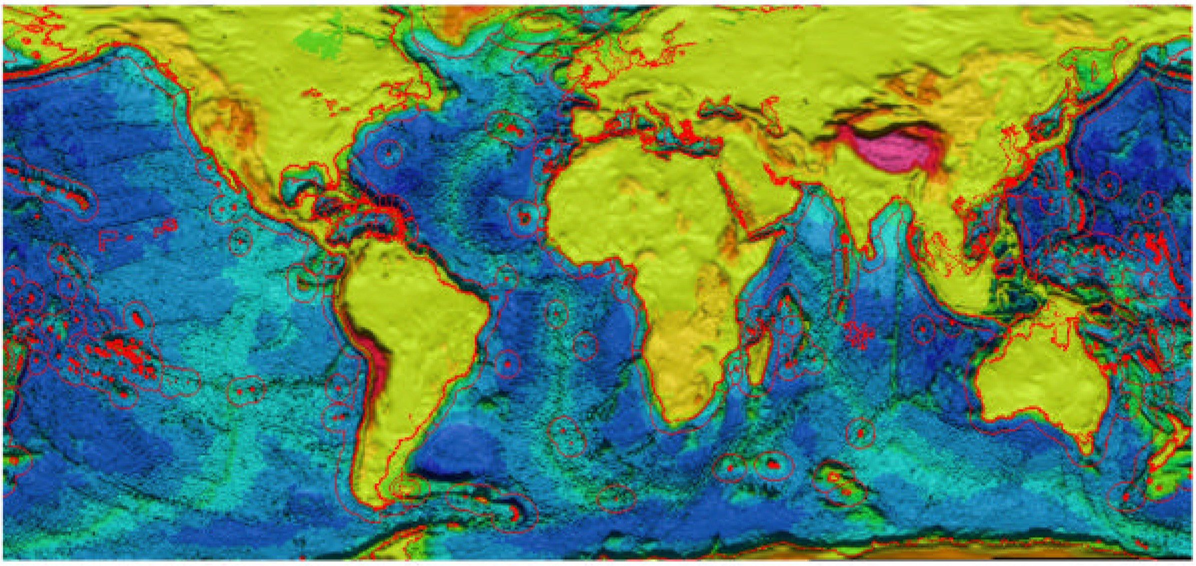

Figure 1: *High-seas are all those areas beyond Exclusive Economic Zone Limits (marked in red)*

A Report for WWF (World Wide Fund for Nature) and IUCN (International Union for the Conservation of Nature), April 2001

The status of natural resources on the high-seas

- Part 1 - an environmental perspective -

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Executive Summary

Approximately 50% of the Earth's surface is occupied by High-Seas areas – open ocean and deep-sea environments lying beyond the 200 nautical mile limit of the Exclusive Economic Zones of coastal states. These high-seas areas are open-access common resources, and as such may be particularly susceptible to over-exploitation. Until relatively recently there was little perceived threat to these areas. However, in recent years there has been a rapid expansion in two industries (demersal fishing and oil production) that can currently operate down to water depths of at least 2,000 m. These operations pose a potential threat to the deep-sea environment of high-seas areas. There are also a number of existing threats to open ocean areas, e.g. direct and indirect impacts on fish, seabirds and cetaceans. Further, there are a number of suggested or developing technologies that could pose a threat to high-seas areas, e.g. CO_2 dumping, biotechnology, the exploitation of gas hydrates and hydrothermal vent heat energy.

It is therefore timely to review the status of natural resources in high-seas environments in light of these existing or potential threats. Deep-sea and open ocean environments are continuous and highly interconnected, however, there are a number of relatively discrete or localised geographic features / habitats / biological communities that have particular scientific, societal or economic interest.

- Hydrothermal vents
- Deep-sea trenches
- Polymetallic nodules
- Gas hydrates
- Seabirds
- Transboundary fish stocks
- Seamounts
- Deep-sea 'coral reefs'
- Cold seeps and pockmarks
- Submarine canyons
- Cetaceans

This report identifies these areas of interest, reviews their significant characteristics, assesses existing or potential threats to them, and their potential value as High-Seas Marine Protected Areas (HSMPAs). For each area of interest, the report reviews habitat characteristics, global distribution, associated fauna, exploitation value, biodiversity issues and potential / actual threats. Based on these reviews, a number of recommendations are presented regarding the need for protection and potential HSMPA status.

Contents

SECTION A

INTRODUCTION

In the past, the inshore environment has been the prime focus for 'marine conservation' efforts. Only one or two 'campaigns' have addressed open ocean problems – the whaling industry, drift-net fisheries and fossil fuel extraction. The focus on the inshore environment is understandable given: a) the vast majority of harmful human impacts occur in shallow water, and b) the inshore environment is visible to, and understood by, the 'public'. In contrast, deep-sea and open ocean environments are out of sight, poorly known and there is little perceived threat to these areas. It is only in recent years that long-term [i] and large-scale research [ii] of the deep-sea environment has begun. Recent decades have, however, seen a continuous increase in the human exploitation of these offshore environments, principally via the fishing and the oil and gas industries. Both of these commercial industries are now capable of operating in water depths of at least 2,000 m [iii,iv]. These operations are generally limited to areas within national jurisdictions, i.e. within the 200 mile Exclusive Economic Zone (EEZ) of coastal states. They do, however, point to the likely eventual exploitation of areas beyond the EEZs – on the high-seas.

The term 'high-seas' applies to all parts of the oceans that are not included in the EEZs, territorial seas or internal waters of a state, and within the archipelagic waters of an archipelagic state. The high-seas include both the water column and the seabed that lies beyond the 200 mile limit. All member states of the United Nations Convention on the Law of the Sea have the right for their nationals to engage in fishing on the high-seas, and shall cooperate with one another in the conservation and management of the living resources of the high-seas. Oceanographers, and other marine scientists, would classify the high-seas as the open ocean and deep-sea environments.

Until recently, the enormous area of open ocean beyond the 200 mile limit was generally regarded as a wilderness. This region comprises ca. 50% of the Earth's surface. It is only in the last few decades that the importance of the open ocean has been recognised, not only in terms of its natural resources but also as playing a critical role in the regulation of global climate and the general 'health' of our planet. Today it is thought possible that there are more species in the deep sea than in all the other environments on Earth combined [v]. The previously unsuspected high diversity of the deep-sea floor was first revealed in the late 1960s [vi], and remains a major focus for current deep-sea research.

In addition to the discoveries of high species richness, more-recent 'mapping' studies are revealing a wealth of different habitats in the deep sea [vii]. It is only 25 years since the startling discovery of deep-sea hydrothermal vents and the exotic biological communities that surround them[viii]. Note, however, that the deep-sea environment remains rather poorly studied and understood – only some 0.0001 % of the deep-sea floor has been subject to biological investigations. The situation is little better in the rather more accessible upper water column of the open ocean. Major, fundamental discoveries continue to be made: unexpectedly high levels of primary production, the discovery of the pico- and nano-plankton and the Prochlorophytes, microscopic plants which are now thought to contribute almost as much to primary production in some regions as all previously known primary producers combined [ix].

It is, perhaps, the discovery of high diversity in the deep sea that has provided the greatest impetus for marine conservation measures on the high-seas – *"biodiversity"* continues to be a key environmental 'buzzword'. The term biodiversity was widely adopted in the 1980s as a contraction of 'biological diversity' – but as a meaningful term it has been rather overused and abused since then. Generally, biodiversity is used to mean some measure of taxonomic variety, usually at the species level, e.g. the number of species in a sample, habitat or region. It can, however, be applied to all levels of biological organisation, from a measure of the genetic variability of one population of a single species, to a count of the number of major ecosystem-types in a whole ocean. In addition to the problem of defining what 'biodiversity' now means, there are a host of problems associated with its measurement [x].

At its simplest, biodiversity might consider the number of major animal types – *the phyla*; there are 14 phyla that occur exclusively in the sea. Despite the high probability that the ocean environment has a greater biodiversity than any other environment, of all the Earth's currently known animal species (ca. 2 million), less than one quarter come from the ocean. A detailed study of animals on the deep-sea floor off the eastern United States [xi] led to predictions that the global deep-sea floor alone might harbour several million species[iii].

Why is (high) biodiversity thought to be a good thing? Society may place a higher 'value' on an area of higher than lower biological diversity. Areas of higher biodiversity may offer greater potential for the exploitation of natural products and genes, and therefore have greater economic value. The relative 'value' of high and low diversity areas become less clear when considered on ecological grounds. By virtue of their complexity, high diversity biological communities may be more stable and resistant to natural and anthropogenic change than lower diversity communities. In this way, it might be argued that low diversity communities are more 'deserving' of conservation and protection measures. Similarly, some of the most productive biological communities, for example those of estuarine muds or the open ocean plankton, are of relatively low biological diversity, yet are critical to the function of the marine ecosystem as a whole. It is, therefore, important that (high) biodiversity is not necessarily equated with ecological significance.

It is equally important to understand the processes that control biological diversity – both those that are evident today, and those that have operated over geological and evolutionary timescales. Note for example that: a) contrary to popular expectation, pollution and other forms of man-made disturbance can act to alter biological diversity in the marine environment [xii]; and b) that regions of apparently low diversity in the deep sea, e.g. the Norwegian Sea, may reflect events of geological antiquity (e.g. the last ice age) [xiii], and that these areas may yet re-establish their full potential diversity.

Our knowledge of open ocean and deep-sea environments, and the significant ecological processes that operate in these environments, is still developing. Any discussion of high-seas marine protected areas must acknowledge this limitation – there are no complete catalogues of the species or habitats present in these environments, certainly not globally, and not even on local regional scales. This report considers high-seas Marine Protected Areas on the basis of the current state of knowledge, consequently a precautionary approach is advisable.

Marine Protected Areas (MPAs), marine parks, reserves and sanctuaries have the general goal of conserving areas of high biological importance and productivity. The implementation and management of any particular MPA may encompass a number of objectives, for example:

- To help protect vulnerable habitats and threatened species
- To increase fisheries productivity
- To protect breeding populations
- To reduce the adverse impacts of human activities

To-date, the overwhelming majority of MPAs have been established within national jurisdictions. Establishing high-seas MPAs will undoubtedly pose a number of legal and institutional problems; consider for example the International Whaling Commission's problems in enforcing the Indian Ocean and Southern Ocean Whale Sanctuaries [xiv]. The United Nations Convention on the Law of the Sea regards the high-seas as "open-access commons", a resource type that is particularly vulnerable to over-exploitation [xv].

Although our knowledge of high-seas environments is limited and establishing high-seas MPAs will be complicated, there are clear actual and potential environmental threats to high-seas areas. It is, therefore, timely to consider the potential for High-seas MPAs (HSMPAs).

AIMS AND ORGANISATION OF THIS REPORT

Much of the deep-sea floor and the open ocean above, that comprise the high-seas, is continuous and highly interconnected. There are, however, a number of relatively localised areas, geographic features, 'habitats' and biological communities that, by virtue of their living and non-living resources, may be of particular scientific, societal or economic interest. This report aims to identify these areas, to review their significant characteristics, assess existing or potential threats to them and to consider their potential value as HSMPAs.

This report is divided into two parts: section A summarises the major findings of the review, while section B gives a more detailed appraisal of the areas, geographic features, 'habitats' and biological communities considered. The overviews of each topic are not intended to be exhaustive, but to address the most significant factors connected with potential value as HSMPAs.

OVERVIEW

This section of the report provides a summary of the more detailed reviews of the high-seas areas, geographic features, 'habitats' and biological communities of scientific, societal or commercial interest that might be considered as potential HSMPAs. The summary is presented as three tables:

Table 1.
An area-by-area listing of the key environmental characteristics and potential threats.

Table 2.
A comparative summary of environmental characteristics.

Table 3.
A comparative summary of scientific, societal and commercial interests and their threats.

TABLE 1:
SUMMARY REVIEW OF HIGH-SEAS AREAS, GEOGRAPHIC FEATURES, 'HABITATS' AND BIOLOGICAL COMMUNITIES OF SCIENTIFIC, SOCIETAL OR COMMERCIAL INTEREST

1. Hydrothermal vents

- Highly localised sites of high temperature fluid-escape from the seabed
- Typically located on mid-ocean ridges (10s known, 100s suspected)
- Typically support abundant biological populations, fuelled by chemosynthesis
- Highly specialised fauna, of relatively low diversity, but high endemism
- Vents and their communities are ephemeral (10s of years)
- Subject of intensive scientific study – an actual threat
- Considerable biotechnology potential ("extremophiles") – a potential threat
- Interest in commercial resource (ores and energy) exploitation – a potential threat

2. Seamounts

- Undersea mountains of volcanic / tectonic origin
- May interact with upper water column (e.g. enhancing surface ocean productivity)
- Found in all ocean, 30-40,000 known
- Tops and upper flanks of seamounts may be biological 'hot spots'
- Hard substrate suspension feeding communities (sponges, corals etc) may be common
- Potentially high species diversity and endemism
- May act as 'stepping stones' for transoceanic dispersal of species
- Fish and seabird populations may be enhanced over seamounts
- Considerable commercial fishing – an actual threat
- Interest in commercial resource (ores) exploitation – a potential threat

3. Deep-sea trenches

- A feature of subduction zones, the deepest areas on the planet
- Few in number (37), but up to 1,000s of kilometres in length
- Most lie within EEZs
- Largely endemic fauna, adapted to extreme hydrostatic pressure
- Interest in biotechnology potential – a potential threat
- Interest in use as waste disposal sites – a potential threat
- Significant potential for direct influence from terrestrial pollutants – a potential threat

4. Deep-sea 'coral reefs'

- Several species (e.g. Lophelia pertusa) of deep-sea coral are capable of forming 'reefs'
- They are widely distributed in the world's oceans, from 10s to 1,000s m water depth
- Occur in wide variety of environmental settings
- They vary in size from individual colonies (10s cm) to extended patch-reefs of 10 km extent
- Provide habitat for high diversity of associated species (few or no obligate associates known)
- Extensive damage by commercial trawling evident – an actual threat
- Deep-water oil exploitation within areas of known occurrence – an actual threat
- Interest in biotechnology potential – a potential threat

5. Polymetallic nodules

- 'Manganese' nodules may occur in vast fields on the deep-ocean floor
- Provide a hard substratum for epifaunal species, increasing local / regional diversity
- Considerable potential for commercial exploitation – a potential threat
- Pilot scale mining studies have been undertaken
- Environmental impact studies have been undertaken

6. Cold seeps and pockmarks

- Highly localised sites of low temperature fluid escape from the seabed
- Occur in a wide variety of physiographic and geological settings
- Typically support abundant biological populations, fuelled by chemosynthesis
- Highly specialised fauna, of relatively low diversity, but high endemism
- Seeps and their communities may be ephemeral
- Interest in biotechnology potential – a potential threat
- Connection with deep-water oil exploitation – a potential threat

7. Gas hydrates

- Frozen methane gas
- Probably abundant and widespread in deep-sea environments
- Associated fauna little known
- Interest in biotechnology potential – a potential threat
- Considerable interest in direct exploitation – a potential threat

8. Submarine canyons

- Common deep-sea features that cut across continental slopes
- They influence local bottom water flows and may acts as traps for organic matter
- They may be biological 'hot spots' with enhanced benthic populations
- Fish (and possibly cetacean) populations may also be enhanced
- Commercial fishing (trap and long-line) may be important – and actual threat
- Significant potential for direct influence from terrestrial pollutants – a potential threat

9. Seabirds

- ca. 22% of the world's seabird species are "threatened" species
- Many seabirds have low reproductive rates; they are sensitive to additional sources of mortality
- Pelagic and demersal long-lining fisheries are the largest threat to seabirds
- Changes in long-lining methods and better regulation may reduce seabird casualties

10. Cetaceans

- Some species migrate thousands of miles during their lifetime
- Many whale populations have failed to recover despite many years of protection
- Whale mortalities arise mainly from commercial whaling and fishing
- Molecular genetic methods indicate significant illegal sales of whale products

11. Transboundary Fish Stocks

- Fish do not respect national EEZ boundaries
- Over-fishing on the high-seas has become particularly acute in recent years
- Some deep-sea species have life histories that make them very susceptible to exploitation and over fishing
- High-seas fishing fleets typically use non-selective equipment producing high by-catch mortalities

TABLE 2:
TABULAR SUMMARY OF ENVIRONMENTAL CHARACTERISTICS

TYPE	TYPICAL DEPTH	SCALE	FREQUENCY / EXTENT	TYPICAL DEPTHS	GEOLOGICAL CHARACTERISTIC	BIOLOGICAL CHARACTERISTIC	NATURAL STABILITY
Hydrothermal vents	500–4,000 m	<1 km	100s	Sublittoral to hadal	High temperature fluid escape, tectonic / volcanic	Chemosynthesis, endemism, and enhanced productivity	Ephemeral Fluid flow dependant
Seamounts	10s-5,000 m (summit depth)	10s-100 km	1,000s	Sublittoral to abyssal	Tectonic / volcanic	Biological 'hot spots', endemism, and enhanced productivity	Variable, possible seismic and volcanic activity
Deep-sea trenches	6,000-11,000 m	100s-1,000s km	10s	Hadal	Subduction zones	Ultra-extreme environment, endemism	Focal sites for tectonic activity
Deep-sea reefs	80–1,000 m	<1-10s km	Common	Sublittoral to bathyal	Various settings	Biological 'hot spots', enhanced diversity	Stable
Manganese nodules	4,000–6,000 m (economic deposits)	100s-1,000s km	Vast fields	Abyssal	Abyssal plains	Enhanced diversity	Stable
Seeps and pockmarks	10s-6,500 m	<1-10s km	? 1,000s	Sublittoral to abyssal	'cold' fluid escape, various settings	Chemosynthesis	Ephemeral Fluid flow dependant
Gas hydrates	>300 m	<1-100s km	Vast resource	Bathyal to abyssal	Frozen methane	Chemosynthesis	Stable ?, potentially subject to catastrophic outgassing
Submarine canyons	10s-3,500 m	10s-100s km	Common	Bathyal to abyssal	Continental slopes	Biological 'hot spots', enhanced productivity	Variable, may be subject to frequent or catastrophic natural disturbance (i.e. downslope sediment transport)
Seabirds	Na	Na	Na	Epipelagic	Na	Breeding and feeding areas	<?>
Cetaceans	Na	Na	Na	Epipelagic to bathypelagic	Na	Migration routes, breeding and feeding areas	<?>
Transboundary fish stocks	Na	Na	Na	Epipelagic to bathypelagic	Na	<?>	<?>

TABLE 3:
TABULAR SUMMARY OF SCIENTIFIC, SOCIETAL AND COMMERCIAL INTERESTS AND THEIR THREATS

TYPE	SCIENTIFIC 'INTEREST'	SOCIETAL 'AWARENESS'	COMMERCIAL 'POTENTIAL'	MAIN PRESENT THREATS	POTENTIAL THREATS
Hydrothermal vents	High for geology and biology	Quite high	Considerable	Scientific (tourism)	Mineral and energy extraction
Seamounts	High biological interest	Possibly moderate	Considerable	Fishing	Mineral extraction
Deep-sea trenches	Potentially high, but technology limited	Limited	Limited / moderate	(nil, pollution)	Waste disposal
Deep-sea reefs	High for geology and biology	Becoming high	Considerable	Fishing	(adjacent industry)
Manganese nodules	Moderate, linked to potential exploitation	Limited	Considerable	(nil, trial mining)	Mineral extraction
Seeps and pockmarks	High for geology and biology	Limited	Considerable	(nil, oil and gas exploration)	Mineral extraction
Gas hydrates	High for geology, potentially high for biology if novel communities located	Very limited	Considerable	(nil, oil and gas exploration)	Mineral extraction
Submarine canyons	High for geology and biology	Possibly moderate	Moderate / considerable	Fishing (pollution)	Waste disposal (adjacent industry)
Seabirds	<?>	High	Limited	Fishing	(adjacent industry)
Cetaceans	<?>	High	Moderate	By-catch and whaling	(adjacent industry)
Transboundary fish stocks	<?>	High	Considerable	Fishing	(adjacent industry)

References

i) Billett, D.S.M. and Rice,A.L. (in press). The BENGAL Programme: introduction and overview. Progress in Oceanography.

ii) Bett, B.J. (2000). Signs and symptoms of deepwater trawling on the Atlantic Margin. Man-made objects on the seafloor. Society for Underwater Technology, London. 107-118

iii) Merrett, N.R. and Haedrich, R.L. 1997. Deep-sea demersal fish and fisheries. London, Chapman & Hall.

iv) Crook, J. (2000). Roncador – the World's deepest field. *Petroleum Review* **54**: 14-16

v) Gage, J.D. and May, R.M. (1993). A dip into the deep seas. *Nature* **365**: 609-610

vi) Hessler, R.R and Sanders, H.L., 1967. Faunal diversity in the deep sea. *Deep-Sea research I*, **14**, 65-78.

vii) Atlantic Frontier Environmental Network, 2000. Environmental Surveys of the Seafloor of the UK Atlantic Margin [CD-ROM]. Available from Geotek Limited, Daventry, Northants NN11 5EA, UK.

viii) Lonsdale, P., 1977. Clustering of suspension-feeding macrobenthos near abyssal hydrothermal vents at oceanic spreading centers. *Deep-Sea Research I*, **24**, 857-863.

ix) http://www.mlml.calstate.edu/groups/biooce/lesn.htm. "Prochlorophytes: The most important plants on earth?"

x) Magurran, A.E., 1988. Ecological Diversity and its Measurement. Princeton University Press, New Jersey.

xi) Maciolek, N.J., Grassle, J.F, Hecker, B., Boehm, P.D., Brown, B., Steinhaur, W.G., Baptiste, E., Ruff, R.E and Petrecca, R., 1987. Study of the biological processes of the US mid Atlantic slope and rise. Final report for the US Department of the Interior, Mineral Management Service. Washington, DC, 310pp.

xii) Pearson, T.H., and Rosenberg, R., 1978. Macrobenthic succession in relation to organic enrichment and pollution of the marine environment. *Oceanography and Marine Biology, an Annual Review,* **16**, 229-311.

xiii) Bett, B.J., 2000. Comparative benthic ecology of the Rockall Trough and Faeroe-Shetland Channel, Section 4.3.2 in Environmental Surveys of the Seafloor of the UK Atlantic Margin, Atlantic Frontier Environmental Network [CD-ROM, 51 pp., 51 figs, 11 tabs]. Available from Geotek Limited, Daventry, Northants NN11 5EA, UK.

xiv) Simmonds, M.P. and Judith D. Hutchinson, J.D. (eds), 1996. Conservation of whales and dolphins: science and practice. John Wiley & Sons, New York.

xv) Hardin, G., 1968. The tragedy of the commons. *Science*, **162**, 1243-1248.

SECTION B

INTRODUCTION

A comprehensive selection of 'distinct' areas, features, habitats and biological communities of potential scientific, societal or commercial interest on the high-seas has been made. Each of these topics is covered in detail below.

1. HYDROTHERMAL VENTS

1.1 Introduction and habitat characteristics

In 1977, scientists discovered the first deep-sea hydrothermal vent at a depth of ca. 2,500 m on the Galapagos Rift, off the coast of Ecuador(1). Subsequently, many other vent systems have been found mainly along the mid-ocean ridge systems to depths of ca. 4,000 m. Vast tracts of ridge crest remain unstudied and the abundance of vents is unknown; only 10% of the 50,000 miles of ridge system has been explored. However, it has been estimated that there is 1 vent per 100 km of ridge length, giving an approximation of 500 vents worldwide(2).

At seafloor spreading centres, cold water penetrates into the seafloor through fissures. It is then superheated near the roof of shallow magmatic chambers beneath the ridge axis. The heated seawater, enriched with metal ions and other substances leached from surrounding rock, is then expelled at the seafloor in highly localised sites known as hydrothermal vents. The plumes of mineral-laden water are known as 'smokers' and the minerals may precipitate out to form large chimneys.The fluids can reach temperatures of ca. 400^{o}C. They are acidic, have highly variable salinity and contain high levels of hydrogen sulphide, metals, carbon dioxide and methane(3). In addition to venting via chimney structures, heated water may also appear as diffuse flow around the vent field. These diffuse hydrothermal fluids of lower temperature (ca. 25^{o}C) were first discovered in 1995 on the eastern flank of the Juan de Fuca Ridge(4).

The sulphide in the vent fluid is the primary substance that supports the unique vent ecosystem, through chemosynthesis. The fauna of hydrothermal vents is vastly different from the surrounding deep-sea benthos. Primary production at vents is reliant upon microbes that have the ability to use the reduced inorganic compounds in vent fluids to synthesise organic matter. These microbes are found in the gills and other tissues of some vent invertebrates and also live free on suitable hard substrates around the vent site.

1.2 Global distribution

Hydrothermal vents are found on active spreading ridges, in subduction zones, fracture zones, back-arc basins and on seamounts(3) (see Figure 2). Active venting occurs only at restricted locations on spreading ridges.

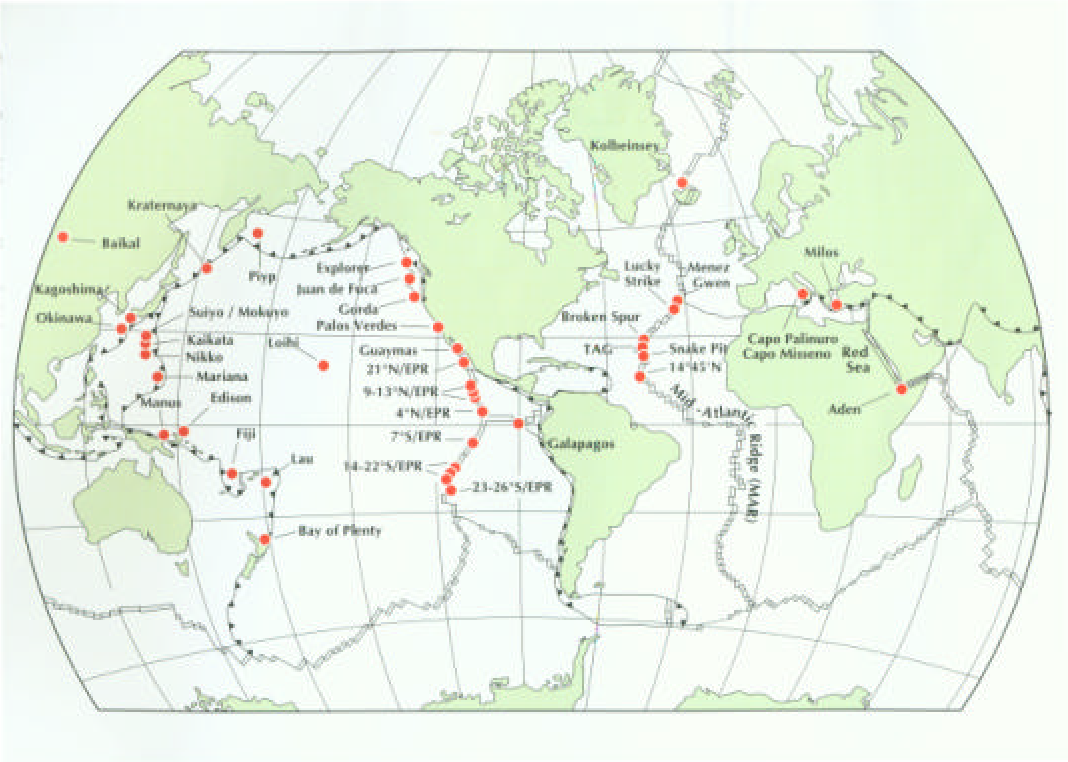


Figure 2 [6]***:*** *Global distribution of hydrothermal vents. (After Desbruyères, D. and Segonzac, M. (1998) Handbook of deep-sea hydrothermal vent fauna. Editions IFEMER, France 297 pp)*

1.3 Associated fauna

Hydrothermal vents may be considered as isolated 'biological' islands. Around 90% of the species described to-date from vents are endemic. A very specialised fauna has adapted to exploit the extreme physico-chemical conditions found at vents. Over the past 24 years 30 vent sites have been studied, mostly in the Pacific and Atlantic Oceans. Vents display very high productivity compared with other non-vent abyssal environments, but have a relatively low diversity with a rather simplified trophic structure.

Approximately 450 invertebrate species have been identified to generic level although many more are currently being studied. Three phyla dominate (ca. 90%) the vent fauna described to date: molluscs, arthropods and annelids[3]. Some 32 octopus and fish species have also been observed in and around vents. Over 75% of vent species occur at only one site. No single species occurs at all sites[3]. Eleven of the 80 species identified from the northeast Pacific (Explorer, Juan de Fuca and Gorda Ridges) are known from the East Pacific Rise or Galapagos vent sites. Long-range dispersal of larvae or slow speciation for these particular fauna may explain these shared species[3].

Life is concentrated in the zone of mixing between the hydrothermal vent fluid and seawater. In this zone environmental conditions are extremely variable with temperatures as high as 50^{o}C[7]. There have been reports of polychaete worms (*Alvinella pompejana*) enduring hot water venting at temperatures in excess of 80^{o}C[8].

It should be noted that not all of the hydrothermal vent sites discovered to date have large populations of 'unusual' faunal assemblages. For example, the latest vent to be discovered at 30^{o}N on the Mid-Atlantic Ridge on 4th December 2000 has been dubbed 'The Lost City' field. This site is ~700 m deep. There are no obvious mega/macrofauna at this site. The investigators also reported a 180 ft (55m) chimney structure at this site – the largest of its kind[9]. Other sites in relatively shallow water also have no "typical" vent fauna associated with them (e.g. vents on the Don João de Castro seamount in the Azores – ca. 15 m deep). Specialised vent fauna have been found only at depth greater than 400 m to date[10].

1.4 Exploitation value

Present exploitation of hydrothermal vents occurs only in relation to scientific research. Geographically isolated hydrothermal vents provide a good testing ground for theories concerning speciation and patterns in species diversity[3]. Major new scientific questions have come from the initial studies of hydrothermal vents. For example, it is thought that events such as El Niño may be partly controlled by hydrothermal activity[11]. Ocean volume regulation has also been linked to hydrothermal processes[12,13]. Studies of the vent biological communities have transformed views of deep-sea ecology. These animals have the ability to adapt to extreme physical and chemical conditions, and are able to cope with extraordinary temperature variations and highly toxic substances. The giant tubeworms (vestimentiferans) found around vents grow faster than any other marine invertebrate (ca. 1 m per year). It has even been suggested that the first life on Earth appeared at hydrothermal vents[14,15,16]. Studies of chemosynthetic communities at vents and in other extreme environments have influenced space scientists to abandon their emphasis on searching for photosynthetic organisms on Mars in favour of chemoautotrophic forms[17].

In addition to the scientific value of vents, there are potential economic reasons for their exploitation. Vent biological communities may be an important source of novel products for biotechnological applications. Bioprospecting involving genetic resources from vents is a matter of increasing international interest[18]. The identification of new "hyperthermophiles" from hydrothermal vents has generated recent press coverage[19,20]. *Archaeoglobus fulgidus* is the first sulphur-metabolizing organism to have its genome sequenced. These bacteria contribute to deep sub-surface oil well souring by iron sulphide, which causes corrosion of iron and steel in oil-and gas-processing systems[21]. Vents give rise to some of the most unusual microorganisms on the planet, able to grow at temperatures exceeding 100^{o}C. Enzymes isolated from hyperthermophiles show a corresponding tolerance for high temperatures[22]. Research on extreme ecosystems has yielded potentially valuable new extremophiles capable of living at a variety of temperatures and pressures, and on a range of carbon and energy sources. For example, enzymes from bacteria of the strain *Bacillus* collected from around the TAG mound may be of use in food processing, detergents and the degradation of toxic wastes[23]. Bacterial bioremediation of waste sulphides for industrial purposes has already been developed on laboratory scales. Bacterial biomass generated by this process can be used as a food source for aquaculture or in the production of synthetic fuels[24]. Extremophile research is still in its infancy and the extent to which new, commercially useful extremophiles may come from vents is not known. Consequently, the economic value of this market is entirely speculative and, to-date, unrealised. However, the market for biotechnology enzymes derived from extremophiles is forecast to grow at 15-20% per year [25].

The mining of polymetallic sulphide crusts from vent systems beyond national jurisdiction will become economically viable within an estimated time scale of 10-15 years[18]. These crusts are potentially rich in gold and other valuable metals. Hydrothermal chimneys are almost pure metallic sulphides[3]. New discoveries of these massive consolidated sulphides continue to be made with the further exploration of rifts, spreading centres and subduction zones[26]. However, to date, relatively few seafloor sulphide deposits have been shown to be of sufficient size and quality to be potential candidates for commercial exploitation[27].

Hydrothermal vents give off substantial amounts of energy in the form of heat. A maximum heat flux of 50 MW was calculated for a single vent on the Juan de Fuca Ridge. Proposals have been made for the ocean production of hydrogen fuel using vent systems. A single smoker may produce up to 300,000 kg of hot water per hour, with the ability to produce ca. 10 kg of liquid hydrogen per hour. By-products from this process include liquid oxygen and distilled water[28,29].

Tourist trips in the form of manned submersible trips to active vent sites have already taken place and more are scheduled for 2001. Zegrahm Deep Sea Voyages propose to take tourists to the Rainbow hydrothermal vent system aboard the Russian research submersible MIR.

1.5 Biodiversity issues

Hydrothermal vent systems host one of the highest levels of animal abundance on Earth, up to 0.5 million worms and brittlestars.m^{-2} compared to the deep ocean nearby with only ~20.m^{-2}[30]. However, in terms of diversity, 1 or 2 species account for 70 to 90% of the total number of individuals in sediments, whereas in non-vent deep-sea sediments, abundances are more evenly distributed among species, with the single most common species comprising <20% of the total [17]. Vents support communities of highly endemic fauna which have adapted in numerous and diverse ways to cope with this extreme environment. This endemism may extend as far as restricting species to individual vent fields. Different biogeographic hydrothermal provinces have been recognised between vents[31]. For example, vents in the Atlantic Ocean support quite different biological communities to those in the Pacific Ocean. The Atlantic vents are characterised by an abundance of shrimp whereas the Pacific vents are dominated by vestimentiferan tubeworms. The number of species known from both the Atlantic and Pacific is at present very small: only two copepods, commensals of shrimps, and a polychaete have been reported so far from both oceans[32]. The two most similar vent sites in terms of similar species and genera are in the Pacific Ocean on the East Pacific Rise at 13 and 21^{o}N. The Mid-Atlantic Ridge fauna is at present the most isolated based on taxonomic uniqueness of its species and genera[17]. New ecological studies are being conducted on habitat requirements, larval dispersal and population genetics to understand the distribution of species along mid-ocean ridges[17].

1.6 Potential / actual threats

The underlying magmatism and rock structure determine the predictability and stability of individual vents. Hydrothermal vent habitats are patchy in space and time. The life span of a hydrothermal vent field is estimated to be in the order of 10 to 100 years on fast spreading ridges, such as the East Pacific Rise. Hydrothermal activity is more 'stable' on the slower spreading ridges found on the mid-Atlantic Ridge[33].

The only current anthropogenic threat to hydrothermal vent systems is from marine scientific research. Following the initial vent research studies, which focused on exploration and discovery, the science is now moving towards direct sampling and concentrates on temporal change at individual sites[34]. This latter type of research often involves repeated sampling, observation and instrumentation of a small number of well-known hydrothermal sites. This has led to incompatibility between some research projects – those that aim to understand undisturbed vent system functioning and those that are investigating vent processes by manipulation and sampling. Mullineaux *et al*. (1998) noted that: "anthropogenic changes in the distribution and occurrence of vent fluid flows and of associated vent communities have been well documented at vents along the East Pacific Rise, on the Juan de Fuca Ridge and at the TAG field on the Mid-Atlantic Ridge". Scientific research may also lead to pollution at vents via waste, noise, light and toxic spills.

Bioprospectors may require large quantities of a particular organism in order to obtain useful quantities of natural products. Clearly, harvesting specimens at high, unsustainable levels could have an effect upon both the target species and the ecosystem as a whole. However, with advances in molecular techniques, this may be less of a problem as the requirement of large quantities of animal tissue will be reduced [35].

The mining of polymetallic sulphide deposits associated with vent systems poses a substantial threat in terms of physical damage and inevitable severe disturbance to the associated biological community. Mining activities may also result in increased sedimentation and plume generation, and disturb the vent water circulation systems. Although vent fauna in the vicinity of mining activities would undoubtedly be impacted, this should be set in context that natural disturbances and extinctions of vent populations do occur. On fast spreading ridges such as the East Pacific Rise, new vents may be colonised rapidly (depending upon larval recruitment range) and vent species appear to be well adapted to the ephemeral nature of hydrothermal sites. In addition, vent chimney formation may also be remarkably quick, with new chimneys forming within only months or years[36]. Conversely, on slow spreading ridges like the Mid-Atlantic Ridge where vents are fairly old and stable, and biodiversity may be higher, the impact of mining activities may be greater. Such sites may be regional sites of species origin and dispersal. It is on these slow spreading ridges where the larger sulphide deposits are to be found[3].

Those areas of venting that have so far been identified as having large enough sulphide deposits for commercial interest include the TAG site on the Mid-Atlantic Ridge. This location contains up to 5 million tonnes of consolidated massive sulphide, which is of a similar order to most terrestrial deposits currently being mined[27]. There have also been proposals to extract minerals and metals from vents in the South Pacific. However, commercial mining of these deposits appears to be only speculative at present[32]. Inactive vent sites are likely to be targeted by miners. Extinct vents have been seldom studied and no typical vent fauna has been found associated these sites. It is unclear whether they host only the "normal" deep sea fauna or whether they may act as seed areas for newly developing active vent sites.

In terms of geothermal exploitation, large-scale hydrothermal fluid extraction will reduce the flow of hydrothermal fluid to natural outlets, including those supporting vent organisms. This type of extraction may be regarded as leading to a premature ageing of vent sites, rather than to the immediate removal of the sites[26].

A further potential threat to hydrothermal vents is tourism. Tourist trips to vents may be valuable in terms of education to highlight awareness of the sensitivity of vent sites. However, uncontrolled visits to vents have the potential to have a negative impact on vent animals and their habitats via physical damage and light. It is thought that the bright lights from submersible vehicles may damage the sensitive eyes or light receptive organs of some vent animals[37].

Hydrothermal vent fluids may be an important source for biologically significant metals in seawater, for example iron, manganese and sulphur are essential to phytoplankton growth, the most fundamental process in ocean ecology.

References

1) Corliss, J.B., Dymong, J., Gordon L.I., Edmond, J.M. von Herzen, R.P., Ballard, R.D., Green, K., Williams, D., Bainbridge, A., Crane, K. and Andel, T.H. (1979). Submarine thermal springs on the Galapagos Rift. *Science* **203**: 1073-1083

2) Parson, L.M. and German, C. (Feb. 2001) Southampton Oceanography Centre, U.K. Pers. comm.

3) Tunnicliffe, V., McArthur, A.G., McHugh, D. (1998). A biogeographical perspective of the deep-sea hydrothermal vent fauna. *Advances in Marine Biology* **34**: 355-442

4) Mottl, M.J., Wheat, G., Baker, E., Becker, N., Davis, R., Feely, A., Grehan, D., Kadko, M., Lilley, G., Massotu, C., Moyer, C. and Sansone, F. (1998). Warm springs discovered on 3.5 Ma oceanic crust, eastern flank of the Juan de Fuca Ridge. *Geology* **26**: 51-54

5) Gage, J.D. and Tyler, P.A. (1991). Deep-Sea Biology – A Natural History of Organisms at the Deep-Sea Floor. Cambridge University Press, Cambridge, U.K. 504pp

6) Desbruyéres, D. and Segonzac, M. (1998) Handbook of deep-sea hydrothermal vent fauna. Editions IFEMER, France 297pp

7) Childress, J.J. and Fisher, C.R. (1992). The biology of hydrothermal vent animals: physiology, biochemistry and autotrophic symbioses. *Oceanography and Marine Biology Annual Review* **30**: 337-441

8) Cary, S.C., Shank, T. and Stein, J. (1998). Worms bask in extreme temperatures. *Nature* 391(6667): 545-546

9) InterRidge Website - http://triton.ori.u-tokyo.ac.jp/ca.intridge/

10) Rogers, A.D. (1994). The biology of seamounts. *Advances in Marine Biology* **30**: 305-350

11) Walker, D.A. (1995). More evidence indicates link between El Ninos and seismicity. Eos: Transactions, American Geophysical Union **76**: 33-36

12) Kasting, J.F. and Holm, N.G. (1992). What determines the volume of the oceans? *Earth Planet Scientific Letters* **109** (3/4): 507-515

13) Holm, N.G. (1996). Hydrothermal activity and the volume of the oceans. *Deep-Sea Research II* **43**(1): 47-52

14) Corliss, J.B., Baross, J.A. and Hoffman, S.E. (1981).*Oceanologica Acta Special Issue No4*: 59-69

15) Baross, J.A. and Hoffman, S.E. (1985). Submarine hydrothermal vents and associated gradient environments as sites for the origin and evolution of life. *Naval Research Reviews* **38**(2): 2-12

16) Miller, S.L. and Bada, J.L. (1988). Submarine hot springs and the origin of life. *Nature* **334** (6183): 609-611

17) Van Dover, C.L. (2000). <u>The Ecology of Deep-Sea Hydrothermal Vents.</u> Princeton NJ: Princeton, University Press 350pp

18) Glowka, L. (1999). Testing the waters: Establishing the legal basis to conserve and sustainably use hydrothermal vents and their biological communities. *InterRidge News* **8**(2): 45-50

19) New York Times. 1993. Strange oases in sea depths offer map to riches. by William J. Broad (16 November).

20) Nikkei Weekly. 1995. Tapping bacterial pioneer spirit: Microbes' ability to live in extreme conditions has wide implications. by Shigehiko Nakajima (11 December).

21) Klenk, H.P., Clayton, R.A., Tomb, J.F., White, O., Nelson, K.E., Ketchum, K.A., Dodson, R.J.,Gwinn, M., Hickey, E.K., Peterson, J.D., Richardson, D.L. Kerlavae, A.R., Graham, D.E., Kyrpides, N.C., Fleishmann, R.D., Quackenbush, J., Lee, N.H., Sutton, G.G., Gill, S., Kirkness, E.F., Dougherty, B.A., McKenney, K., Adams, M.D., Loftus, B. Venter, J.C. et al. (1997). The complete genome sequence of the hyperthermophilic, sulphate-reducing archaeon *Archaeoglobus fulgidus*. *Nature* **27**(6688): 364-370

22) Jannasch, HW. (1995). Deep-sea hot vents as sources of biotechnologically relevant microorganisms. *Journal of Marine Biotechnology* **3**:5-8.

23) Parkes, J., Palmer, M., Cragg, B., Telling, J., Rhodes, J., Mills, R., Severmann, S., Cowan, D. (1998). A bug's life. *Bridge Newsletter* **17**: 31-33

24) Jannasch, H.W., Taylor, C.D. and Hare, L.R. (1992). The chemosynthetic production of potentially useful biomass by sulphide oxidising bacteria: In: Proceedings of International Marine Biotechnological Conference Wm.C.Brown Publications, Dubuque, I.A. 22-27

25) New England Biolabs. Inc., Beverly, Massachusettes, USA.

26) Cronan, D.S., Hodkinson, R. and Stoffers, P. (1992). Submarine hotspot hydrothermal mineralization in the Pitcairn Island EEZ, South Pacific. Abstracts, 23rd Underwater Mining Institute, Washington DC, Sept 27-29

27) Thiel, H., Angel, M.V., Foell, E.J., Rice, A.L., Schriever, G. (1997). Environmental risks from large-scale ecological research in the deep sea. Report prepared for Commission of the European Communities. Directorate-General for Science, Bremerhaven.

28) Bubis, Y.V., Molochnikov, Z.N., Bruyakin, Y.V. (1993). Hydrogen fuel production in the ocean using the energy of 'black smokers'. *Marine Georesources and Geotechnology* **11**: 259-261

29) Bemis, K.G., Von Herzen, R.P., Mottl, M.J. (1993). Geothermal heat flux from hydrothermal plumes on the Juan de Fuca Ridge. *Journal of Geophysical Research* **98** (B4): 6351-6365

30) http://www.oceansconservation.com/newenglish/htmdocs/mpas/endeavour.htm

31) Van Dover, C.L., Desbruyeres, D., Segonzac, M., Comtet, T., Saldanha, L., Fiala Medioni, A. and Langmuir, C. (1996). Biology of the Lucky Strike hydrothermal field. *Deep-Sea Research I* **43**: 1509-1529

32) Gebruk, A.V., Galkin, S.V., Vereshchaka, A.L., Moskalev, L.I. and Southward, A.J. (1997). Ecology and biogeography of the hydrothermal vent fauna of the Mid-Atlantic Ridge. *Advances in Marine Biology* **32**: 93-144

33) Comtet, T. and Desbruyeres, D. (1998). Population structure and recruitment in mytilid bivalves from the Lucky Strike and Menez Gwen hydrothermal fields (37o17'N and 37o50'N) on the Mid-Atlantic Ridge. *Marine Ecology Progress Series* **163**: 165-177

34) Mullineaux, L.S, Juniper, S.K., Desbruyères, D. and Cannat, M. (1998). Deep-Sea Reserves at Hydrothermal Vents. *EOS, Transactions of the American Geophysical Union* **79**(44): 533-538.

35) Rogers, A.D. (Feb. 2001). Southampton Oceanography Centre, U.K. Pers. comm.

36) Lutz, R.A., Shank, T.M., Fornari, D.J., Haymon, R.M., Lilley, M.D., Von Damm, K.L. and Desbruyeres, D. (1994). Rapid growth at deep-sea vents. *Nature* **371**: 663-664

37) Herring, P.J., Gaten, E. and Shelton, P.M.J. (1999). Are vent shrimps blinded by science? *Nature* **398**(6723): 116

2. SEAMOUNTS

2.1 Introduction and habitat characteristics

Seamounts are steep-sided, typically conical, undersea mountains. They have been defined as circular or elliptical features of volcanic origin(2). Elevation is used to define seamounts. Features >1,000 m high with limited extent across the summit are defined as seamounts, whereas features of lower elevation <1,000 m high are termed knolls and features <200 m are termed hills. Seamounts with flat summits, formed by wave action when originally above sea level, are referred to as guyots(3).

Seamounts are generally of volcanic origin, though some are formed by vertical tectonic movement along converging plate margins. They comprise a distinct deep-sea environment, with hard, exposed substrata being a common feature and relatively little sediment deposition. Polymetallic crusts, mounds or chimneys may also be present, formed via hydrothermal precipitates. Seamounts are a relatively recently discovered deep-sea habitat type and knowledge of their distribution has only come to light in the last 50 years(3,4,5). They often occur in chains or clusters, known as provinces, which may be associated with seafloor ‘hotspots’, locations of repeated volcanic activity.

Interesting hydrodynamic features are often associated with seamounts, including jets and eddies. Some of these eddies are known to become trapped over seamounts to form closed circulations (Taylor columns) which may persist for several weeks(6). On a larger scale, ocean currents may be deflected by seamounts.

2.2.Global distribution

Seamounts are distributed through all ocean basins. Estimations of their abundance suggest over 30,000 exist in the Pacific, 810 in the Atlantic and an intermediate number in the Indian Ocean(6). Figure 3 shows the location of seamounts in the North Atlantic. The majority occur along the Mid-Atlantic Ridge, with the greatest concentration between the Charlie-Gibbs Fracture Zone and the latitude of the Azores.

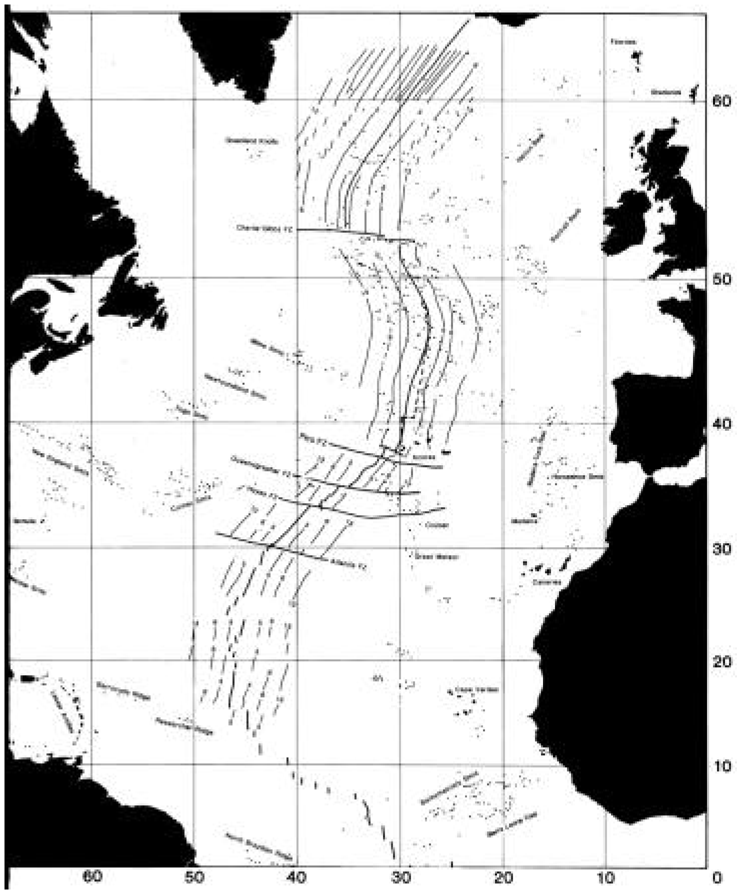


Figure 3: *Seamount distribution in the North Atlantic*
(Epp, D. and Smoot, N.C. (1989). Distribution of seamounts in the North Atlantic. Nature 337(6204):254-257)

2.3 Associated fauna

Suspension feeders, such as corals, dominate seamount benthic fauna (see Section 4). Corals generally occur on the most exposed portions of the seamount, where water currents are strongest, supplying the corals with food, removing waste products and avoiding potentially harmful excess sedimentation. Other conspicuous elements of the seamount fauna comprise sponges, hydroids and ascidians. Where areas of soft sediment occur on seamounts, giant protozoans known as xenophyophores are often the most abundant epifauna(7,8). Some 600 invertebrate species have been recorded from seamounts(9). However, studies of only 5 of the estimated >30,000 seamounts around the world accounted for 72% of these recorded species. This would suggest that many more species remain undiscovered.

The majority of studies to date have indicated that the abundance of fish around seamounts is higher than in the surrounding waters(6). Some evidence exists for an increase in primary production associated with seamounts. These areas of enhanced production are thought to support an abundance of pelagic fauna such as macroplankton, which, in turn, support an increased fish population. An alternative hypothesis suggests that seamounts support large pelagic and benthopelagic fish communities by trapping diurnally migrating plankton. Further research is required to investigate the processes involved in this enhanced productivity. Some studies have identified a decrease in the biomass of planktonic organisms over seamounts. It has been suggested that this may be a function of intensive grazing by predators or the downward migration and scattering of migrating euphausiids and other animals during the day[6].

Some of the commercially valuable fish species associated with seamounts include the orange roughy (*Hoplostethus atlanticus*), some deep-water oreos (Oreosomatidae) and the pelagic armourhead (*Pseudopentaceros wheeleri*). Seabirds have also been shown to aggregate at seamounts in response to the abundance of pelagic organisms associated with these seabed features. Seamounts may therefore provide reliable feeding sites for wide-ranging seabirds foraging in this relatively food-poor environment[10].

Some seamounts have associated hydrothermal venting. The biology of these seamount vents appears to be markedly different from vents located on mid-ocean ridge systems, with few 'typical' vent species detected[6]. This is likely to be a function of depth, with seamount vents occurring at shallower depths than most mid-ocean vents.

2.4 Exploitation value

Over 70 species of commercially valuable fish, shellfish and corals are found on and around seamounts[6]. As a result of the aggregation effect, these populations are readily exploited. Some of the most extensively fished species are given in a comprehensive list in Rogers (1994).

Valuable ferromanganese oxide encrustation and polymetallic sulphides commonly occur at seamounts[11]. Good quality crust deposits are found on many Pacific and Mediterranean seamounts, which offer great potential for mining. Ferromanganese crusts (often referred to as cobalt-rich crusts) are highly valued. At current prices, cobalt represents the dominant value metal in crust deposits. The ore grade is highly variable between sites and is governed by water depth, substrate type, geographic location, current regime and geological history. Crust thickness varies from 1mm to 15 cm, with some crusts of 40 cm thickness reported[12]. The potential for mining this valuable resource is being assessed in terms of the technological challenges associated with crust harvesting. Crusts are usually firmly attached to rock substrate and require *in-situ* separation before the ore can be bought to the surface. Once the most effective and economic methods have been developed, seamount-associated mining is inevitable.

Scientific exploration of seamounts is somewhat lacking, particularly biological sampling. These areas are difficult to sample and require expensive sampling equipment such as Remotely Operated Vehicles (ROVs) or manned submersibles. Consequently, there is still considerable ignorance of seabed ecology. Many new species are found with each investigation[13].

2.5 Biodiversity issues

Although the importance of seamounts with respect to their value in the study of ocean biogeography and diversity was recognised over 40 years ago, this habitat has been seldom explored. When photographic transects were made across two seamounts south of Tasmania, it was reported that most of the seafloor surrounding the seamounts at ca. 1,000 m deep showed only a few animal burrows. A huge contrast was seen over the seamount location that were found to support a diverse, abundant assemblage of hard and soft corals and other filter-feeding organisms[13]. It has been reported that ca. 15% of the 597 species, mainly megafauna, which occur on seamounts globally were considered to be endemic[14].

At a local scale, greater than 850 macro- and megafaunal species were discovered from seamounts in the Tasman Sea and south-east Coral Sea[9]. Of these, an estimated 29-34% were new to science and potential seamount endemics. Low species overlap was found between seamounts in different portions of the region suggesting that these seamounts function as islands or chains with important consequences for speciation. On 14 seamounts off southern Tasmania 24-43% of the species sampled were new to science and 16-33% were endemic[15]. Many other studies have reported similar levels of endemism. Further study is required in order to quantify these findings on a larger scale. Nevertheless, these high levels of endemism suggest that reproductive isolation and speciation may occur in seamount populations, especially in sessile organisms that display limited larval dispersal[16]. For mobile species, seamounts may be used as 'stepping stones' for the transoceanic dispersal of species over evolutionary timescales[14].

The deepest known plant life has been discovered on a seamount[17]. Macroalgae live below depths of 200 m, highlighting their ability to survive in very low levels of light. They contribute to the primary productivity of seamounts and may play an important role in food webs, sedimentary processes, and as reef builders.

2.6 Potential / actual threats

The depletion of many inshore fish stocks has led to increasing fishing pressure in the open ocean. Improved fishing technology is aiding this exploitation. Rich fishing grounds are often found over seamounts, where high yield per unit effort is obtained, rendering the seamount fauna subject to extensive physical damage by trawling, and stock and by-catch depletion by long-lining. Many animals are likely to have extremely limited regenerative capacity[15]. Recovery from impact might be measured in decades[18,19]. Deep-water precious corals are slow growing and often have very low levels of recruitment[20]. If depleted, their recovery could take centuries[20,21]. Some of the fish species exploited on seamounts have low productivity and extreme longevity. These life history traits are not conclusive to intensive fishing, such that exploited populations are likely to reduce quickly and take decades, or longer, to recover[22].

A rock lobster population (*Jasus tristani*) discovered by biologists on the Vema seamount was subsequently severely depleted by fishing in the 1960s. Recovery from this impact took some 10 years, in part a function of sporadic recruitment to this island population. Shortly afterwards, the population was over-exploited once more[23].

The pelagic armourhead (*Pseudopentaceros wheeleri*) populations over the southern Emperor seamounts and the seamounts in the northern Hawaiian Ridge were severely over-fished from the late 1960s to mid 1970s. Catches dropped from ca. 30,000 t in 1976 to only 3500 t in 1977. It is thought that the intense and localised fishing strategy coupled with the rather complex life-history of this fish contributed to its commercial extinction[24].

Another example of a seamount fish that has been subject to unsustainable levels of fishing is the orange roughy (*Hoplostethus atlanticus*). New discoveries of stocks are typically fished down to 15-30% of their initial biomass within 5-10 years on seamounts off the coasts of New Zealand and Australia[25]. The aggregative spawning behaviour that this species displays around seamounts increases its susceptibility to severe fishing impacts. It has also been suggested that this and other fish species use seamount habitats as a nursery area[13]. Precious corals, highly valued for jewellery items and ornaments, have been extensively harvested from the Emperor-Hawaiian Seamounts. For example, in 1983 ca. 70% of the world's harvest of red coral came from these seamounts amounting to ca. 140,000 kg. Red, pink, gold, black and bamboo corals have all been depleted from Mediterranean seamounts[20]. These corals are slow growing with very low levels of natural mortality and recruitment and hence are threatened by over fishing. The longevity of some deep water corals on seamounts may be similar to that found in old growth forest[13]. However, *Lophelia* has comparable growth rates to some shallow water corals. Estimates range from 5.5 mm per year to 25 mm per year[26]

In addition to the depletion of particular target species of fish, coral or shellfish, the benthic fauna on seamounts is also impacted by extensive trawling operations. Such damage to the fauna has been reported from seamounts south of Tasmania and is undoubtedly widespread[15]. This may have a knock on effect in terms of the survival of the surrounding pelagic fauna that depend upon the productive benthic environment.

Little information exists about many of the species associated with seamounts that have been over-fished in the past. Many of these species display life-history strategies that allow only low sustainable yields of these organisms. The intense and localised exploitation of these species, coupled with no formal stock assessment and quotas, will result in the continued demise of these habitats.

In the future, seamounts may be targeted by mining companies for ferromanganese crust and polymetallic sulphides(27). An environmental impact assessment was made for the Cross Seamount prior to crust mining. This particular seamount was characterised by low diversity and abundance in terms of benthic fauna relative to the surrounding seabed. Pelagic species were not dealt with by the authors(28). Seamounts generally support communities of high diversity and/or high productivity, consequently any physical impact of mining activities could be devastating.

References

1) http//:www. Pac.dfo-mpo.gc.ca/oceans/Bowie/BowieFactSheet.htm

2) Epp, D. and Smoot, N.C. (1989). Distribution of seamounts in the North Atlantic. *Nature* **337**(6204):254-257

3) Hess, H.H. (1946). Drowned ancient islands of the Pacific basin. *American Journal of Science* **244**(10): 772-791

4) Menard, H.W. and Dietz, R.S. (1951). Submarine geology of the Gulf of Alaska. *Bulletin of he Geological Society of America* 62: 239-253

5) Menard, H.W. and Ladd, H.S. (1963). Oceanic islands, seamounts, guyots and atolls. In M.N. Hill (ed.) The Sea. Wiley Interscience, New York and London. Vol. 3 365-385.

6) Rogers, A.D. (1994). The biology of seamounts. *Advances in Marine Biology* **30**: 305-350

7) Levin, L.A., DeMaster, D.J., McCann, L.D. and Thomas, C.L. (1986). Effects of giant protozoans (class: Xenophyophorea) on deep-seamount benthos. *Marine Ecology Progress Series* **29**: 99-104

8) Levin, LA. and Thomas, C.L. (1988). The ecology of xenophyophores (Protisa) on eastern Pacific seamounts. *Deep-Sea Research* **12**(12): 2003-2027

9) De Forges, B.R., Koslow, J.A., Poore, G.C.B. (2000). Diversity and endemism of the benthic seamount fauna in the southwest Pacific. Nature 405 (6789): 944-947

10) Haney J.C., Haury L.R., Mullineaux LS., Fey, C.L. (1995). Sea-bird aggregation at a deep North Pacific seamount. *Marine Biology* **123**(1) 1-9

11) Thiel, H., Angel, M.V., Foell, E.J., Rice, A.L., Schriever, G. (1997). Environmental risks from large-scale ecological research in the deep sea. Report prepared for Commission of the European Communities. Directorate-General for Science, Bremerhaven.

12) Friedrich, G. and Schmitz-Wiechowski, A. (1980). Mineralogy and chemistry of a ferromanganese crust from a deep-sea hill, Central Pacific, "Valdivia" Cruise 13/*2 Marine Geology* **37**: 71-90

13) Koslow, T. and Exon, N. (1995). Seamount discoveries prompt calls for exploration and conservation. *Australian Fisheries* **54**(2): 10-13

14) Wilson, R.R. and Kaufmann, R.S. (1987). Seamount biota and biogeography. In B.H. Keating, P. Fryer, R. Batiza and GW. Boehlert (eds.) Seamounts, Islands and Atolls. Geophysical Monography 43. American Geophysical Union, Washington D.C. 319-334

15) Koslow, J.A. and Gowlett-Holmes, K. (1998). The seamount fauna of southern Australia: benthic communities, their conservation and impacts of trawling. Report to Environment Australia and the Fisheries Research Development Corporation. FRDC Project 95/058

16) Creasy, S.S. and Rogers, A.D. (1999). Population genetics of bathyal and abyssal organisms. *Advances in Marine Biology* **35**: 1-151

17) Littler, M.M., Littler, D.S., Blair S.M., Norris, J.N. (1985). Deepest known plant life discovered on an uncharted seamount. *Science* **227**(4682): 57-59

18) Jones, J.B. (1992). Environmental impact of trawling on the seabed: a review. New Zealand *Journal of Marine and Freshwater Research* **26**: 59-67

19) Watling, L. and Norse, E.A. (1998). Disturbance of the seabed by mobile fishing gear: a comparison to forest clear cutting. *Conservation Biology* **12**: 1180-1197

20) Grigg, R.W. (1984). Resource management of precious corals: a review and application to shallow water reef building corals. *Marine Ecology* **5**(1): 57-74

21) Wilson, J.B. (1979). Patch development of the deep-water coral Lophelia pertusa (L.) on Rockall Bank. *Journal of the Marine Biological Association of the United Kingdom* **59**: 165-177

22) Koslow, J.A. (1997). Seamounts and the ecology of deep-sea fisheries. *American Scientist* **85**: 168-176

23) Lutjeharms, J.R.E. and Heydorn, A.E.F. (1981). The rock-lobster Jasu stristani on Vema Seamount: drifting buoys suggest a possible recruiting mechanism.. *Deep-Sea Research* **28A**(6): 631-636

24) Sasaki, T. (1986). Development and present status of Japanese trawl fisheries in the vicinity of seamounts. In R.N. Uchida, S. Hayashi and G.W. Boehlert (eds.) The Environment and Researches of Seamounts in the North Pacific. Proceedings of the Workshop on the Environment and Resources of Seamounts in the North Pacific. US Department of Commerce, NOAA Technical Report MNFS 43: 21-30

25) Koslow, J. A., Boehlert, G.W., Gordon, J.D.M., Haedrich, R.L., Lorance, P. and Parin, N. (2000) The impact of fishing on continental slope and deep-sea ecosystems. *ICES Journal of Marine Science* **57**: 548-557

26) Mortensen, P.B. and Rapp, H.T. (1998). Oxygen and carbon isotope ratios related to growth line patterns in skeletons of Lophelia pertusa (l.) (Anthozoa, Scleractinia): implications for determination of linar extension rates. Sarsia 83: 433-446

27) Sarma, K., Ramana, M.V., Subrahmanyam, V., Krishna, K.S. (1998). Seamounts an additional tool to confirm the nature of the crust and to locate possible mineral resources for dredging. *Marine Georesources and Geotechnology* **16**(1): 41-51

28) Grigg, R.W., Malahoff, A., Chave, E.H. and Landahl, J. (1987). Seamount benthic ecology and potential environmental impact from manganese crust mining in Hawaii. In B.H. Keating, P. Fryer, R. Batiza and GW. Boehlert (eds.) Seamounts, Islands and Atolls. Geophysical Monography 43. American Geophysical Union, Washington D.C. 379-390

3. DEEP-SEA TRENCHES

3.1 Introduction and habitat characteristics

Deep-sea trenches extend along island arcs and continental coastlines. Many are contained within the 200 mile EEZs of a number of nations. In the process of seafloor spreading, the oceanic crust buckles downwards where two tectonic plates collide and is destroyed within the hot interior of the Earth. This 'subduction' process forms deep-sea trenches. The majority of trenches range in depth from 6,000 to 11,000 m and comprise ca. 1% of the total surface of the oceans. Most are separated from each other by shallower ocean bottom. Trench bathymetry may be complex. There are unique features in most trenches. All trenches are elongated and narrow. Most are only a few tens of kilometers wide. Most of them are straight or slightly curved. Their lengths range from 100 to 3,000 km.

Fine sediments cover the bottom and the gentle lower slopes of trenches. Rocky outcrops mainly occur on the trench slopes. Rock fragments can also be found littered along trench bottoms. There is evidence that terrestrial plants accumulate in some deep-sea trenches, having been transported there by rivers and downslope processes or on the wind (3). Deep-sea trenches are subject to considerably higher levels of sedimentation than the surrounding deep-ocean bed.

Prior to 1948, it was generally considered that little or no life existed in the oceans below 6,000 m. This theory was overturned by two expeditions. The Russian "Vityaz" expedition (1949 to 1962) and the Danish "Galathea" expedition (1950 to 1952). They provided the first evidence that life could exist even at the high hydrostatic pressures experienced in deep-sea trenches. Today, the majority of deep-sea trenches have been explored to varying degrees. Some trenches are hypoxic (very low oxygen conditions) e.g. Cariaco Trench off the coast of Venezuela, and some areas of the Puerto Rico Trench. Little is known about their environmental stability. However, physically unstable conditions are thought to prevail in deep-sea trenches as a result of the high levels of local seismic activity.

3.2.Global distribution

There are 37 deep-sea trenches known from the world's oceans. They are located mainly in the Pacific Ocean (28). Only 5 occur in the Atlantic and 4 in the Indian Ocean. The nine deepest trenches are situated in the Pacific Ocean with depths of 9,000 to 11,000 m.

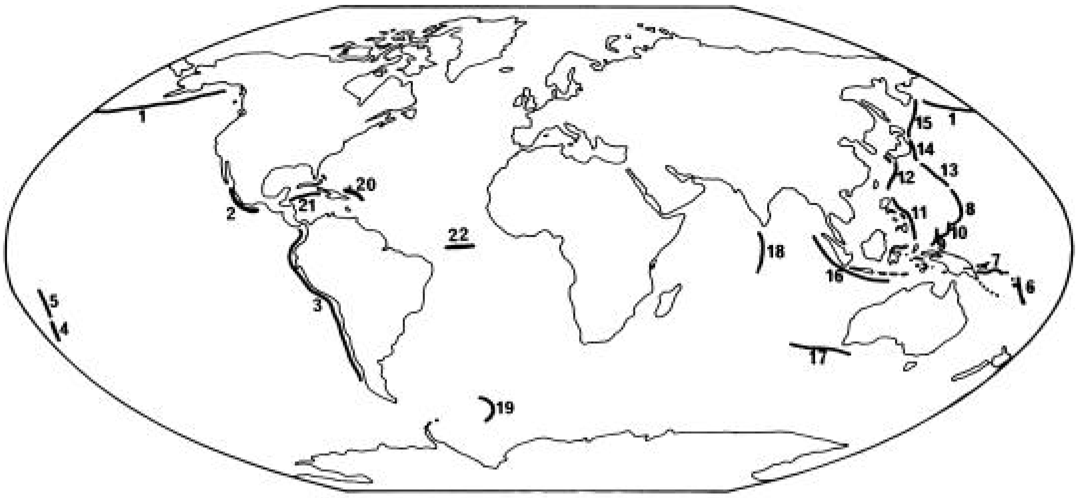


Figure 4 ***(4)***

Geographical distribution of major trench systems in the world's oceans

(Angel, M.V.(1982). Ocean Trench Conservationo. Commission on Ecology Papers Number 1. International Union for Conservation of Nature and Natural Resources).

3.3 Associated fauna

The benthos in deep-ocean trenches have been termed the 'hadal fauna' and they are largely unique. They have adapted to cope with massive hydrostatic pressure, unusual trophic conditions and frequent physical disturbance. Samples of the fauna have been collected from most deep-sea trenches although there have been few detailed studies.

The complex bathymetry of trenches and range of substrata present provides a variety of ecological niches for the benthos. Trenches that are close to productive ocean areas are subject to high levels of sedimentation and abundant food sources compared with surrounding abyssal areas.

Trenches support a fairly diverse and abundant bacterial community that plays an important role in the diet of larger benthic animals. Trench fauna has relatively numerous representatives of most of the major free-living benthic taxonomic groups. In addition to bacteria and Foraminifera, representatives of at least 30 metazoan classes have been recorded. Faunal vertical zonation exists in trenches. The fauna is most diverse in the shallower parts of the trenches, with lower diversity at greater depths. Animals adapted to life at maximum ocean depths belong to a comparatively small number of species in a few major taxonomic groups. A gradual elimination of major taxa with depth is likely to be the result of increasing pressure. The metazoan fauna known from depths greater than 10,000 m consists of only 10 classes and 12 species and these are the most specialised(5).

The fauna of deep-sea trenches consists mainly of animals living on soft sediment, notably the detritus-feeding, and frequently abundant, holothurians. In the Kurile-Kamchatka Trench, 54% of the bottom megafauna consists of holothurians (mostly *Elpidia* but also *Peniagone* and *Scotoplanes*)(6). Holothurians dominate in terms of biomass and density in the hadal zone, followed by bivalve molluscs and polychaetes. Quantitatively important components of the upper zone are ophiuroids, sipunculans crustaceans and sea stars.

3.4 Exploitation value

In terms of fisheries and mineral resources, deep-sea trenches are unlikely to prove economically viable for exploitation. Nevertheless, they are valued in terms of scientific research. Deep-sea trenches provide valuable ecosystems to study ecological theories. The study of hadal fauna is important to learn how living processes adapt to extreme hydrostatic pressure. The similarity between pressure effects and the physiological effects of anaesthetics could be the key to important medical advances(4). Deep-sea trenches are highly stable in terms of temperature, salinity and oxygen concentrations, but have complex sedimentation patterns and frequent seismic activity causing physical disturbance. Undoubtedly there are many new species to be discovered, some of which may have important medical and biotechnological applications in the future. For example, bacteria from trenches have been found to contain novel genes of unknown function (*Pyrococcus horikoshii*) and bioprospecting genes for industrial application is currently underway(7).

The deepest colony of shellfish yet discovered from the hadal zone was recently found 7,326 m deep in the Japan Trench(8). These bivalves appear to be sustained by chemosynthesis. This finding suggests that a range of chemosynthesis-based communities may exist in deep-sea trenches.

The consideration of the use of trenches as a disposal site for waste has led to much debate. For example, they have been considered as isolated containment sites for the disposal of high level radioactive wastes and mining tailings(4).

3.5 Biodiversity issues

Much of the fauna associated with deep-sea trenches is highly specialised and is comprised of newly discovered species and genera. Although there is a decrease in the total number of species in the hadal zone compared with the abyssal environment, some species may be particularly abundant(6). A high percentage of species are endemic to only one trench(9,4). Endemic species constitute 56% of the total hadal fauna, some 600 species(2). This level of local speciation is thought to be the result of physical isolation. If polychaetes are excluded, the proportion of species endemism in trenches rises to ca. 80%. In terms of genera, about 10% are endemic to deep-sea trenches. Among hadal endemics, 95% live in only one trench or in a group of neighbouring trenches. A change in faunal composition is seen between the abyssal and hadal environments, with a dominance in trenches of groups such as pogonophora, echiuroidean worms, holothurians and isopods. Taxa mostly absent from trenches include fish, tunicates, bryozoans and sponges(9).

Deep-sea trenches differ from one another not only in the taxonomic composition of the fauna and the degree of endemism, but also in the numerical abundance of the fauna. Much of this variation is a function of the quantity and quality of organic matter supplied to the trench. Most deep-sea trenches lie relatively close to shore and hence are influenced by inshore and terrestrial food sources. The variation in the abundance of trench fauna is hence likely to be a function of proximity to shore and productivity of the surface ocean. This is highlighted in Figure 5, which shows the quantitative distribution of benthos in the Pacific. Lowest abundances are found in the Tonga, Mariana, Volcano and New Hebrides trenches, which lie in relatively unproductive areas of the tropical ocean, distant from land, and greatest abundances are found in the coastal trenches of the north-western part of the Pacific (Kurile-Kamchatka, Japan, Aleutian), in the southern part of Kermadec Trench and in some tropical trenches situated in highly productive areas (the northern part of the Peru-Chile Trench and Java Trench). The Peru-Chile Trench underlies the Peruvian upwelling zone, and receives substantial inputs of organic matter from the highly productive waters above.

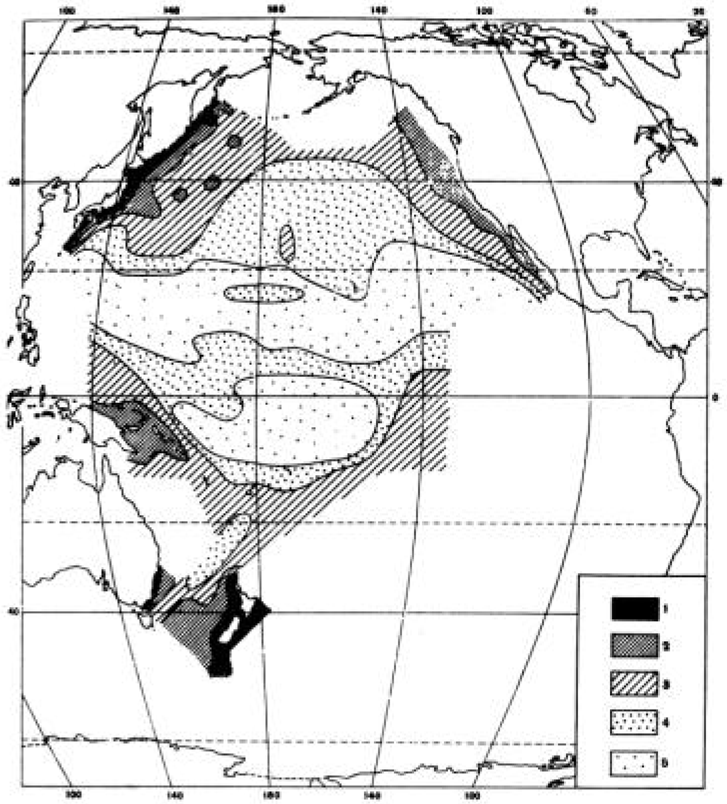


Figure 5 [5]
Quantitative distribution of zoobenthos in the Pacific Ocean. Biomass(g.m^{-2})
1=more than 10; 2=1-10; 3=0.1-1; 4=0.05-0.1; 5=less than 0.05.
(Belyaev, G.M. (1966) (Hadal bottom fauna of the world ocean. Academy of Sciences of the USSR Institute of Oceanology)

A few biological 'peculiarities' have been found in trench species. For example, the body size of many crustaceans tends to increase with depth to a maximum in the hadal zone. Gigantism has been reported in some hadal isopods and tanaids. The largest known species of tanaid and mysid have been found in trenches[10,11]. Differences in morphological characteristics have also been reported between trench and abyssal faunas. For example, some trench animals are blind, lack pigmentation and show a decrease in armament and colour [9].

3.6 Potential / actual threats

Deep-sea trenches have been proposed as suitable sites for waste disposal owing to their supposed isolation and supposed ability to retain waste materials. It is considered that any waste disposal impact will not extend beyond the particular trench dumpsite as they are geographically separated. Deep-sea trenches are also often close to land where the wastes are created, such as mining tailings. Consideration has been given to the disposal of high-level nuclear wastes in trenches[12,4]. Other forms of waste might also be considered for disposal in deep-sea trenches, such as mining tailings, decomissioned oil platforms, sewage sludges, dredge spoils and excess industrial CO_2 (in liquid or frozen form). However, trenches are often located near human populations. They are biologically productive systems. Contaminants may enter the marine food chain and ultimately may enter the human food chain. There are unknown risks associated with waste disposal as trenches are tectonically active. In addition, waters in deep-sea trenches often undergo thorough and relatively rapid mixing, extending to the deepest regions[13]. Conversely, photographs analysed from five different trenches show the absence of ripple and scour marks and the apparent fossilization of tracks suggesting only minimal water movements in the absence of seismic disturbances[14].

The main direct threat to trench fauna is through poisoning by toxic chemicals from waste disposal.

There would be limited flushing from the trench and microbial activity may be a relatively low level, especially when faced with new substances. Also, sedimentation rates are comparatively slow compared to shelf-sea environments, so detoxification by chelation or absorption on to particles would also be slow.

References

1) http//:www.jamstec.go.jp/amstec/dsrp/dsrp.html

2) Belyaev, G.M. (1989). Deep-sea trenches and their fauna. Nauka, Moscos. (In Russian)

3) Jumars, P.A. and Hessler, R.R. (1976). Hadal community structure: Implications from the Aleutian Trench. *Journal of Marine Research* **34**: 547-560

4) Angel, M.V. (1982). Ocean Trench Conservation. Commission on Ecology Papers Number 1. International Union for Conservation of Nature and Natural Resources.

5) Belyaev, G.M. (1966). Hadal bottom fauna of the world ocean. Academy of Sciences of the USSR – Institute of Oceanology.

6) Wolff, T. (1970). The concept of hadal or ultra-abyssal fauna. *Deep-Sea Research* **17**: 983-1003

7) Kawarabayashi, Y., Sawada, M., Horikawa, H., Haikawa, Y., Hino, Y., Yamamoto, S., Sekine, M., Baba, S., Kosugi, H., Hosoyama, A., Nagai, Y., Sakai, M., Ogura, K., Otsuka, R., Nakazawa, H., Takamiya, M., Ohfuku, Y., Funahashi, T., Tanaka, T., Kudoh, Y., Yamazaki, J., Kushida, N., Oguchi, A., Aoki, K., and Kikuchi, H. (1998). Complete sequence and gene organization of the genome of a hyper thermophilic archaebacterium, Pyrococcus horikoshii OT3. *DNA Research* **30**(5-2): 55-76

8) Fujikura, K., Kojima, S., Tamaki, K., Maki, Y., Hunt, J., Okutani, T. (1999). The deepest chemosynthesis-based community yet discovered from the hadal zone, 7326 m deep, in the Japan Trench. *Marine Ecology Progress Series* **190**: 17-26

9) Menzies, R.J., George, R.Y., Rowe, G.T. (1973). Abyssal Environment and Ecology of the Worlds Oceans. John Wiley and Sons, Canada. 488 pp.

10) Wolff, T. (1956a). Isopoda from depths exceeding 6,000 meters. Galathea Report 2: 243-253

11) Wolff, T. (1956b). Crustacea Tanaidacea from deths exceeding 6,000 meters. Galathea Report 2: 187-241

12) Hollister, C.D. (1977). The seabed option. *Oceanus* **20**: 18-25

13) Bogorov, V.G. and Kreps, E.M. (1958). On the possibility of burying radioactive waste in deep-sea trenches of the ocean. *Priroda* **9**: 45-50

14) Lemche, H., Hansen, B., Madsen, F.J., Tendal, O.S. and Wolff, T. (1976). Hadal life as analysed from photographs. *Vidensk Medd. Dansknaturh. For.* **139**: 263-336

4. Deep-Water, Reef-Forming Corals

4.1 Introduction and habitat characteristics

To-date we have a somewhat limited knowledge of deep-water corals, despite the fact that they were discovered over 100 years ago. The most studied cold-water coral is the stony coral, *Lophelia pertusa*. This coral forms a hard, branched, external skeleton of calcium carbonate that houses the individual polyps. It is quite variable in colour, ranging from white to pink and bright orange. *L. pertusa* is a colonial coral that generally develops in deep (down to 2,000 m), cold (4 to 8°C), dark, environments, with potentially high particulate loads associated with the seasonal deposition of phytodetritus. They are commonly found in areas of accelerated current flow associated with topographic highs such as seamounts (see Section 2), carbonate mounds, sand mounds, ridges and pinnacles. These have increased currents that act to maintain sediment-free surfaces for colonisation and increase the particulate food supply. Deep-sea corals have been observed feeding raptorially, catching passing plankton such as copepods. *L. pertusa* requires hard substrate on which to attach. This may be a small hard object such as a stone or worm tube. As the coral grows, this colony forms an increasingly larger attachment area of hard substrate for the coral to inhabit(2). *L. pertusa* is associated particularly with oceanic waters(3). Other primary deep-sea reef-forming corals such as *Goniocorella dumosa*, and *Oculina varicosa* and the secondary reef builder *Madrepora oculata*, require very similar physical habitats as *L. pertusa* indicating that common biological and physical factors determine their distributions (3).

The morphology of *L. pertusa* colonies, thickets and reefs varies considerably. For example, single colonies have been found west of the Shetland Islands, whereas larger coral thickets have been found in Rockall up to 50 m across and several meters high(3). Thickets consist of either single colonies or groups of colonies separated by areas of seabed. Coral patches have been found to occur on circular mounds up to 100 m in diameter and several meters high northwest of the Hebrides(4). Large reefs have been found on 'haystack' shaped mounds, up to 1,800 m in diameter at their base and some 200 m in height, recorded from the Porcupine Seabight(5). Detailed reef morphology has been described for large mounds from the northern Porcupine Seabight area(6). These mounds vary in shape from subcircular to elongate, or they are compound, with circular and elongate elements. The largest was up to 4,000 m long and may have resulted from the build-up of several elongate mounds. Barrier-like reefs at 750 m depth associated with a buried, fossil, shelf edge have been described from the eastern Porcupine Seabight(7). It has been suggested that the different reef morphologies may have occurred because of both the differing physical conditions at various locations and the age of the reefs(3). The present extent of northeast Atlantic reefs are thought to have developed since the last ice age(8). The morphology of other cold-water coral reefs is similar to that of *L. pertusa.*

Deep-water corals are often found to be associated with carbonate mounds. Carbonate mounds are believed to originate from hydrocarbons migrating upwards along faults(5,8) or via marine precipitation(9). Investigations into this are continuing at present though there is no evidence the corals derive nutrition from hydrocarbon seeps although there maybe an indirect link between the two.

4.2 Global distribution

Figure 6 shows the known distribution of *L. pertusa*. The primary locations of *L. pertusa* are throughout the North Atlantic, including parts of west Africa, and persist down the sides of the Atlantic. It is also found in the Gulf of Mexico and the Caribbean and in some areas of the Pacific and Indian Oceans*.* *Lophelia* reefs have been found in the vicinity of cold-water seeps in the Gulf of Mexico and at the Lucky Strike hydrothermal vent field(10). It is also found in shallower waters (ca. 50 m deep) in the fjords of western Norway, off the Norwegian coast (e.g. Sula Ridge) and on the Swedish west coast. *L. pertusa* is often difficult to detect and may actually be more widespread than the map suggests[3]. This map also includes records of dead or subfossil remains, which may have led to an overestimation of the living coral distribution.

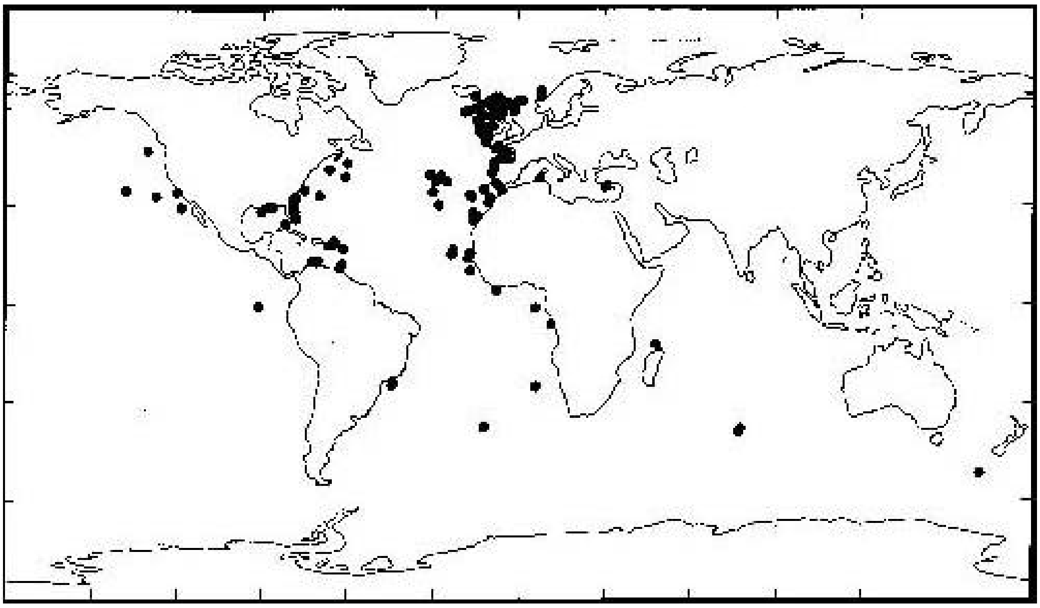


Figure 6 [3]: *Distribution of Lophelia*
(Rogers, A.D. (1999). The biology of Lophelia pertusa and other deep-water reef-forming corals and impacts from human activities. International Review of Hydrobiology ***84****(4): 315-406)*

L. pertusa has been recorded from the continental shelf of the North-East Atlantic Ocean more frequently than in any other part of the world suggesting that this area is globally significant for this species[3].

Knowledge of the distribution of other deep-water, reef-forming corals is very poor. However, some limited information does exist. For example, *Madrepora oculata* contributes to deep-water reefs made up primarily of other coral species. It is probably one of the most widespread deep-water corals. The solitary coral *Desmophyllum dianthus* and the corals *Solenosmilia variabilis* and *Goniocorella dumosa* also commonly contribute to the framework of deep-coral reefs[3]. These latter two species are sometimes the main framework building species.

In terms of their general distribution, azooxanthellate coral reefs are found on the shelf break and upper bathyal zone on the continental margins around most of the world[3]. Recent deep-sea coral reef discoveries have been made that implies there may be other systems awaiting discovery[3].

4.3 Associated fauna

There are few quantitative studies of megafauna associated with deep-water corals. Fauna associated with *L. pertusa* is present on living coral but mainly occurs within and on the dead coral and coral debris field[11]. Four microhabitats associated with *L. pertusa* colonies have been described: (1) the smooth surface of living *Lophelia*, (2) the detritus laden surface of dead *Lophelia*, (3) the cavities inside dead *Lophelia* made by boring sponges, polychaetes and other borers, and (4) the free space between the coral branches[12]. Consequently, these bioherms are complex with more ecological niches than stones on the adjacent sea floor.

Some of the common invertebrate fauna found to live in association with *Lophelia* reefs are boring sponges, anemones, bryozoans, gorgonians, polychaetes, barnacles and bivalves[2,12]. The squat lobster, *Munida sarsi*, occurs in high densities on *Lophelia* rubble(12). In addition to *Lophelia*, other hard corals such as *Madrepora oculata* and *Solenosmilia variabilis* may also be present. Living *M. oculata* was found to be more abundant than *L. pertusa* in some areas on the Porcupine Seabight(13). Many of the coral inhabitants (including bacteria, fungi, sponges and polychaetes) erode the coral's calcium carbonate skeleton through boring, grazing or burrowing. This process acts to increase habitat complexity and may form part of the delicate balance between overall growth and overall destruction of the reef.

Lophelia reefs also attract fish aggregations. For example, large mounds found in the northern Porcupine Seabight appeared to have shoals of fish associated with their peaks(6). Aggregations of gravid females of the redfish *Sebastes viviparus* have been observed on the *Lophelia* reefs off the coast of Norway, suggesting the reefs are being used as spawning or nursery areas by some fish(13). Fish catches of *Sebastes marinus*, *Molva molva* and *Brosme brosme* were significantly higher in coral areas than on the surrounding seabed(14).

4.4 Exploitation value

Deep-water coral reefs are of great importance from a natural history perspective and as a new source of knowledge. In terms of environmental technology and medicine, they may also be useful. For example, fouling resistant substances may occur in corals and may possibly be used as an environmentally safer alternative to heavy metal compounds currently used in ship-bottom painting. In addition, antivirus substances have been found in sponges from tropical coral reefs. Reefs also have an important role in the earth's CO_2 balance via the calcium skeleton, which serves as a sink for dissolved CO_2 in seawater(15).

Buried carbonate reefs are favoured hydrocarbon prospecting targets as they have high porosity and the potential for containing large quantities of petroleum.

4.5 Biodiversity issues

Tropical coral reefs are considered to have the highest habitat diversity in the oceans and deep-water corals are no exception(3). More than 800 species have been recorded living on or in *L. pertusa* reefs in the NE Atlantic(3) although this may be an underestimation as few studies have been conducted in any detail. Nevertheless, the diversity of *L. pertusa* reef communities and those of some tropical shallow-water reef communities seem to be of a similar order of magnitude(3). However, the diversity of fish and mollusc species is much lower than in tropical coral reefs. Only 23 fish species have been recorded on *L. pertusa* reefs in the North-East Atlantic compared to ca. 3,000 species on reefs in the Indo-West Pacific region(3). In addition, the diversity of the framework building corals themselves is far less in deep-water reefs than on shallow tropical reefs.

Thirty-six taxa were found to live in and around the *Lophelia* reefs of the coast of Norway. Five of these taxa were only found on the corals and not on the adjacent seabed(12). There have been no studies of meiofaunal diversity associated with *L. pertusa*.

A detailed study of another deep-water reef-forming coral, *Solenosmilia variabilis*, was conducted on the Southern Tasmanian Seamounts(16). Of the 242 invertebrate species and 37 fish species identified on a few of these seamounts, most were associated with live or dead corals and at least 24-43% of them were new to science and many of them had not been recorded in Australian waters.

4.6 Potential / actual threats

Coral reefs are delicate structures that are easily destroyed. One of the major threats to the reef structures is demersal fisheries. Much of the coral habitat in the N.E. Atlantic region coincides with suitable seabed for trawling operations(3). Deep-sea trawlers operate to depths of 1,900 m. Reef damage has been documented in many areas and is likely to have occurred in many more areas.

Evidence of the extent of impacts of trawling is rather limited although side-scan sonar surveys from the eastern Porcupine Seabight and from the continental slope West of Shetland show evidence of trawl scouring on the seabed and damage to coral[17,18]. As *L. pertusa* occurs in these same regions, it is highly likely that it has been impacted heavily by deep-sea fishing. The total destruction of some *L. pertusa* reefs as a result of demersal trawling has been reported in shallower Norwegian waters around Storegga and present estimates suggest that 30-50% of Norwegian reefs have already been damaged or destroyed[15]. Growth rates of *L. pertusa* have been estimated from 4 – 25 mm per year[19] similar to some massive shallow-water coral species but slower than other massive branching corals. Slow growth may limit or prevent its recovery from reef damage. Substantial destruction of the reef-building coral, *Solenosmilia variabilis*, has been reported from southern Tasmanian Seamounts as a direct result of a trawl fishery for orange roughy (*Hoplostethus atlanticus*) and oreos (*Pseudocyttus maculates*, *Allocyttus niger*). The most heavily fished seamount consisted of >90% bare rock at most depths. Biomass and species richness were both drastically reduced. Should community recovery occur, it is likely to be a lengthy process[16].

Trawling will kill off the coral polyps and may break up the reef structure. Although new colonies can grow from broken fragments of coral, the increased sedimentation resulting from trawling can severely disrupt any re-growth. Coral feeding, respiration and settlement may be inhibited by this activity[3]. Many of the species associated with the coral reefs are also suspension feeders and the impact of sediment resuspension may have a similar effect upon these animals. Damage may decrease reef size and the abundance and diversity of fauna. In addition to direct effects of trawling upon the *L. pertusa* colonies, the removal of target fish species from the region may indirectly alter the community balance and may result in reef loss[3].

Oil exploration and production is currently occurring the areas where *L. pertusa* reefs are abundant in the N.E. Atlantic. Discharges of drilling mud and drill cuttings from these activities may negatively effect the corals. It is difficult to predict the area of drill cutting and mud dispersal and hence the magnitude of the impact upon local coral communities[3]. Studies in shallower waters have shown that contaminants from oil platforms may be detected in significant quantities up to 6,000 m from the installation, covering an area up to 100 km^2[20]. In deeper water operations where there is surface discharge of contaminants, the physical extent of contamination may be far greater[3]. In shallow water corals, drill cutting exposure has been shown to cause coral death, alter feeding behaviour, alter coral physiology and induce morphological changes[3]. In addition to drill cuttings, oil contamination has been shown to effect shallow-water coral communities, having toxic effects on corals resulting in reduced growth, tissue damage, disruption of cell structure, damage to stimuli response and feeding behaviour, excessive mucus production, alterations to reproductive success or mortality[21]. Recovery of *L. pertusa* reefs and their communities from the potential impacts of oil exploration and production may be extremely slow[3]. It should be noted that many colonies of *L. pertusa*, estimated to be around 15 years old, have recently been found growing on North Sea oil production installations built in the mid 1970s. These platforms are providing artificial substrates as for the corals and other organisms such as sponges and anemones[22].

Traditional methods of scientific sampling of deep-sea corals using dredges and trawls caused extensive impact to both the coral banks and surrounding seabed. New technologies in the form of ROVs and submersible vehicles cause far less damage using video techniques and benthic grabs but are expensive[23].

It has been reported that *L. pertusa* may be associated with hydrocarbon seeps, even though this is unproven[3]. Nevertheless, this theory may be a threat to the coral as it may be used as an indicator of underlying hydrocarbon reserves by the oil industry[3].

Lophelia colonies may be lost because of naturally occurring slumps and erosion (e.g the Storegga slide)[13] or as a result of climate change over long timescales.

References

1) Bett, B. Deep-Seas Group, George Deacon Division, Southampton Oceanography Centre, U.K.

2) Wilson, J.B. (1979). Patch development of the deep-water coral Lophelia pertusa (L.) on Rockall Bank. *Journal of the Marine Biological Association U.K.* **59**: 165-177

3) Rogers, A.D. (1999). The biology of Lophelia pertusa and other deep-water reef-forming corals and impacts from human activities. *International Review of Hydrobiology* **84**(4): 315-406

4) Bett, B.J. (1999). Cruise Report No.25 RRS Charles Darwin Cruise 112C, 19th May – 24th June, 1998. Atlantic Margin Environmental Survey: Seabed survey of the deep-water areas (17th Round Tranches) to the north and west of Scotland. NERC/University of Southampton. Published by Challenger Division for Seafloor Processes. Southampton Oceanography Centre, European Way, Southampton SO14 3ZH

5) Hovland, M., Croker, P.F. and Martin, M. (1994). Fault-associated seabed mounds (carbonate knolls?) off western Ireland and north-west Australia. *Marine Petrol. Geol.* **11**(2): 233-246

6) Kenyon, N.H., Ivanov, M.K. and Akmetzhanov, A.M. (1998). Cold water carbonate mounds and sediment transport on the Northeast Atlantic margin. Preliminary results from the geological and geophysical investigations during the TTR-7 cruise of R/V Professor Logachev in co-operations with the CORSAIRES and ENAM2 programmes July-August, 1997. Intergovernmental Oceanograhic Commission Technical Series 52 179pp. UNESCO, Paris, France.

7) Hentiet, J.P., De Mol, B., Pillen, S., Vanneste, M., Van Rouij, D., Versteeg, W., Croker, P.F., Shannon, P.M., Unnithan, V., Bouriak, S. and Chachkine, P. (1998). The Porcupine-Belgica 97 Shipboard Party, 1998. Gas hydrate crystal may help build reefs. *Nature* **391**: 648-649

8) Hovland, M., Mortensen, P.B., Brattegard, T., Strass, P. and Rokoengen, K. (1998). Ahermatypic coral banks off mid-Norway: evidence for a link with seepage of light hydrocarbons. *PALAIOS Research Reports V*(13): 189-200

9) Peckmann, J., Reitner, J. and Neuweiler, F. (1998). Seepage related or not? Comparative analysis of phanerozoic deep-water carbonates. TTR7 Postcruise meeting Conference. Carbonate Mud Mounds and Cold Water Reefs: Deep Biosphere – Geosphere coupling. 27

10) Van Dover, C.L., Desbruyeres, D., Segonzac, M., Comtet, T., Saldanha, L., Fiala-Medioni and Langmuir, C. (1996). Biology of the Lucky Strike hydrothermal field. *Deep-Sea Research* **43**: 1509-1529

11) Freiwald, A. (1998). Geobiology of Lophelia pertusa (Scleratinia) reefs in the North Atlantic. Habilitationsschrift zur Erlangung der venia legendi am Fachbereich Geowissenschaften der Univeritat Bremen 116pp

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

13) Gubbay, S. (1999). Offshore directory. Review of a selection of habitats, communities and species of the North-East Atlantic. WWF-UK, NEA Programme.

14) Fossa, J.H., Furevik, D.M., Mortensen, P.B. and Hovland, M. (1999). Effects of bottom trawling on Lophelia deep water coral reefs in Norway. Poster presented to the ICES workshop on the ecosystem effects of fishing. February 1999.

15) Kjolner, T. and Knoph, M.B. (1998). The conservation of coral reefs in Norwegian coastal waters. Bellona Working Paper No.1
webpage http://www.bellona.no/imaker?sub=1&id=12784

16) Koslow, J.A. and Gowlett-Holmes, K. (1998). The seamount fauna of southern Australia: benthic communities, their conservation and impacts of trawling. Report to Environment Australia and the Fisheries Research Development Corporation. FRDC Project 95/058

17) Kenyon, N.H. and the Shipboard Scientific Party of RV Professor Logachev TTR7 Cruise, 1999: Abstract. Effects of bottom trawling in deep water, west of Ireland and Scotland. In: Friend, P. and N. Kenyon (eds.). North-East Atlantic Slope Processes: Multi-Disciplinary Approaches. Incorporating IGCP Workshop 432, Contourites and Bottom Currents. 24th – 27th January. Southampton Oceanography Centre, Southampton, U.K. 45pp.

18) Wheeler, A..J., Bett, B.J., Billett, D.S.M. ,Masson, D.G. and scientific party, officers and crew of Discovery 248 (2000). Very high resolution side-scan mapping of deep-water coral mounds: surface mapping and processes affecting growth. Abstract AGU Fall Meeting, 2000, San Fransisco, USA

19) Mortensen, P.B. and Rapp, H.T. (1998). Oxygen and carbon isotope ratios related to growth line patterns in skeletons of Lophelia pertusa (l.) (Anthozoa, Scleractinia): implications for determination of linar extension rates. *Sarsia* **83**: 433-446

20) Olsgard, F. and Gray, J.S. (1995). A comprehensive analysis of the effects of offshore oil and gas exploration and production on the benthic communities of the Norwegian continental shelf. *Marine Ecological Progress Series* **122**: 277-306

21) Loya, Y. and Rinkevich, B. (1980). Effects of oil pollution on coral reef communities. *Marine Ecological Progress Series* **3**: 167-180

22) Shimmield, GB. (1999). Deep-water corals growing on North Sea oil structures. *The Scottish Association for Marine Science Newsletter* **20**: 3

23) Roberts, J.M., Mortensen, P.B. and Sundt, R.C. (2000). No more dredging in the dark – towards less damaging methods of sampling cold water corals. First International Symposium on Deep Sea Corals, Halifax, Nova Scotia. July 30 – Aug 2 (2000).

5. POLYMETALLIC NODULES

Figure 7 ***(1)*****:** *Polymetallic nodule ('cauliflower' type).*
(Thiel, H., Schriever, G., Bussau, C. and Borowski, C. (1993). Manganese nodule crevice fauna. Deep-Sea Research ***40****(2): 419-423)*

5.1 Introduction and habitat characteristics

Deep-sea polymetallic nodules were first discovered southwest of the Canary Islands in the nineteenth century during the HMS "Challenger" expedition of 1872-1876. Polymetallic nodules, commonly referred to as either manganese or ferromanganese nodules, are potato-shaped concretions which range in size from 1 cm up to ca. 25 cm in diameter. They vary not only in size but also in shape, texture, abundance, coverage and chemical composition. These variations may occur over relatively small distances[2]. There has been much debate with regards to their origin and formation. This has stimulated research in the physical, chemical and biological parameters that control the variability seen in nodules. It is thought that the amount of organic matter falling from surface waters, the calcium carbonate compensation depth and biogenic silica production all exert some influence. The decay of organic matter promotes chemical reactions, which concentrate a number of chemical elements in the nodules. The precise latitude of the peak concentration depends on interference with these reactions from the redissolving of $CaCo_3$ at depth, and from the presence of biogenic silica. All nodules contain a core or nucleus comprising some foreign material e.g. sharks teeth, fish bones, basalt fragments or, most commonly, fragments of other nodules[2,3]. New nodule material accretes upon the nuclear material. Accretion rates vary, but are typically slow, in the order of a few millimetres per million years[4].

Nodules are typically rounded and may be elongated or flattened[4]. Young nodules tend to undergo fairly uniform accretion on all sides. As they grow larger, they tend to sink into seafloor sediment and they therefore become rather more flattened. The surface of nodules ranges from smooth to coarse, depending upon accretion conditions[5]. Nodules with smooth surfaces are common in the vicinity of seamounts, where substantial local currents preclude high sedimentation.

Polymetallic nodules are composed of varying amounts of nickel (Ni), copper (Cu), cobalt (Co), manganese (Mn), all of which are valuable. They also contain many other metals including gold (Au), silver (Ag), platinum (Pl), titanium (Ti), molybdenum (Mo) and zinc (Zn), but in small quantities.

5.2.Global distribution

Polymetallic nodules occur in all oceans as well as in certain freshwater environments. Nodules and polymetallic crusts can be found over a vast area of the deep-sea floor[6]. Nodules often form flat horizontal fields at depths between 4,000 and 6,000 m. Nodule abundance depends strongly on sedimentation rates, with the most abundant deposits occurring where sedimentation is the lowest, such as in the Pacific[7].

The nodules with the greatest commercial value are found in the Pacific and Indian Oceans. In the Pacific Ocean, the majority of nodules are concentrated in the central abyssal basins[8]. In the Indian Ocean, polymetallic nodules are most abundant south of the Equator, in basins to the east and west of the Ninety Degree Ridge. Areas that show moderate to high nodule coverage are the Central Indian Basin, the Crozet Basin, the Agulhas Plateau, the Wharton Basin, the Madagascar Basin, the South Australian Basin, and the Mozambique Ridge and Channel[9]. Some correlation is seen between nodule morphology, chemical composition, seafloor topography and distribution patterns[4].

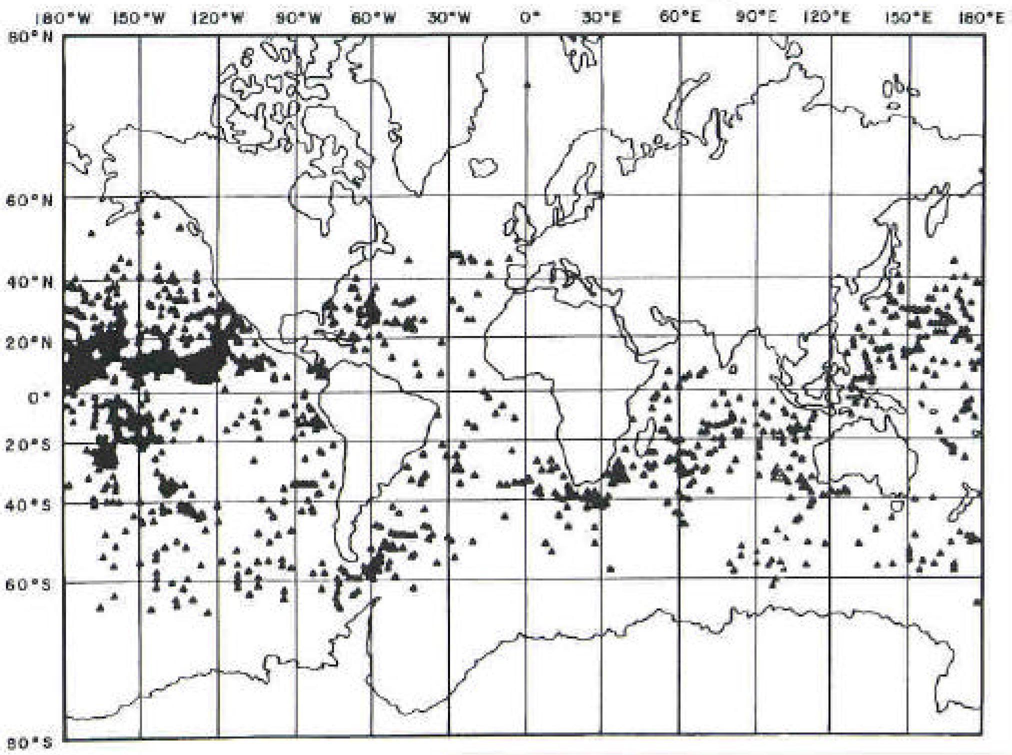


Figure8* [4]*: Global distribution of polymetallic nodules.
(Thiel, H., Angel, M.V., Foell, E.J., Rice, A.L. and Schriever, G. (1997). Environmental risks from large-scale ecological research in the deep sea. Commission of the European Communities Directorate-General for Science, Research and Development. 210 pp)

5.3 Associated fauna

The surfaces of some forms of polymetallic nodules are inhabited by diverse epifauna composed of bacteria, protozoa and metazoa, typically hard-bottom taxa[10,6,1]. In one study, up to 20% of the nodule surface was covered by eukaryotic organisms. Foraminifera are the predominant taxonomic group associated with nodules, both in terms of number of individuals and percentage cover[6]. Suspension-feeding metazoans, and rhizopod protozoans suspected of suspension feeding, are common fauna. This hard-substrate community is diverse, abundant and geographically widespread[6]. Because of the relatively large size and abundance of the organisms attached to nodules, their contribution to the benthic community interactions and to benthic fluxes may be substantial relative to adjacent sediment-dwelling organisms[6]. Nodule size may influence the type and number of sessile taxa occurring in a given region. The lowest populations of megafauna were noted in areas with large numbers of small densely packed nodules. Areas with fewer but larger nodules offered the best conditions for both sessile and free-living organisms[11].

Fauna are also found to inhabit the crevices and interstitial space between sub-nodules (at least of the botryoidal or cauliflower type). The maximum density of total crevice fauna was found to be 170 within one nodule. The faunal composition was primarily nematodes but also present were harpacticoids and their nauplii, polychaetes, tanaids, tardigrades, isopods, echiurans and sipunculands[1].

5.4 Exploitation value

The enormous potential value of nodules as metal ores was first seriously considered following the publication of 'The Mineral Resources of the Sea'[(12)]. The amount of Ni, Co and Mn contained in oceanic nodule deposits is thought to greatly exceed the known terrestrial reserves[(4)]. This has stimulated considerable commercial and industrial attention to nodule mining. The economic feasibility of mining polymetallic nodule deposits is assessed in terms of their abundance and ore grade. The higher the average concentration of value metals such as Cu, Ni and Co, the greater the commercial value of the deposit. Depending upon the current market value of these metals, typically, nodules with combined Cu and Ni concentrations >2% are considered to be at the minimum level to justify commercial interest[(4)]. In the Clarion-Clipperton Fracture Zone (CCFZ - also known as the Nodule Belt), between Hawaii and Mexico, an area of 5 million km^2, it has been estimated that 5-10 billion tons of nodules could be exploited from the estimated 30 billion tons that occur here. These deposits appear to be the best in the world in terms of commercial value, with good to very good metal assays[(13)]. Nodules around the Cook Islands also occur at high abundance and are of high ore grade and hence are of great interest to the mining industry[(14)].

Studies conducted in the USA are examining the feasibility of using the high platinum content nodules of the Blake Plateau off the USA southeast coast (Georgia and northern Florida) as a catalytic stack gas cleaner in coal-fired power plants[(15,16)]. The reduced nodule material could then be further processed for value metals.

As it stands today, from a technological point of view, nodule mining is feasible. However, present metal prices and mineral recycling excludes commercial deep-sea mining in the very near future[(17)].

5.5 Biodiversity issues

The presence of nodules on the seabed provide hard substratum that enhances local/regional diversity. Overall, the crevice fauna is distinctly different from the ooze fauna surrounding the nodules.

5.6 Potential / actual threats

In order to achieve economically sound nodule mining, thousands of square kilometres of relatively flat seabed, with few obstructions in terms of outcroppings or slopes, are needed for dredging[(4)]. For a reasonable return, it has been calculated that around 1km^2 of seafloor will be mined on a daily basis, or about 6,000 km^2 over the life of a 20 year mine site[(18)]. Most of the current claim applications for nodule mining are in excess of 100,000 km^2 in area. These initial claims are large to account for the relatively small percentage of the area to be exploitable[(4)].

A number of nodule mining techniques have been proposed over the past 30 or so years ranging from a simple continuous line and bucket system[(19)] to autonomous robot submersible shuttles[(20)]. The present industrial consensus favours nodule recovery by a riser system pump[(17)]. Each of these proposed techniques entails some degree of environmental disturbance. However, the actual impacts remain poorly studied and rather unpredictable[(4)].

One of the major problems associated with any form of nodule mining is sediment plume generation both on the seabed and from particle-laden water discharged from the mining platform[(21)]. Sediment plumes generated by nodule mining operations may have a large-scale environmental impact. Currents may redeposit plume particles some unknown distance from the mining site. The scale of these impacts will be related to local hydrodynamics, particle characteristics and mining technique used. A crude estimation of sediment volume that may be mobilised during one day of nodule mining (not including discharge from the mining platform) has been calculated as 2×10^4 m^3[(18)]. This sediment may bury organisms and their food supply, may clog respiratory surfaces of filter feeders and may change the upper sediment structure. Near-bed plumes are likely to cause the partial destruction of the local sediment fauna and the total destruction of suspension-feeding nodule fauna. In addition toxic substances may be mobilised within the disturbed sediment, which may be consumed by organisms or decrease dissolved oxygen levels. This may lead to anaerobic conditions and sub-lethal and lethal impacts on the fauna. The impact of such sedimentation upon the surrounding benthos remains largely unknown(26), and is also an effect associated with deep-sea trawling activity(28).

Sediments discharged from the mining platform may have an impact not only on the benthos but also on the surrounding planktonic community, including fish and their larvae. Depending upon the plume magnitude, processes such as primary production may well be affected. An increase in food supply may also result in the form of benthic animals being released in surface waters. This process would also introduce deep-sea microbes into surface waters. However, the mining tailings impact could be eliminated by directing the sediments via long pipelines into deep waters(17). Alternative innovative proposals have also been suggested for mining tailings disposal to reduce potential environmental damage. It has been suggested that tailings can be made into useful construction products. These include tiles, ceramics, coatings, resin castings for plumbing fixtures, additives to strengthen concrete, stack gas cleaners, rust-proofing and anti-biofouling coatings(22).

The main tests and experiments, which have been conducted to date in order to assess the potential environmental impact of nodule mining, are (chronologically):

1. Tests in early seventies (Blake Plateau, North Atlantic, Deep-sea Ventures Inc. (DVI), USA, 1970; The Bermuda Rise Study, IDOE/NSF, USA, 1972; The Continuous Line Bucket Mining Test Study, Pacific, Japan-USA-France, 1972)
2. The Deep Ocean Mining Environmental Study (DOMES) Project, NOAA, Clarion-Clipperton Fracture Zone (CCFZ), USA, 1975-1980.
3. The Ocean Management Inc. (OMI) pre-pilot mining test, DOMES Site A, (USA) 1978.
4. Ocean Mining Associates (OMA) / Deep-sea Ventures Inc. (DVI) pre-pilot mining test, DOMES Site C, (USA) 1978.
5. The MESEDA Program, Atlantis Deep, Red Sea (BMFT Germany/Saudi-Sudanese Red Sea Commission, the program depicted metalliferous sediments) (1977-79).
6. Chatham Rise phosphorite nodules (Germany/New Zealand), 1978.
7. ECHO-1 Expedition, Scripps Institution of Oceanography, NOAA, NSF, at OMA test site (DOMES Site C), (USA) 1983.
8. The Acute Mortality Experiment, NOAA, Santa Catalina Basin, (USA) 1987.
9. QUAGMIRE II Expedition, Scripps Institution of Oceanography and NOAA, OMA / DVI test site (DOMES Site C), (USA) 1990.
10. DISCOL Expedition, Peru Basin, TUSCH Research Group, BMFT, (Germany) 1989-96.
11. Benthic Impact Experiment (BIE), NOAA (Ocean Minerals and Energy Division) and international group (USA, Russia, Japan), 1993-94 (BIE-I: 1991-92, unsuccessful, BIE-II: 1993-94).
12. Japan Deep Sea Impact Experiment (JET), Clarion-Clipperton Zone, Metal Mining Agency of Japan, Japan (and Russia) 1994.
13. IOM test in summer 1995 in eastern CCFZ (Interoceanmetal consortium).

There were also numerous expeditions in the areas of potential ocean mining, without the character of a specially organised mining test or experiment, conducted by East-European (Interoceanmetal), French, German, Indian, Japanese, Korean, New Zealand and Russian consortia, national organisations and various scientific groups(17).

The DOMES project in the 1970s was conducted in the CCFZ region as a precursor to nodule mining activities. Post-DOMES experiments concentrated on bottom sedimentation and seafloor destruction and all were small scale. The general conclusions from these studies (so far) showed that a few centimetres of sediment coverage was sufficient to cause a near total burial and mortality of the benthic fauna. However, recolonisation of disturbed areas was apparently completed within a few years[(23)]. The DISCOL experiments in the Peru Basin reported high benthos abundance after 3 years in an artificially disturbed area compared with pre-experimentation abundance[(24,25)]. However, significant displacement of Macrofaunal depth distributions were evident after the 3 years and indicated sustained disturbance effects with significantly reduced diversity[(26)]. In addition, the near-total removal of nodules during mining will destroy the hard bottom habitat and result in the formation of a pure soft bottom community of lower diversity[(27)].

In 1994, in the Japanese mining claim area in CCFZ, an environmental impact assessment - Japan Deep-Sea Impact Experiment (JET) - was initiated by the Metal Mining Agency of Japan to evaluate the effects of sediment resuspension and redeposition resulting from deep-sea mining. 352 tonnes of sediment were dredged, discharged and resuspended using a 'benthic disturber'. The abundance of meiofauna was monitored before, just after, and one and two years after the JET experiment in areas without deposits, and in those with light, moderate, and heavy deposits. In the post-disturbance survey two years after the experiment, the macro- and megabenthos were also studied. Immediately after the experiment, the abundance of meiofauna decreased drastically where deposition had occurred, but by two years later numbers had returned to original levels and differences were not found between affected and control areas. In contrast, the abundances of certain groups of macro- and megabenthos were lower in the affected area than in the control area.

In conclusion, commercial deep-sea mining for polymetallic nodules will have a significant impact on deep-sea benthic and pelagic communitites[(27)]. The rate of recolonization of disturbed areas will depend on the area swept for polymetallic nodules and on the timing and intensity of mining events.

References

1) Thiel, H., Schriever, G., Bussau, C. and Borowski, C. (1993). Manganese nodule crevice fauna. *Deep-Sea Research* **40**(2): 419-423

2) Siebold, E. (1978). Deep sea manganese nodules. The challenge since "Challenger". *Episodes* **4**: 3-8

3) Halbach, P.E., Friedrich, G., von Stackelberg, (1988). The manganese nodule belt of the Pacific Ocean: geological environment, nodule formation and mining aspects. F. Enke Verlag, Stuttgart, 254pp.

4) Thiel, H., Angel, M.V., Foell, E.J., Rice, A.L. and Schriever, G. (1997). Environmental risks from large-scale ecological research in the deep sea. Commission of the European Communities Directorate-General for Science, Research and Development. 210 pp.

5) Sorem, R.K. and Fewkes, R.H. (1979). Manganese nodules – research data and methods of investigation. IFI/Plenum Press, New York. 723pp.

6) Mullineaux, L.S. (1987). Organisms living on manganese nodules and crusts: distribution and abundance at three North Pacific sites. *Deep-Sea Research* **34**(2): 165-184

7) Frazer, J.Z. and Fisk, M.B. (1981). Geological factors related to characteristics of sea-floor manganese nodule deposits. *Deep-Sea Research* **28**: 12a

8) Skornyakova, N.S., Bischoff, J.L. and Piper, D.Z. (1979). Zonal regularities in occurrence, morphology and chemistry of manganese nodules of the Pacific Ocean. In: Marine geology and oceanography of the Pacific manganese nodule province. Plenum, New York: 699-728

9) Cronan, D.S. (1992). Marine Minerals in Exclusive Economic Zones. [Topics in Earth Science 5]. Chapman and Hall, London. 209 p

10) Murray, J. and Renard, A. (1891). Manganese nodules: In: Report of the scientific results of the voyage of the HMS Challenger vol.5 C.W. Thomson ed. Eyre and Spottiswoode, London 341-378

11) Foell, E.J., Hennigar, H.F. Jr., Pawson, D.C. (1989). Assessment of abyssal benthic megafauna on a ferromanganese nodule deposit using videotaped television survey data. Offshore Technology Conference 1989 2 (5996): 313-320

12) Mero, J.L. (1965). The Mineral Resources of the Sea. Elsevier Oceanography Series 1. Elsevier, New York 312 pp.

13) Amann, H. and Beiersdorf, H. (1993). The environmental impact of deep sea mining. In "25th Annual Offshore Technology Conference" vol.1 "Geology, Earth Sciences and Environment". 231-231. Houston, Texas.

14) Bechtel Corporation 1996. Deep-sea nodule mining pre-feasibility study (Executive summary). Bechtel Corp. Mining and Metals, San Fransisco, CA. 24pp.

15) Woolsey, J.R. (1992). Offshore minerals for flue gas desulfurization and by-product strategic metals and superphospate fertilizer. Abstract, 23rd Underwater Mining Institute, Washington DC Sept. 27-29, 1992

16) Buchannon, R.C. (1995). A model of the economic feasibility of utilizing Blake Plateau manganese nodules for desulfurization and metals recovery. Unpublished Ph.D. dissertation, University of Mississippi 91pp.

17) Jankowski, J.A. and Zielke, W. (1996). Data support for the deep-sea mining impact modelling. Report. Institut für Strömungsmechanik und Elektronisches Rechnen im Bauwesen der Universität Hannover.

18) Thiel, H., Foell, E.J. and Schriever, G. (1991). Potential environmental effects of deep seabed mining. Ber. Zentrum Meeres. U. Klimaforsch. University of Hamburg 26: 1-243

19) Masuda, Y., Cruickshank, M.J. and Mero, J.L. (1971). Continuous bucket-line dredging at 12,000 feet. Proceedings of the Offshore Technology Conference, Houston, Texas 19-21 April 1971. Vol. 1 (OTC paper 1410): 837-858

20) Moreau, J.P. (1984). La construction navale et les projects miniers en mer. Proceedings of the 2nd International Seminar on the Offshore Mineral Resources, Germinal, Brest, France: 427-440

21) Amos, A.F., Garside, C., Haines, K.C. and Roels, O.A. (1972). Effects of surface-discharged deep sea mining effluent. *MTS Journal* **6**(4): 40-45

22) Wiltshire, J.C. (1995). Innovative tailings management for marine ferromanganese nodule and crust processing. Oceans '95: Challenges of our changing global environment. MTS/IEEE, New York vol2: 723-730

23) Smith, C., Bennet, B., and Brumsicle, S., 1988. Assessment of benthic faunal sensitivity to rapid sediment burial at DOMES Site C. I. Final Report to NOAA/OME, University of Washington, Seattle, WA. 14 pp.

24) Thiel, H., and Schriever, G., 1989. Cruise report DISCOL 1, SONNE-cruise 61. Report Nr. 3, Zentrum für Meeres- und Klimaforschung der Universität Hamburg. 75 pp. 90.

25) Thiel, H., and Schriever, G., 1990. Deep-sea mining, environmental impact and the DISCOL project. *AMBIO*, **19**(5), 245-250

26) Borowski, C. & Thiel, H. (1998) Deep-sea macrofaunal impacts of a large-scale physical disturbance experiment in the Southeast Pacific. *Deep-sea Research II* 45: 55-81

27) Bluhm, H. (1993). Effects of deep-sea mining for manganese nodules on the abyssal megabenthic community. Proceedings of the 25th Annual Offshore Technology Conference, Houston, Texas 3-6 May, 1993 vol.1 (OTC Paper 7134): 521-529

6. COLD SEEPS AND POCKMARKS

6.1 Introduction and habitat characteristics

The dynamic geological process of seabed 'seepage' encompasses everything from the vigorous bubbling of gas from the seabed to the small-scale emanation of microscopic bubbles or hydrocarbon compounds in solution. Seep fluid may be of hydrocarbon, hydrothermal or volcanic origin, or it may simply represent a groundwater escape. Seeps are related to a variety of geological processes: tectonically induced high-fluid pressures, petroleum or natural gas escape, artesian flow or catastrophic sediment slumps and slides(2). These seepages may be highly localised or diffuse(2) and continuous or intermittent, some only occurring as short bursts once or twice per year(3). Fluid seepage through some sediment types leads to the formation of 'pockmarks'. Seabed pockmarks were first reported from the continental shelf off Nova Scotia, Canada having been originally detected by side-scan sonar(4). The discovery of these pockmarks was the first evidence of seabed seepage. Subsequently, many other areas have been found to be heavily cratered with these features, e.g. the North Sea. Pockmarks vary in size and shape, both within and between areas. Circular and elliptical pockmarks are the most common. Pockmarks can measure several hundred meters in diameter and can be depressed tens of metres below seabed level. Their shape and size depend on sediment type and the gas and pore-water seepage rate(3). Pockmarks are most common in soft, muddy sediments. Relict pockmarks, i.e. where seepage has ceased and the crater has been infilled, are also known(5). Pockmark craters may contain hard substrata, both rocks exposed by the expansion of overlying fine sediments and 'cemented' sediments formed by chemical reaction with the escaping seep fluids(3).

Seep research was primarily instigated because of their hazard potential to the offshore petroleum industry in terms of blow-outs during drilling operations(3). Subsequently, non-pockmarked seepage areas have been discovered with novel biological communities. The first discovery of cold-seep organisms on a passive margin (i.e. non-tectonic) was on the Florida escarpment in the Gulf of Mexico at ca. 3,000 depth(6). Here, seepage is characterised by hypersaline cold sulphide fluids. The biological community present covered an area some 30 m wide and 1,500 m long. On the Louisiana slope in the Gulf of Mexico, and on the continental slope off California, hydrocarbon seeps were found to support abundant communities of mussels(7,8). Rich cold-seep communities have also been found on active margins (some associated with trenches) down to depths of 6,000 m. Cold-seeps also occur along the Laurentian fan at ca. 4,000 m and they may be linked to a major slope failure assumed to have been originally triggered by an earthquake(9).

At cold-seeps, methane-rich fluid of thermogenic and/or biogenic origin is the principal source of energy for the associated biological communities, although sulphide (produced by sulphate reduction in the sediment) may also play a major role(2). Biogenic fluids are the product of microbial organic matter decomposition in anoxic sediment layers, whereas thermogenic fluids are produced by high temperature, fast transformation of deeply buried organic matter(2).

A correlation has been proposed between seepages and global biological productivity. With the contributions from all submarine seepages (including hydrothermal vents), it is clear that a substantial contribution to the marine biomass is made by chemosynthesis(3).

6.2 Global distribution

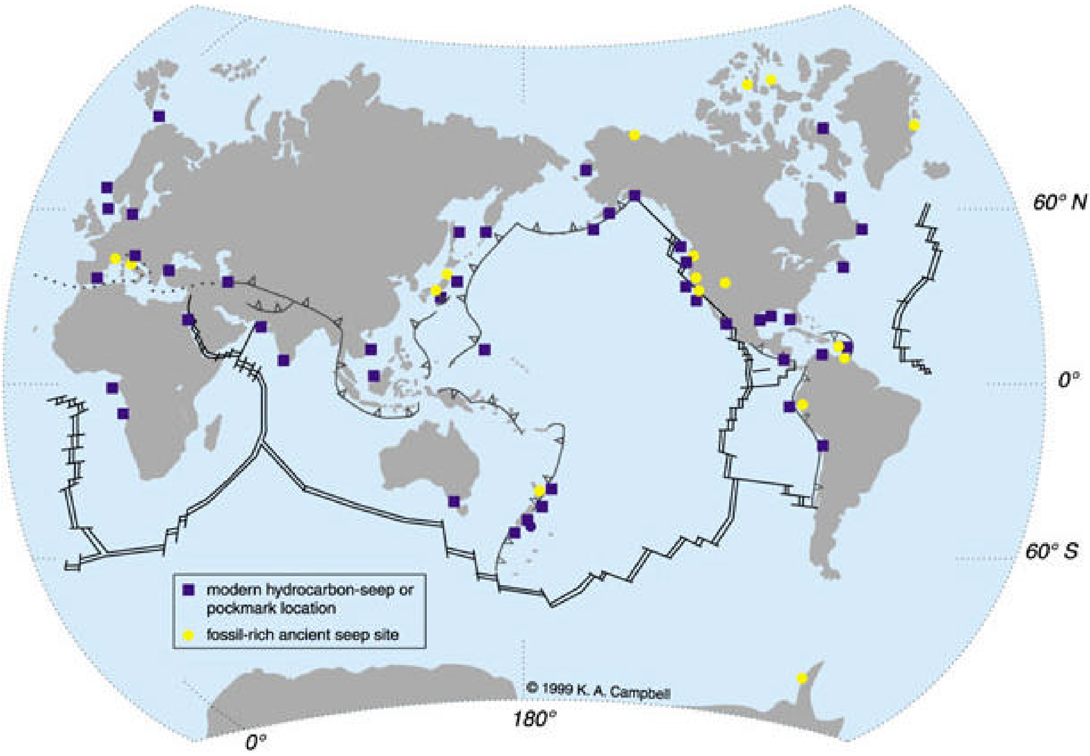


Figure 9 **[19]:** *Global distribution of seeps.*
(http://www.ldeo.columbia.edu/margins/seeps_workshop.html#fig1)

Seabed seepages occur in all the world's oceans and are associated with a wide variety of geological settings: on the continental shelf; in the deep ocean; and on the intervening slope[3,2]. Figure 9 shows the seepage areas known to date; however, most deep-sea areas have not been surveyed and the absolute number of seeps is not known and difficult to evaluate.

6.3 Associated species

As with hydrothermal vents (section 1), cold-seeps fuel chemosynthetic-based benthic communities. Cold-seep communities have been explored in 24 seep areas ranging in depth from 400 to 6,000 m in the Atlantic Ocean, east and west Pacific Ocean and in the Mediterranean sea[2]. The dominant seep species comprise large bivalves from the families Vesicomyidae and Mytilidae. Of the 211 species inventoried, 64 (ca. 30%) host microbial symbionts and most are new to science. These animals rely on methane or sulphide oxidation, or both, via chemoautotrophic endosymbiotic bacteria. Biological production at cold-seeps is related to the intensity of the fluid flow[10,11,12,13]. Large flow rate variations have been observed, both within and between seep areas[10].

A recent discovery has been made of a polychaete worm (Hesionidae) living in great densities on the surface of exposed methane hydrates in the Gulf of Mexico. At present, the worms' dependence upon the fluids is not clear[14]. Dense biological communities dominated by mussels have also be photographed around gas hydrates on a passive margin off North Carolina over the Blake Ridge diapir at depths of ca. 2000 m[15].

6.4 Exploitation value

Seep communities are of great value scientifically. Many new species have been discovered in these habitats over the past 20 years. Ecological studies remain to be undertaken both inside and outside seep areas to quantify the impact of seeps on the deep ocean[2].

Bacteria from seeps may contain novel genes which may be useful to the biotechnology industry. For example, applications such as the bioremediation of oil pollution may be of particular interest.

Seepages may be used alongside other methods as a prospecting tool for the petroleum industry[3]. Seepages themselves may become of economic interest in the future, if high-grade mineral-laden fluids expelled from the seabed can be tapped. Several patents exist for the direct harvest of seepage minerals from point sources on the seabed[3].

6.5 Biodiversity issues

The large majority of seep fauna are endemic to single seep sites and to the cold-seep ecosystem. Of the 211 species so far reported, only 13 species occur at both seeps and vents[2]. Most symbiont-containing species are endemic to a single seep site. However, vestimentiferan worms and *Calyptogena* clams have been found at cold-seep sites in both the Pacific and Atlantic Oceans. Conversely, bathymodiolid mussels are not found in the Pacific seep sites. It has been suggested that barriers to larval migration may exist or there has been insufficient migration from the Atlantic[2]. Other workers have suggested that methane seepage rates may be slower and unable to support the mussels[16,17]. Seep communities typically have a higher diversity than hydrothermal vent sites. This may be explained by the fluid flow duration, the sediment habitat and seep evolution[2]. Seeps are also a less extreme habitat for species to adapt to. The community patch size is generally <20 m^2 and frequently ca. 0.5 to 2 m^2. However, there are exceptions in the Gulf of Mexico and in the Peru Trench where much larger patches up to 6,000 m^2 exist. These large patches are thought to be a function of regular and diffuse fluid expulsion[12].

6.6 Potential / actual threats

The Gulf of Mexico is a rich oil and gas province[18] that is characterised by extensive seepage[2]. The biological communities associated with these seeps are wide-spread and may be effected by physical disturbance caused by benthic trawling activities or destructive scientific investigation.

References

1) http://www.gomr.mms.gov/homepg/regulate/environ/chemo/chemo.html

2) 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**(1-3): 517-567

3) Hovland, M. and Judd, A.G. (1988). Seabed Pockmarks and Seepages. Impact on Geology, Biology and the Marine Environment. Graham and Trotman, London. 293pp.

4) King L.H. and MacLean, B. (1970). Pockmarks on the Scotian Shelf. *Geological Society American Bulletin* **81**: 3141-3148

5) Long, D. (1992). Devensian Late-glacial gas escape in the central North Sea. *Continental Shelf Research* **12**(10): 1097-1110

6) Paull, C.K., Hecker, B., Commeau, R., Freeman-Lunde, R.P., Neumann, A.C., Corso, W.P,. Golubic, S., Hook, J.E., Sike, E. and Curray, J. (1984). Biological communities at the Florida escarpment resemble hydrothermal vent taxa. *Science* **226**: 965-967

7) Kennicutt, M.C., Brooks, J.M., Bidigare, R.R., Fay, R., Wade, T.L. and McDonald, T.J. (1985). Vent type taxa in a hydrocarbon seep region on the Louisiana slope. *Nature* **317**: 351-353

8) Kennicutt, M.C., Brooks J.M., Bidigare, R.R., McDonald, S.J., Adkison, D.L. and Macko, S.A. (1989). An upper slope "cold" seep community: Northern California. Limnology and Oceanography 34(3): 635-640

9) Mayer, L.A., Shor, A.N., Hughes-Clarke, J. and Piper, D.J.W. (1988). Dense biological communities at 3850 m on the Laurentian Fan and their relationship to the deposits of the 1929 Grand Banks earthquake. *Deep-Sea Research* **35**(8A): 1235-1246

10) Henry, P., Foucher, J-P., Le Pichon, X., Sibuet, M., Kobayashi, K., Tartis, P., Chamot-Rooke, N., Furuta, T. and Schultheiss, P. (1992). Interpretation of temperature measurements from the Kaiko-Nankai cruise: Modelling of fluid flow in clam colonies. *Earth and Planetary Science Letters* **109**(3-4): 355-371

11) Sibuet, M., Fiala-Médioni, A., Foucher, J.P. and Ohta, S. (1990). Spatial distribution of clam colonies at the toe of the Nankai acretionary prism near 138^{o}E. In: J.P. Cadet and X. Le Pichon (eds.) International conference on fluids in subduction zones and related processes, Paris Nov 5-6, 1990. Ecole Normale Supérieure, Paris.

12) Olu, K., Duperret, A., Sibuet, M., Foucher, J-P. and Fiala-Medioni, A. (1996a). Structure and distribution of cold seep communities along the Peruvian active margin: Relationship to geological and fluid patterns. *Marine Ecology Progress Series* **132**(1-3): 109-125

13) Olu, K., Sibuet, M., Harmegnies, F., Foucher, J-P. and Fiala-Medioni, A. (1996b). Spatial distribution of diverse cold seep communities living on various diapiric structures of the southern Barbados prism. *Progress in Oceanography* **38**(4): 347-376

14) Fisher, C. (2000). Pennsylvannia State University, USA. Pers. comm.

15) Paull, C.K., Ussler, W. III., Borowski, W.S. and Spiess, F.N. (1995). Methane-rich plumes on the Carolina continental rise: Associations with gas hydrates. *Geology* **23**(1): 89-92

16) Barry, J.P., Greene, H.G., Orange, D.L., Baxter, C.H., Robinson, B.H., Kochevar, R.E., Nybakken, J.W., Reed, D.L. and McHugh, C.M. (1996). Biologic and geologic characteristics of cold-seeps in Monterey Bay, California. *Deep-Sea Research I* **43**: 1739-1762

17) Barry, J.P., Kochevar, R.E. and Baxter, C.H. (1997). The influence of pore-water chemistry and physiology in the distribution of vesicomyid clams at cold-seeps in Monterey Bay: implications for patterns of chemosynthetic community organization. *Limnology and Oceanography* **42**: 318-328

18) Brooks, J.M., Cox, H.B., Bryant, W.R., Kennicutt, M.C., Mann, R.G. and McDonald, T.J. (1986). Association of gas hydrates and oil seepage in the Gulf of Mexico. *Organic Geochemistry* **10**(1-3): 221-234

19) http://www.ldeo.columbia.edu/margins/seeps_workshop.html#fig1

7. GAS HYDRATES

7.1 Introduction and habitat characteristics

Gas hydrate is a gas (predominantly methane) that is housed within the crystalline cage structure of ice. It is packed at very high densities – around 160 times greater than gas at normal atmospheric pressures. Thus, $1m^3$ of methane hydrate may contain about 160 m3 of methane gas[(2)]. These hydrates look like dry ice but will burn. Gas hydrate in marine sediments is composed mostly of methane (methane usually comprises >99% of the hydrocarbon gas mixture) that has been produced largely by biogenic activity (bacterial methanogenesis) at moderately low temperatures and high pressures. This renders the methane in oceanic hydrate deposits virtually free from liquid petroleum and condensates, and allows them to be considered as having a very low potential for pollution hazard[(3)]. Methane can also be formed by abiotic processes at elevated temperatures and pressures (e.g. thermal breakdown of organic matter, crustal and hydrothermal processes). Naturally occurring gas hydrate was first discovered in the 1960s by Russian scientists exploring for gas in permafrost regions of northern Russia.

7.2 Global distribution

Stable gas hydrate occurrence is restricted to the shallow depths in the earth's crust. They may be found in three distinct global locations[(4)]:

1. in polar regions, where temperatures are cold enough for onshore and offshore permafrost to be present
2. in offshore sediment where there are cold bottom-water temperatures and water depth exceeds 300-500 m
3. in deep-water environments of inland lakes and seas (>300 m depth)

These regions have the necessary temperature and pressure environments to enable gas hydrate formation, (high temperature environments require high pressures whereas low temperature conditions need only low pressures) and an abundance of methane (CH^4) present. Methane accumulates in continental margin sediments as this is where the flux of organic carbon to the seafloor is greatest and organic detritus from the continents also tends to collect. Sedimentation rates are fast on the continental margins and the accumulated sediment covers and seals the organic material before it is oxidised. It is then available to bacteria in the sediment to use as a substrate, forming methane that becomes incorporated into gas hydrate. The worldwide occurrence of known and inferred gas hydrate is shown in Figure 10.

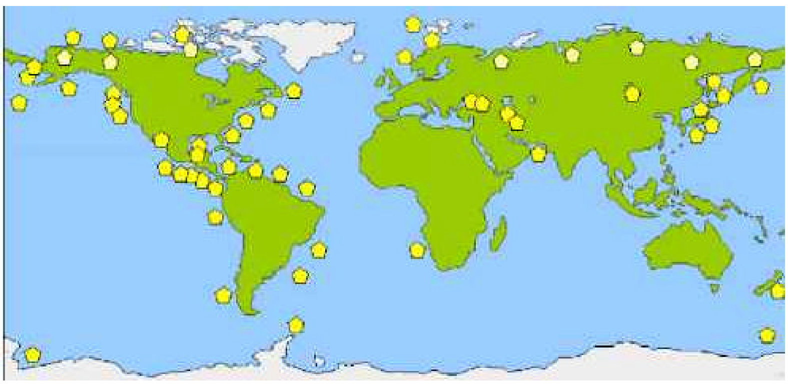


Figure 10 ***[(22)]*: *Gas hydrate structure***
(http://woodshole.er.usgs.gov/project-pages/hydrates/where.html)

Samples of gas hydrate have been found at about 30 oceanic locations. They have been recovered via deep-ocean drilling in offshore locations from Peru, Costa Rica, Guatemala, Mexico, western and eastern United States, Japan and in the Gulf of Mexico. Gas hydrates at or near the seafloor have been recovered at locations in the Black Sea, Caspian Sea, Sea of Okhotsk, offshore from northern California, Oregon, Nigeria, in the northern Gulf of Mexico, offshore Norway[(6)] and offshore Oregon[(7)]. Most oceanic occurrences of gas hydrates are inferred, based mainly on the appearance on marine seismic reflection profiles of an anomalous bottom-simulating reflection (BSR). BSRs were used to infer gas hydrate presence before any gas hydrate was ever recovered from oceanic sediment. Today, more than 60 sites are known worldwide where gas hydrate occurs in oceanic sediment based on BSRs and/or sample recovery[(3)].

7.3 Associated species

In July 1997, polychaete worms, *Hesiocaeca methanicola*, were found on exposed gas hydrate at 550 m depth on the Louisiana Slope in the Gulf of Mexico[(8)]. The gas hydrate exposure was the result of a 1.5 m crack in the sediment surface. Approximately 2,500 polychaetes.m^{-2} were found on the surface of the hydrate. It is likely that there is a strong nutritional tie between the worms and the hydrate and it has been proposed that the dominant food source of the worms are methanotrophic bacteria[(8)]. The discovery of this 'ice worm' demonstrates a previously unknown ecological niche (Figure 11).

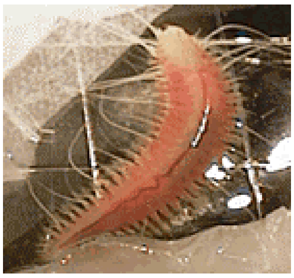


Figure 11 ***[(9)]:*** *Iceworm*
(Photo by Ian MacDonald))

7.4 Exploitation value

Methane hydrate is an attractive economic target as a source of methane (i.e. energy), especially when it occurs relatively close to the seabed surface[(10)]. Estimates of the methane content of natural gas hydrate all suggest that the methane quantities are very large[(11)]. Oceanic gas hydrate apparently contains significantly more methane than polar region gas hydrate[(3)]. The methane content of the oceanic gas hydrate worldwide has been estimated by various workers with a resultant consensus value of around 21 x 1015 m^3 [(5,12)]. If these estimates are correct then the amount of methane in gas hydrate is almost two orders of magnitude larger than the estimated total remaining recoverable conventional methane resources, estimated to be about 25 x 1013 m^3 [(13)].

The transition from a liquid petroleum to gas-based economy has already begun[(3)]. Methane must now be considered as a primary fuel for the future. The methane may be used directly as a fuel or may be converted to methanol, or higher molecular weight synthetic fluid fuel. Methane can be burned to produce energy in a variety of ways including direct use in methane fuel cells. In addition, methane could be transported to a point of use and transformed to hydrogen (with inert carbon by-product) and used directly in virtually pollution-less hydrogen fuel cells[(3)]. Methane-based mixed gas hydrate can be used to desalinate seawater[(14)]. Specially fabricated methane clathrates may be used to transport and store methane[(3)]. Investigations are underway to determine the possibility of submersible vehicles using methane hydrate an on-board fuel[(3)]. Gas hydrates have also been considered as a basic fuel and industrial feedstock as part of space travel. Large amounts of methane hydrate may exist on Mars, which would provide the basic elements for human habitation of the planet[(15)].

In scientific terms, the potential significance of gas hydrate in oceanic sediments to energy resources, climate, and seafloor stability are compelling reasons to continue their study. So far, little is known about the nature of gas hydrate reservoirs[(3)]. The future of gas hydrate research will aim to focus upon resource occurrence and concentration, global climate change and seafloor stability[16]. There have been few studies to date that have covered these areas. The Gulf of Mexico is the best natural laboratory in the world for the study of gas hydrates because they outcrop on the seafloor as mounds and so can be easily sampled[17]. A research team from India is embarking on an applied research effort to drill wells in deep water and learn how to produce gas hydrates. Similar efforts are also proceeding offshore near Japan[17].

The amount of methane in natural gas hydrates is twice the total recoverable fossil fuel reserve that includes gas, oil, coal and shale[16]. Recent interest in the exploration of gas hydrates is partly a result of their potential as an energy resource and also for energy storage. Methane combustion produced around half of the CO_2 emissions of coal and around two thirds of oil when producing the same amount of thermal energy and hence may be considered a more environmentally sound option.

At present, gas hydrate is termed an 'unconventional' resource. This infers that it is either uneconomic to extract or that it requires new technologies for extraction. As the cost of traditional fuel inevitably increases with its demise, the economic viability of alternative energy sources will follow and research into the extraction of gas hydrates will take hold. In short, oceanic methane hydrates constitute a major energy exploration frontier in the future. Methane is an environmentally cleaner fuel than oil, coal or oil shale, all of which have a greater adverse environmental impact during production and combustion.

7.5 Biodiversity issues

Recent studies have identified the presence of bacteria at depths of over 800 m below the seafloor in marine sediments in the Pacific Ocean[18]. Bacterial populations and their activity are stimulated in oceanic hydrate deposits to such an extent that some processes are more intense at depth than in near-surface sediment[19]. This demonstrates that gas hydrates are a unique deep subsurface habitat. A bacterial population model indicates that bacteria in deep-sea sediments account for ca. 10% of living biomass on Earth[20]. It has been estimated that about 60% of all bacteria on Earth live in sub-seafloor sediments[21]. Hydrates constitute a unique deep bacterial habitat in marine sediments, as the abundance and activity of bacteria are elevated at depth[3].

7.6 Potential / actual threats

The huge gas hydrate reservoir in ocean sediments has significant implications for climate because of the vast amount of methane situated there and the strong greenhouse warming potential of methane in the atmosphere[3]. A unit mass of methane introduced into the atmosphere would have 56 times the global warming effect of an identical mass of carbon dioxide over a 20 year period[3]. Conservative estimates suggest that there is ca. 3,000 times as much methane in the gas hydrate reservoir as there is in the present atmosphere[5]. Methane from the gas hydrate reservoir may have escaped to the atmosphere and affected climate in the past. There is some evidence to suggest that methane escaped as a result of seafloor collapses and sediment slides.

References

1) *http://woodshole.er.usgs.gov/project-pages/hydrates/what.html*

2) Davidson, D.W., El-Defrawy, M.K., Fuglem, M.O. and Judge, A.S. (1978). Natural gas hydrates in northern Canada. In: Proceedings of the 3rd International Conference on Permafrost 1, National Research Council of Canada, 938-943

3) Max, M.D. (2000). Natural Gas Hydrate in Oceanic and Permafrost Environments. Coastal Systems and Continental Margins Volume 5. Kluwer Academic Publishers, The Netherlands

4) Kvenvolden, K.A., Ginsburg, G.D. and Soloviev, V.A. (1993). Worldwide distribution of subaquatic gas hydrates. *Geo-Marine Letters* **13**: 32-40

5) Kvenvolden, K.A. (1988). Methane hydrates and global climate. *Biogeochemical Cycles* **2**: 221-229

6) Ginsburg, G.D., Milkov, A.V., Soloviev, V.A., Egorov, A.V., Cherkashev, G.A., Vogt, P.R., Crane, K., Lorenson, T.D. and Khutorskoy, M.D. (1999). Gas hydrate accumulation at the Hakon Mosby mud volcano. *Geo-Marine Letters* **19**: 57-67

7) Suess, E., Bohrmann, G., Greinert, J. and Lausch, E. (1999). Flammable ice. *Scientific American* **281**(5): 76-83

8) Fisher, C.R., MacDonald, I.R., Sassen, R., Young, C.M., Macko, S.A., Hourdez, S., Carney, R.S., Joye, S. and McMullin, E. (2000). Methane ice worms: *Hesiocaeca methanicola* colonizing fossil fuel reserves. *Naturwissenschaften* **87**(4): 184-187

9) Photography by Ian MacDonald

10) Pellenbarg, R.E. and Max, M.D. (2000). Introduction, physical properties, and natural occurrences of hydrate. In: Max, M.D. (ed.) Natural Gas Hydrate in Oceanic and Permafrost Environments. Coastal Systems and Continental Margins Volume 5. Kluwer Academic Publishers, The Netherlands

11) Kvenvolden, K.A. (1999). Potential effects of gas hydrate on human welfare. Proceedings of the National Academy of Sciences (USA) 96: 3420-3426

12) MacDonald, G.T. (1990). The future of methane as an energy resource. *Annual Reviews of Energy* **15**: 53-83

13) Masters, C.D., Root, D.H. and Attanasi, E.D. (1991). Resource constraints in petroleum production potential. *Science* **253**: 146-152

14) Max, M.D. and Pellenbarg, R.E. (1999). Desalination through methane hydrate. U.S. Patent 5,873,262 Issued February 23, 1999

15) Max, M.D. and Clifford, S. (2000). The state, potential distribution, and biological implications of methane in the Martian crust. *Journal of Geophysical Research – Planets* **105**(E2): 4165-4171

16) Sloan, E.D., Brewer, P.G. and Paull, C.K. (1999). Future of gas hydrate research. EOS *Transactions of the American Geophysical Union* **80**(22): 247-249

17) Sassen, R. (1997). Gas hydrate gardens of the Gulf of Mexico. *Quarterdeck* **5**(3)

18) Parkes, R.J., Cragg, B.A. and Wellsbury, P. (In press). Recent studies on bacterial populations and processes in marine sediments: a review. Hydrogeological Reviews.

19) Cragg, B.A., Parkes, R.J., Fry, J.C., Weightman, A.J., Rochelle, P.A. and Maxwell, J.R. (1996). Bacterial populations and processes in sediments containing gas hydrates (ODP Leg 146: Cascadia Margin). *Earth and Planetary Science Letters* **139**: 497-507

20) Parkes, R.J., Cragg, B.A., Bale, S.J., Getliff, J.M., Goodman, K., Rochelle, P.A., Fry, J.C., Weightman, A.J. and Harvey, S.M. (1994). Deep bacterial biosphere in Pacific Ocean sediments. **Nature** *371*: 410-413

21) Whitman, W.B., Coleman, D.C. and Wiebe, W.J. (1998). Prokaryotes: the unseen majority. Proceedings of the U.S. National Academy of Sciences 95: 6578-6583

22) http://woodshole.er.usgs.gov/project-pages/hydrates/where.html

8. SUBMARINE CANYONS

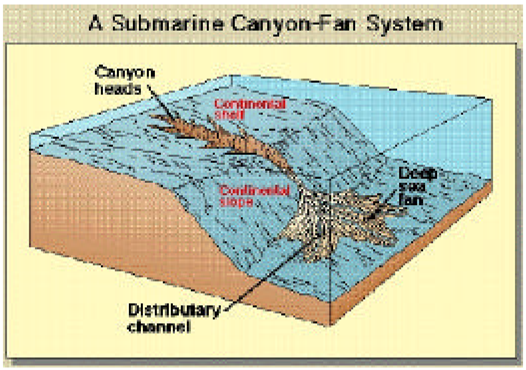


Figure 12 **[1]*:*** *Submarine Canyon*
(http://www-ocean.tamu.edu/~wormuth/marineprovinces/subcanyonfan.gif)

8.1 Introduction and habitat characteristics

Submarine canyons are erosional features that cut across the continental slope and, less commonly, the continental shelf. They are steep-sided, V- or U-shaped features that are likely to have been formed by turbidity currents or sediment slumps, or both(2,3). Turbidity currents are density currents attributable to an increase in suspended matter and may be one of the major erosion and sedimentation processes in the deep ocean(2). The Hudson Gorge, off New York Harbour, was the first canyon to be discovered in the 1800s(4,5). As canyon discoveries increased in number, much speculation relating to their origin began. Hypotheses included erosion by submerged rivers(5,6,7,8), diastrophism or continental uplifts(9,10,11,12), and erosion by submarine currents(13). However, evidence seems to suggest that the principal agents responsible for the formation of submarine canyons are marine processes, most notably the erosion and transportation of sediments by turbidity currents activated by the slumping of unconsolidated rock material near the heads of the canyons(14).

Each individual canyon is unique. They are characterised by shape, distance from shore, sediment supply and organic matter, flow in the canyons and sediment type. The Grand Bahama Canyon is an example of an extensive canyon, rising nearly 5 km from the canyon floor, and measuring 37 km at its widest point. Most submarine canyons extend only about 48 km or less in length, but a few are more than 320 km long. They have a substantial number of tributaries at their heads but generally do not have as many tributaries in their lower courses(14). At the mouths of many canyons, enormous fan-like sediment deposits are found. These sediments are likely to have been channelled down the canyon by turbidity currents. Canyons form a natural break in the flow of water along the continental slope and may result in particles such as larvae being transported up or down canyon, away from their ambient environment(15).

8.2 Global distribution

Submarine canyons are found along the slopes of most continental margins. They also occur along the slopes of the Hawaiian Islands and other ocean islands. Figure 18 shows a well-studied canyon region

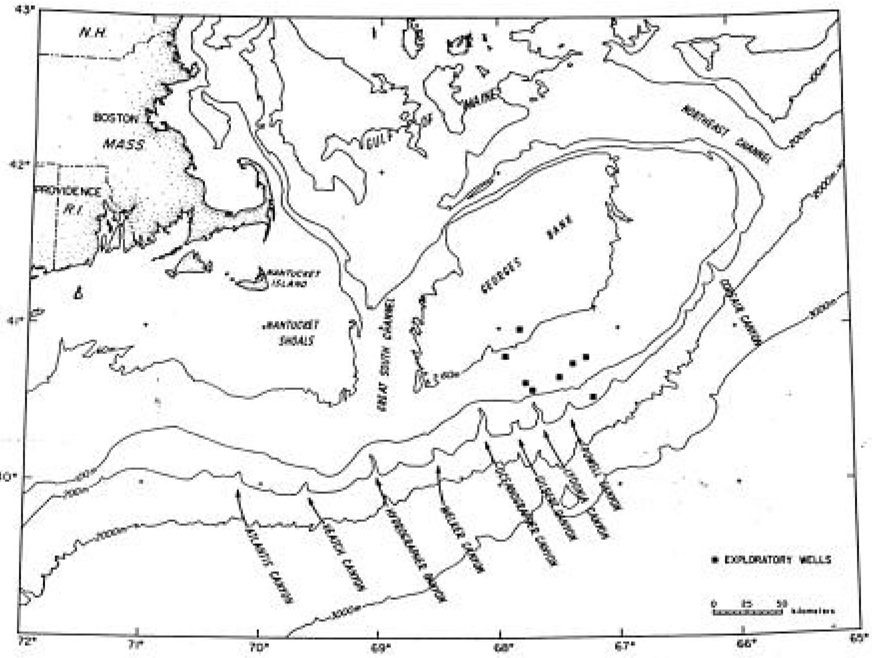


Figure 13: *Nine major submarine canyons along the southern flank of Georges Bank.*
(Hecker, B. (1989). Megafaunal populations in Lydonia Canyon with notes on three other North Atlantic canyons. Proceedings of the North Atlantic Submarine Canyons Workshop Feb 7 - 9, 1989 Vol 11. 63-66)

Evidence from side-scan sonar data indicates that the continental slope is dominated by canyons along the Atlantic coast from Hudson Canyon to Baltimore Canyon. Around twenty percent of the upper continental slope off Georges Bank is occupied by submarine canyons. They exhibit wide variability in size and shape.

8.3 Associated species

Canyons accumulate organic debris and can support hotspots of secondary production[16,17,18,19]. Biological investigations indicate that the faunal composition of canyons is quite different from adjacent depths without canyons[e.g. 2,17]. Mobile fauna dominate parts of canyon-dwelling communities, suggesting that in some cases motility has allowed survival in an unstable sedimentary environment. Alternatively, it may be that these species are trophic opportunists with the ability to take advantage of the significant source of trapped organic matter in the canyons[20].

A study of the distribution of fauna in the Hatteras Canyon and found that species in this canyon were different from those of the adjacent slope and thus formed a group of 'canyon indicator species'[2]. 'Canyon indicators' include the seastars *Dytaster* and *Benthopecten*, the seapen *Kophobelemnon*, the holothurian *Peniagone* and the anemone *Cerianthemorpha*. Canyon species were different and dominated by suspension feeders supported by the high concentrations of suspended material within the canyon. Variation was found in the biomass, abundance and wet weight of benthic infauna between the Hudson Canyon and non-canyon sample sites[21], although in the Carson Canyon there was no significant difference[22].

The distribution of canyon fauna is related to sediment type. Flow patterns in the channels, governed by both internal waves and storms, erode and deposit sediment and result in the distribution of different feeding modes. One of the most detailed studies of the relationship between sediment suspension and transport was conducted in the Baltimore Canyon[(23)]. The faunal component was also analysed[(24)]. These studies comprise one of the most detailed studies of canyon fauna to date in which the fauna of the Lydonia Canyon and the Baltimore Canyon are compared with local slope fauna. Photographic evidence, collected by towed camera sledge, of approximately 750,000 animals was analysed from the Lydonia Canyon. Animal collections were also made using the submersible vehicle 'Alvin'. Canyon fauna was much more abundant than that on the slope. High abundances of sea pens, tubeworms, corals, sponges, hydroids and brittle stars were seen. Brittle stars were sometimes stacked five deep over each other in the depositional part of the canyon. Gorgonians up to 15 feet tall were very common canyon fauna. Many juvenile fish were found associated with these corals. Canyon fauna is very patchily distributed. From examination of a few other canyons it was concluded that each canyon is quite different in terms of fauna[(24)]. Most of the canyon fauna is dominated by sessile filter feeders, both hard and soft substrate organisms. The physical environment of the canyon is reflected in the fauna. The largest canyons contain the most heterogeneous habitat types and consequently the epibenthic fauna exhibits the highest diversity and greatest biomass in these larger canyons.

The floor of the La Jolla submarine canyon is inhabited by a dense assemblage of amphipod and leptostracan crustaceans that achieve high densities in excess of 3 million individuals and biomass exceeding 1 kg (dry weight).m^{-2}[(16)]. These dense crustacean populations attract fish predators. Large numbers of both demersal and pelagic fishes are nearly always present, feeding on these animals. This food hotspot may be critical for many species of pelagic animals. It is expected that this situation occurs in other submarine canyons near to populations of marine macrophytes[(16)].

The walls of submarine canyons may be susceptible to bioerosion by burrow-forming organisms. Small to moderate scale erosional phenomena have been noted in some canyons and it is thought that erosional products of bioerosion are probably an important component of the sediment budget in some canyon systems[(25,26,27)].

Huge densities of giant clams (*Calyptogena* sp.) were discovered at a depth of 3,830 m in the Tenryu Canyon off the Pacific coast of Japan[(28)]. One box core of 250 cm^2 in cross-sectional area contained 40 living clams. These clams have been reported from hydrothermal vent and seep communities.

The largest submarine canyon off the coast of eastern Canada is known as the Gully. The abundance of cetaceans in the Gully is higher than in other parts of the Scotian Shelf and Slope. The distribution of cetaceans within the Gully was most strongly correlated with depth, but was also significantly correlated with sea surface temperature and month. Eleven species of cetaceans are commonly found in the Gully[(29)].

8.4 Exploitation value

Compared to the surrounding slope and shelf seas, submarine canyons have been shown to have a higher biomass and diversity of commercially important species such as lobsters, crabs, shrimp, flounders, hake, ocean pout, cusk and tilefish[(24)]. This is primarily because of the availability of a wide variety of substrate types, providing shelter. Such shelters are frequently used by juveniles, making canyons important nursery grounds. Some canyons are particularly important for fisheries.

In terms of scientific investigation, a thorough knowledge of submarine canyons is needed in order to assess slope stability for offshore oil drilling and production platforms and suitability of canyon heads for sites as disposal of sewage and industrial wastes, for their eventual transport to the deep sea[(30)].

8.5 Biodiversity issues

Megafaunal densities and biomass are generally higher in canyons than on the adjacent slope and shelf with higher diversity in canyons[24]. Canyons are also areas of nurseries from some commercial marine species and have a higher concentration of commercial species than the surrounding seabed[24]. A number of species are particularly diagnostic of canyon environments, namely the white hake (*Urophycis tenius*), tilefish (Malacanthidae), lobster and various corals and sponges. Canyons are unique for lobsters in that they serve as a major nursery site as well as home grounds.

Submarine canyons are commonly found to contain distinct species assemblages or higher faunal densities and/or biomass than nearby non-canyon regions at similar depths[17].

8.6 Potential / actual threats

The processes of sediment resuspension have been shown to be far more frequent and much more intense in some canyons than on the adjacent continental shelf or slope[24]. This increases the opportunity of particles to adsorb and transport dissolved contaminants from the water column to the bottom sediment. This hypothesis is supported by evidence of lead-210 and plutonium-239/240 distributions in sediment cores from the axis of Lydonia Canyon and from the open slope. Studies of the Lydonia and Baltimore Canyons showed evidence of a near-bottom convergence zone in the shallow portion of the axis. This indicates that canyon systems may well serve a role in pollutant transport to fauna inhabiting these areas. Pollutants that adhere to fine suspended material may be concentrated in the axis and ingested by the faunal inhabitants, especially filter feeders, and thus, enter the food web[24]. Possible deleterious effects upon the dominant canyon fauna, the filter feeders, include increased particle loading. This could instigate tissue abrasion, smothering or clogging of filtering apparatus or decreased success of larval settlement of sessile species.

Several commercial species are found in high abundance in the heads of submarine canyons. Fishing methods employed in canyons usually include traps and long-line (baited hooks) gear. Some submarine canyons with extreme topography may act as harvest refugia for a number of commercial species and other species on which they feed.

Activities associated with petroleum exploitation may impact these important environments. Nevertheless, an estimate has been made of the impact of drilling mud pollution in a canyon, assuming a wellsite 1 km from a canyon rim. It is proposed that such deposits are unlikely to threaten megafauna, including commercial fish and invertebrate species, except possibly their early life stages. Some or most canyon fauna are relatively insensitive to sediment deposition, having adapted to living in these highly turbulent environments. It is therefore the chemical constituents of drilling muds that would be a greater potential threat to the fauna than sedimentation. Larvae and early juvenile stages are likely to be more sensitive to pollutants. Larval settlement may be inhibited by contaminants. This could lead to a reduction in recruitment of some commercial species. If juveniles are driven from their nursery habitats, they will automatically be exposed to increased predation[24].

References

1) http://www-ocean.tamu.edu/~wormuth/marineprovinces/subcanyonfan.gif

2) Rowe, G.T. (1971). Observations on bottom currents and epibenthic populations in Hatteras Submarine Canyon. *Deep-Sea Research* **18**: 569-581

3) Kenyon, N.H., Belderson, R.H. and Stride, A.H. (1978). Channels, canyons and slump folds on the continental slope between south-west Ireland and Spain. *Oceanologica Acta* **1**(3): 369-380

4) Dana, J.D. (1863). <u>A Manual of Geology</u>. Philadelphia, U.S.A.

5) Lindenkohl, A. (1885). Geology of the sea-bottom in the approaches to New York Bay. *American Journal of Science* **29**: 475-480

6) Davidson, G. (1887). Submarine valleys on the Pacific coast of the united States. *Bulletin of Californian Academy of Science* **2**: 265-268

7) Dana, J.D. (1890). Long Island Sound in the quaternary era, with observations on the submarine Hudson River Channel. *American Journal of Science* **40**: 425-437

8) Le Conte, J. (1891). Tertiary and post-tertiary changes of the Atlantic and pacific Coasts. *Bulletin of the Geological Society of America* **2:** 323-328

9) Lawson, A. (1893). The geology of Carmelo Bay. *University of California Publications Bulletin, Department of Geology* **1**: 1-59

10) Spencer, J.W. (1898). On the continental elevation of the glacial epoch. *Geological Magazine* **4**: 32-38

11) Spencer, J.W. (1903). Submarine valleys off the American coast and in the North Atlantic. *Bulletin of the Geological Society of America* **14**: 207-226

12) Hull, E. (1912). The Sub-oceanic Physiography of the North Atlantic Ocean. London.

13) Smith, W.S.R. (1902). The submarine valleys of the California coast. *Science*, N.Y. **15**: 670-672

14) Thurman, H.V. (1997). Introduction to Oceanography 8th Edition. Prentice Hall, London. 398p

15) Tyler, P.A. (1995). Conditions for the existence of life at the deep-sea floor: an update. In: A.D. Ansell, R.N. Gibson and M. Barnes (eds.). *Oceanography and Marine Biology – An Annual Review* **33**: 221-244

16) Vetter, E.W. (1994). Hotspots of benthic production. *Nature* **372**: 47

17) Vetter, E.W. and Dayton, P.K. (1998). Macrofaunal communities within and adjacent to a detritus-rich submarine canyon system. *Deep-Sea Research II* **45**: 25-54

18) Monaco, A., Biscaye, P.E. and Laborde, P. (1999). The ECOFER (ECOsystème du canyon du cap-FERret) experiment in the Bay of Biscay: introduction, objectives and major results. *Deep-Sea Research II* **46**: 1967-1978

19) Vetter, E.W. and Dayton, P.K. (1999). Organic enrichment by macrophyte detritus, and abundance patterns of megafaunal populations in submarine canyons. *Marine Ecology Progress Series* **186**: 137-148

20) Rowe, G.T. (1972). The exploration of submarine canyons and their benthic faunal assemblages. *Proceedings of the Royal Society of Edinburgh (B)* **73**: 159-169

21) Rowe, G.T., Polloni, P. and Haedrich, R.L. (1982). The deep-sea macrobenthos on the continental margin of the northwest Atlantic Ocean. *Deep-Sea Research* **29**: 257-278

22) Houston, K.A. and Haedrich, R.L. (1984). Abundance and biomass of macrobenthos in the vicinity of Carson Submarine Canyon, northwest Atlantic Ocean. *Marine Biology* **82**: 301-305

23) Gardner, W.D. (1989). Baltimore canyon as a modern conduit of sediment to the deep sea. *Deep-Sea Research* **36**: 323-358

24) Hecker, B. (1989). Megafaunal populations in Lydonia Canyon with notes on three other North Atlantic canyons. Proceedings of the North Atlantic Submarine Canyons Workshop Feb 7-9, 1989 Vol 11. 63-66

25) Dillon, W.P. and Zimmerman, H.B. (1970). Erosion by biological activity in two New England submarine canyons. *Journal of Sedimentary Petrology* **40**(2): 542-547

26) Rowe, G.T., Keller, G., Edgerton, H., Staresinic, N. and MacIlvaine, J. (1974). Time-lapse photography of the biological reworking of sediments in the Hudson submarine canyon. *Journal of Sedimentary Petrology* **44**(2): 549-552

27) Warme, J.E., Slater, R.A. and Cooper, R.A. (1978). Bioerosion in submarine canyons. In: Stanley, D.J. and Kelling, G. (eds.) Sedimentation in Submarine Canyons, Fans and Trenches. Dowden, Hutchinson and Ross Inc. Pennsylvania. USA 65-70

28) Swinbanks, D. (1985). Japan finds clams and trouble. *Nature* **315**: 624

29) Hooker, S.K., Whitehead, H. and Gowans, S. (1999). Marine protected area design and the spatial and temporal distribution of cetaceans in a submarine canyon. *Conservation Biology* **13**(3): 592-602

30) Stanley, D.J. and Kelling, G. (1978). Sedimentation in Submarine Canyons, Fans and Trenches. Dowden, Hutchinson and Ross Inc. Pennsylvania. USA

9. SEABIRDS

Figure 14 ***[1]*** ***:****Albatross caught in long-lining hook*
(Photo by Graham Robertson. Use approved by photographer)

9.1 Introduction

Although this section aims to deal mainly with seabirds outside EEZs, some notes featuring breeding and nesting populations inside EEZs are included for clarity. There are around 320 species of oceanic seabirds[2]. Birds can be both predators (and prey) and scavengers, and use a variety of feeding techniques. These include scooping food from surface waters whilst flying; feeding from the surface layers whilst swimming; deep plunge diving for food and swimming at depth (or a combination of these strategies). Seabirds may feed upon fish, surface-living crustaceans, cephalopods and jellyfish. They also scavenge fish discards from fishing vessels. Seabirds are considered to be global assets and important components of the marine environment. They are also ecological indicators of the health of the environment in which they live.

9.2 Global distribution

Seabirds can be found all over the world's oceans and seas. Important colonies of seabirds have been identified on land. It is far more difficult to ascertain the distribution of seabirds at sea as they are often relatively dispersed. Nevertheless, most species congregate at certain times and in certain areas, their distribution mainly reflecting food availability and the location of breeding sites[3]. Seabirds that venture offshore are often associated with fronts and upwelling areas, which have enhanced productivity compared to the surrounding oceanic waters. Seamounts have also been found to have seabird aggregations associated with these higher productive regions[4]. Seabirds are commonly found close to fishing boats in order to benefit from any discards, offal or fish bait. Isolated islands and archipelagos are an important base for many seabirds and their foraging activities from these breeding sites often extend out into the open ocean environment.

Two of the true oceanic seabird groups that are most likely to be found beyond EEZ regions are albatrosses and petrels. These birds are highly mobile and widely dispersed within very large boundaries. Such boundaries are difficult to define.

9.3 Potential / actual threats

In the past, coastal communities have consumed vast quantities of seabirds[e.g. 5,6]. Harvesting the great auk (*Alca impennis*) for food is partially responsible for its extinction in the North Atlantic ca. 150 years ago[2]. Seabirds are still consumed in Indonesia and elsewhere in the world[5]. Great shearwaters were harvested for bait in New England cod fisheries during the 19th century and were used for this purpose in many fisheries for centuries[2]. Relatively recently, boobies have been used as bait in lobster traps off Brazil[7].

Many seabird species spend the majority of their lives foraging for food on the high-seas, coming ashore only for short periods to breed. These species tend to be relatively long lived compared to land birds. They have low reproductive rates, lay small clutches, delay breeding for 5-10 years and have slow chick growth[2]. Marine birds are affected by human use of the sea, particularly fishing. Currently, the most critical threat facing seabirds globally is thought to be the mortality caused by long-line fisheries[2]. This fishing method is practiced widely in all oceans and seas, and for some fish species, 90% of the commercial catch is taken by this method[8]. Most seabirds forage prey from the top few metres of the water column and the majority will scavenge dead or moribund prey. They are hence attracted to fishing boats to feed on their discarded material. In addition, some birds will steal bait from long-line hooks. As they swallow the baited hooks, they are pulled into the sea and drown. Twelve seabird species, including one of the world's largest flying birds, the Wandering Albatross (*Diomedea exulans*) may be threatened with extinction by long-lining because reproductive rates are low in these species and cannot compensate for this additional mortality. The large albatrosses breed only once every two years, or at most twice in three years. They also form strong pair bonds for life. If one of the pair is killed then the other will not breed again until another bond is formed (which may take several years). Together with the delayed onset of breeding (10+ years) and only one egg laid in a clutch, the killing of only a few birds can have serious, long-term implications for the survival of the population. There is already evidence to suggest that several populations are decreasing as a direct result of long-lining[(3)].

The long-lining fishing method has increased since international protest reduced seine-netting of tuna (because of the concomitant death of thousands of dolphins) and largely eliminated pelagic drift-netting (which caused millions of birds to drown each year). In the 1980s, until banned by the UN, "walls of death" drift nets killed tens of thousands of shearwaters in the Pacific Ocean. Long-line fisheries in which seabird by-catch occurs are: tuna, broadbill (swordfish) and billfish in the South Pacific; Patagonian toothfish in the Southern Ocean, and halibut, black cod, tuna, billfish, Pacific cod, Greenland halibut, cod, haddock, tusk and ling in the Northern Oceans (Pacific and Atlantic). The species of seabirds most frequently taken are albatrosses and petrels in the South Pacific and South Atlantic fisheries, Arctic fulmar (*Fulmarus glacialis)* in the North Atlantic and albatrosses, gulls and fulmars in the North Pacific fisheries[(3)]. The tuna fisheries off Brazil and Uruguay (in the Atlantic) have reported catching one bird per every two or three hundred hooks that are set. Some long-lines are over 100 km in length with more than 20,000 hooks attached. On average each drowned bird has taken four to six baits before being caught. In some fisheries more than half the bait never makes it past the birds.

The long-line industry for the Patagonian toothfish (*Dissostichus eleginoides*) in the Southern Ocean was responsible for killing an estimated 265,000 seabirds between 1996-1999, mostly albatrosses and White-chinned Petrels (*Procellaria aequinoctialis*)[(2)]. In 1991 it was estimated that the Japanese tuna long-liners off Australia alone killed 250,000 birds annually. This figure may have decreased as new measures have been put in place to reduce by-catch.

More than 90% of the seabird deaths described here are attributable to the activities of unlicensed long-line fishing vessels. A rapid containment of illegal and unregulated fishing represents the single most effective strategy for improving the conservation status of affected bird populations. At least three species face extinction unless prompt action is taken.

With some changes in long-line fishing methods, it is thought that the incidents of seabird deaths may be substantially reduced[(9)]. For example, long-lines set at night rather than in daylight are thought to pose less of a threat to seabirds. Other mitigation measures include putting extra weight on the lines to make the hooks sink faster; attaching streamers to trail behind the vessel acts to deter birds from the baited hooks; underwater line-setting techniques are being developed in Norway and New Zealand[(9)].

In addition to the devastating effects of long-line fisheries upon seabirds, other fishing methods have resulted in huge by-catches. For example, monofilament gillnets are generally considered to produce the largest by-catches of seabirds and mammals[(2)]. Prior to the 1992 moratorium on high-seas drift netting, an estimated 500,000 birds were killed annually in the North Pacific, largely a result of salmon and squid fisheries[(10)]. Most of these were shearwaters, which bred in the Southern Hemisphere. Alongside fishing methods, other threats to seabirds include lost fishing gear and litter, in which birds may become entangled and die from starvation. The mortality levels associated with this litter are low but the amount of debris has increased substantially during the 1970s and 1980s[(11)].

Seabirds have also been harvested for use as fishing bait and as a food source in some regions of the world. Birds that eat relatively large fish have also been culled in some inshore areas[(2)].

Changes in stock abundance of fish, either through natural or anthropogenic influences, have also had an adverse effect on some seabird populations.

It should also be noted that human fishing activities may also sometimes have a positive effect for some species of seabirds (potentially at the expense of others) in terms of the provision of discards and offal or the increased availability of small fish as a result of over fishing of larger species[(2)].

Aside from fishing, other human activities may also impact seabirds. Acute oil pollution is one of these. From 1990 to 1999 a total of 364 oil spill incidents (over 7 tonnes) resulted in 1,096,000 tonnes of oil spilt. This is far less than from 1970 to 1979 when oil spill incidents totalled 773 with a resultant 3,179,000 tonnes of oil spilt. (Statistics from International Tanker Owners Pollution Federation Ltd). Oil spills (either acute or chronic) may contaminate birds' feathers and reduce insulating properties. Oil is also toxic when ingested and can lead to death[(12)]. Fairly high concentrations of PCBs have been found in adult albatrosses from a remote area in the North Pacific Ocean. These levels have been found to be similar to those in several fish-eating birds of the North American Great Lakes region. This indicates that contamination with these chemicals is global in nature. Based on observations of the effects of such contaminants on the US bird populations, the levels of PCBs in seabirds far offshore would be expected to be causing subtle population level effects such as embryo mortality and deformities[(13)].

Seventy-two of the world's ca. 320 seabird species are classified as threatened and a further 27 as near-threatened. The current revision being undertaken by BirdLife International lists 99 species.

References

1) Photography by Graham Robertson

2) Tasker, M.L., Camphuysen, C.J., Cooper, J., Garthe, S., Montevecchi, W.A. and Blaber, S.J.M. (2000). The impacts of fishing on marine birds. *ICES Journal of Marine Science* **57**: 531-547

3) Cooper, J 1999. BirdLife International's Seabird Conservation Programme. *World Birdwatch Special Issue* **21**(4), March 1999.

4) Haney, J.C., Haury, L.R., Mullineaux, L.S. and Fey, C.L. (1995). Sea-bird aggregation at a deep North Pacific seamount. *Marine Biology* **123**(1): 1-9

5) Croxall, J.P., Evans, P.G.H. and Schreiber, R.W. (1984). Status and Conservation of the World's Seabirds. International Council for Bird Preservation, London. Technical Publication No.2.

6) Montevecchi, W.A. and Tuck, L.M. (1987). Newfoundland birds: exploitation, study, conservation. Nuttall Ornithological Club, Cambridge, U.S.A. 273 pp.

7) Antas, P.T.Z. (1991). Status and conservation of seabirds breeding in Brazilian waters. In: J.P. Croxall (ed.) Seabird Status and Conservation: a Supplement . International Council for Bird Preservation, Cambridge 141-158

8) Bjordal, Å. and Lokkeborg, S. (1996). Long-lining. Fishing News Books, Oxford 156 pp.

9) Brothers, N.P., Cooper, J and Lokkeborg, S. (1999). The incidental catch of seabirds by long-line fisheries: worldwide review and technical guidelines for mitigation. *FAO Fisheries Circular* **937**: 100pp.

10) DeGange, A.R., Day, R.H., Takekawa, J.E. and Mendenhall, V.M. (1993). Losses of seabirds in gill nets in the North Pacific. In K. Vermeer, K.T. Briggs, K.H. Morgan and D. Siegel-Causey (eds.) The Status, Ecology, and Conservation of Marine Birds of the North pacific. Canadian Wildlife Service Special Publication, Ottawa. 204-211

11) Montevecchi, W.A. (1991). Incidence and types of plastic in gannets' nests in the Northwest Atlantic. *Canadian Journal of Zoology*, **69**: 295-297

12) Tasker, M.L. and Webb, A. (1990). 1990 North Sea Report. London: The Marine Forum of Environmental Issues 103-109

13) Auman, H.J., Ludwig, J.P., Summer, C.L., Verbrugge, D.A., Froese, K.L., Colborn, T. and Giesy, J.P. (1997). PCBs, DDE, DDT and TCDD-EQ in two species of albatross on Sand Island, Midway Atoll, North Pacific Ocean. *Environmental Toxicology and Chemistry* **16**:3 498-504

10. CETACEANS

Figure 15: Humpback whale fluke
(htttp://nmm101.afs.noaa.gov/gallery/cetaceans/cetacean_gallery5.htm)

10.1 Introduction

There are around 80 species of cetaceans (whales, dolphins and porpoises). The two types of whale are toothed and baleen. Baleen whales (also known as Mysticeti whales) filter feed on krill, copepods, plankton, and small fish. They are the largest whales. Baleen whales include Blue, Gray, Humpback, Minke, Bowhead, and Right whales. Of the toothed whales, Sperm whales are the largest. The Sperm whale has a very large head, large teeth, and feed on squid, fish, octopus, eels, etc. Some whale species spend their entire lives in one area whereas others migrate thousands of miles during their lifetime. Migration routes and global distribution of many species of cetaceans may be found on the website:
http://whales.magna.com.au/DISCOVER/GRAY/index.html.

The majority of cetaceans can be found along the coastlines of the major continents. Most are either migratory or wide-ranging. Migratory whales move north and south in both the Northern and Southern hemispheres, but in general the northern populations do not meet their southern counterparts. The equator is a natural barrier to the larger whales. Dolphins are free ranging and are usually found between the continental shelf and the coastline. Some are found around islands and crossing the open oceans. They tend to follow the food hotspots.

10.2 Potential / actual threats

A range of human activities threatens cetaceans. One of the most destructive of these has been commercial whaling for oil and meat. In the past, the oil rendered from the blubber of baleen whales was used to produce soap, margarine and other foodstuffs. From Sperm whales the collection of a waxy substance called 'spermaceti' was first used for lamp oil and then for specialised lubricants in the cosmetic, textile and leather industries, and in the making of pencils, crayons and candles. Meat from sperm whales was used only for animal feed whilst from baleen whales it was used for human consumption. In recent years many suitable alternatives have been found for most of these whale products (meat, oil, animal feed). In the western world whale oil has largely been replaced by vegetable and fish oils, while meat for animal feed has been replaced by fish meal.

Uncontrolled commercial exploitation had a significant impact on most of the great whale species and led to extinction of the North Atlantic, and near extinction of North Pacific, populations of Gray whales. Blue whales show no recovery from their over exploitation in the Southern Hemisphere. Original numbers totalled around 250,000. They are now estimated to number just 500. Many populations of other whales have failed to recover from whaling, despite the many years of protection following the 1986 International Whaling Commission moratorium. As a result, 6 of 11 great whale species are still considered to be endangered or vulnerable.

Minke whales are still legally hunted by Norway (in N.E. Atlantic, North Sea and Barents Sea) and Japan for scientific research (in the Southern Ocean whale sanctuary and western North Pacific). A total of 1978 Minke whales were caught in 1999. The International Whaling Commission allows whale kills for ‘aboriginal subsistence need’. In 1998, 67 Bowheads, 140 Gray whales, 187 Minkes, 12 Fins and 2 Humpbacks were killed for this purpose. Illegal whale hunting is also a problem. For example, products from protected whale species are appearing in Japanese markets. Using molecular genetic methods, 8 species of baleen whales, as well as Sperm whales, Beaked whales, Killer whales, dolphins, and porpoises have been found among 700 "whale" products purchased in Japanese markets from 1993 to 1999, even though it is only legal to catch Minke whales. Large numbers of Bryde's whale are caught each year around the Philippines and Taiwan. There is still international trade in whale meat. Smuggled whale meat totalling 540 tons was confiscated between 1988 and 1996 by Japanese authorities on its way from Taiwan and Korea.

Some fisheries practices impact whales and most species of cetacean may be affected. Entanglement in fishing gear is common and cetacean bycatch is a significant problem. It has been reported that >80,000 small cetaceans drown as bycatch in gillnets annually. This may be an underestimation. In 1990, the IWC estimated the mortality of cetaceans in driftnets in the Pacific and Indian Oceans and the Mediterranean Sea to be between 315,600 and 1,060,200. A total of 128 minke whales were caught in bycatch in 1996 by South Koreans. Intensive fisheries may also result in a decline in the food available for whales in some areas.

In addition to hunting and fishing, other forms of human activities impact cetaceans to some degree. For example, large whales are vulnerable to collisions with ships. Almost 40% of all known Northern Right whale mortality is caused by ships. Noise pollution in the ocean is also a cause for concern for cetaceans. For example, intense ship trafficking and seismic testing, oil drilling ships and research involving low frequency sonars all result in substantial levels of noise pollution. Cetacea largely depend upon auditory capacity for navigation and communication. All toothed species use echolocation for finding their food. These abilities may be severely affected with an increase in noise levels. Research indicates that industrial noise may be responsible for displacement from habitat, stranding and physiological harm. In addition, marine pollution has been reported to cause developmental and immunological abnormalities in many species of cetacean. Sea cows also pass on toxic chemicals to their calves during feeding. Some Beluga whales have been contaminated by DDT and PCBs and the dead carcasses have had to be disposed of as toxic waste. DDT and PCBs cause tumours, reproductive problems such as a decrease in fertility and heavy metal poisoning. Another form of pollution are non-biodegradable products such as plastic debris that have been disposed of in the open ocean. These objects may cause death by ingestion. On a larger scale, global climate change, leading to melting of the polar ice caps, will act to destabilise the ecology of feeding grounds for whales. Natural phenomena, such as the occurrence of toxic algae, have killed cetaceans. 162 dolphins were though to have been killed by a red tide bloom in the open ocean the western USA.

Cetaceans have been held in captivity in zoos and marine parks since the 1860s. The Bottlenose dolphin, *Tursiops truncates*, is the most commonly held species. Many holders of captive animals argue that research is an important part in their role and that knowledge of cetaceans acquired this way is essential for conservation of cetaceans in the wild. This is somewhat debatable. Captive cetaceans generate public interest and revenue for whale conservation. Increasingly, carefully controlled whale watching trips are also promoting whale conservation issues. In 1997 around 7 million enthusiasts were attracted by whale watching trips, generating hundreds of million dollars in revenue.

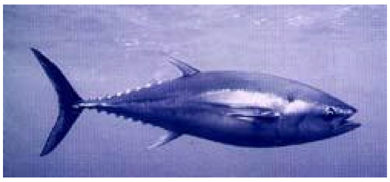
References

http://nmml01.afsc.noaa.gov/gallery/cetaceans/cetacean_gallery5.htm
www.panda.org
www.wdcs.org
whale.wheelock.edu
www.jncc.gov.uk
http://whales.magna.com.au/DISCOVER/GRAY/index.html

Lento, G.M., Dalebout, M.J. and Baker, C.S. (2000). Market survey, 1999: Molecular genetic identification of whale and dolphin products for sale in Japan and Korea. Report Sc/52/SD17 to the Scientific Committee of the International Whaling Commission).

11. TRANS-BOUNDARY FISH STOCKS

Figure 16: *Bluefin tuna*
(http://ens.lycos.com/ens/aug99/1999L-08-23-04.html)



11.1 Introduction

Many fish species migrate for part of their life cycle beyond the EEZ into the high-seas. These fish stocks are termed "straddling stocks". Other species migrate through the high-seas and the fisheries jurisdictions of coastal states to a larger degree and are known as "highly migratory stocks". Examples of fish species with this roaming behaviour are cod, tuna, swordfish and sharks.

11.2 Potential / actual threats

Commercially valuable fish stocks that are found beyond national fisheries jurisdictions are often subject to overfishing by distant water fleets. This is the case for both "straddling stocks" and "highly migratory species".

Straddling fish stocks and highly migratory fish stocks have been vulnerable to depletion on the high-seas in many regions of the globe:

- pollock in the "Donut Hole" of the Bering Sea and the "Peanut Hole" of the Sea of Okhotsk
- orange roughy on the Challenger Plateau in the high-seas off the coast of New Zealand
- hake, southern blue whiting and squid off Argentina's Patagonian Shelf
- jack mackerel off the coast of Chile and Peru; cod in the Barents Sea "Loop Hole" off the coast of Norway
- highly migratory stocks of tuna, dolphin, and shark in the South Pacific and North Atlantic oceans.

The problem of overfishing on the high-seas has become particularly acute in recent years. This is partly because fleets displaced from coastal fishing zones have sought new fishing grounds. In addition, advances in fishing technology have resulted in the expansion of global fishing capacity to new, often unsustainable levels.

The depletion of trans-boundary fish stocks is a global problem owing to the nature of the stocks involved. Migratory fish, such as the Atlantic tuna, can travel thousands of km in short time periods, thereby moving from continent to continent. Areas such as the South Pacific, the Mediterranean, and the North Atlantic are highly prone to conflicts over straddling or migratory stocks.

A straddling stock may stay in coastal waters until it is time to go into deeper water to feed and spawn. While in coastal waters, this stock is within a specific national EEZ, and so it can be managed. However, when it goes to spawn, it leaves the littoral area for the high-seas. It is there that it may be overfished owing to the lack of regulation. When a stock is fished while it spawns, its offspring population diminishes. This smaller population then returns to the EEZ with a resultant decrease in population size, eventually leading to stock collapse.

Deep water fish stocks such as the orange roughy may extend across the EEZ-high-seas boundary. Deep water fish stocks may exhibit life history characteristics that are very different from those found in shelf species. They have extreme longevity, late age of maturity, slow growth and low fecundity. They are therefore highly vulnerable to over fishing and potentially have little resilience to over exploitation. Previously unfished stocks have been typically fished down within 5 to 10 years.

Highly migratory stocks such as the tuna, and tuna-related species such as the swordfish, are important top predators in the ocean. The ecosystem effect of removing these top predators is unknown. North Atlantic bluefin tuna (*Thunnus thynnus*) are regarded as one of the most highly evolved oceanic fish species. They are noted for their extensive migrations and large size. International demand for these fish remains high and has resulted in highly intensive fishing. As a result, breeding populations of bluefin tuna are in sharp decline.

Major conflicts have arisen over high-seas fish stock depletion over the past few years. These conflicts over depletion have already caused "fish wars." In the past five years alone, there have been over a dozen major conflicts, both armed and unarmed between nations who have felt threatened by the fishing practices of another state. To illustrate the interaction between nations who are separated by great distances, Panama and Australia clashed in 1997 over fishing in Arctic waters.

Six countries are responsible for 90 per cent of "distant-water" fishing: Russia, Japan, Spain, Poland, the Republic of Korea, and Taiwan. The United States also does a significant amount of high-seas fishing, especially for tuna. In recent years China has become a major fishing nation. Government subsidies have encouraged over-investment in the distant water fishing industry and have resulted in excess fleet capacity. Higher economic returns are needed in terms of fish catch to compensate for this. According to the FAO, the size of the world's fishing fleet increased at twice the rate of the increase in the global marine catch between 1970 and 1990. This explosion in the number of fishing vessels has helped undermine the sustainability of fisheries and the viability of the fishing industry itself.

According to the FAO, almost 70 per cent of all fish stocks are either fully to heavily exploited (44 per cent), over-exploited (16 per cent), depleted (6 per cent) or very slowly recovering from overfishing (3 per cent). Typically, fleets on the high-seas use non-selective fishing equipment, with the result of high bycatch.

In addition to fishing, the impact of other human activities threatens the sustainability of straddling and highly migratory fish stocks. These include oil spills, destruction of mangrove swamps and estuaries, industrial air pollution, and the production of nutrients, pesticides and other materials that run off the land and pollute the oceans. Some fishing practices, such as using dynamite on coral reefs to kill fish, also destroy critical habitats. Introducing exotic species either accidentally or deliberately into a marine environment can also harm other species in the ecosystem.

References

http://www.un.org/ecosocdev/geninfo/sustdev/fishery.htm
http://www.oceanlaw.net/netpath/page4ss.htm
http://www.iisd.ca/linkages/fish.html
http://www.ecouncil.ac.cr/about/contrib/spirtrio/spi06.htm
http://www.jcaa.org/JCNL9711/9711HMSR.htm
http://ens.lycos.com/ens/aug99/1999L-08-23-04.html

Tahindro, A. (1997). Conservation and Management of Tansboundary Fish Stocks: Comments in Light of the Adoption of the 1995 Agreement for the Conservation and Management of Straddling Fish Stocks and Highly Migratory Fish Stocks. *Ocean Development and International Law* **28**: 1-58.

Koslow, J.A., Boehlert, G.W., Gordon, J.D.M., Haedrich, R.L., Lorance, P. & Parin, N. (2000). Continental slope and deep-sea fisheries: implications for a fragile ecosystem. *ICES Journal of Marine Science* **57**, 548-557.

Recommendations

1) Hydrothermal vents

- At present, the scientific community appears to pose the greatest threat, but has already initiated an 'in-house' protection plan. Such efforts should be encouraged and augmented by international governmental and NGO input.
- The ephemeral nature of hydrothermal vent communities suggests the need to 'protect' relatively large areas of mid-ocean ridge, perhaps a ridge segment at a time to ensure the long-term 'survival' of these communities within particular geographic areas.

2) Seamounts

- Seamount biological communities are already under considerable threat and should be seen as an URGENT and appropriate case for HSMPA designation.
- The widely distributed nature of seamounts, and their role as 'biological islands' and 'stepping stones' requires special attention, and particularly suggests the need for an HSMPA network in this case.

3) Deep-sea trenches

- (If present in high-seas areas) Trenches are presently at relatively minimal threat and have comparatively low levels of 'interest'; consequently there is little HSMPA need / potential at present.
- This conclusion should be kept under review, particularly with regard to their potential as dumpsites.

4) Deep-sea 'coral reefs'

- Extensive destruction of deep-sea coral communities is already evident, and has probably occurred for the last 100 years; protection of these important habitats is therefore urgently needed.
- Any protected area designation should be co-ordinated with existing inshore legislation / protected areas (e.g. European Union Habitats Directive, and Norwegian trawling exclusion areas).

5) Polymetallic nodules

- Deep-sea manganese nodule mining has been long suggested, but is not economically viable and unlikely to become so for decades, threat is consequently minimal at present.
- The need for HSMPA designation is questionable, and certainly of a low priority only; any HSMPA action should be co-ordinated with the International Seabed Authority.

6) Cold seeps and pockmarks

- Though less 'publicised', cold seep communities should certainly warrant the same conservation value as hydrothermal vent communities. However, their occurrence in the deep sea is less well known and less 'predictable' than is the case with hydrothermal vents, consequently the selection of appropriate sites / areas may be problematic.

- Cold seeps and pockmarks are of common occurrence in shallow water (e.g. North Sea), any HSMPA action should be linked with related shallow seas initiatives.

7) GAS HYDRATES

- There is currently insufficient information on biological communities that may be associated with gas hydrates to warrant their separate consideration as HSMPAs at this time.
- For the present, gas hydrates should be considered jointly with cold seep communities (particularly those fuelled by hydrocarbon escapes).

8) SUBMARINE CANYONS

- Deep-sea canyons are common and widespread but do have distinct biological significance. The greatest threats to these environments probably lie within EEZs; canyons are nevertheless clear candidates for HSMPA status.
- Given their intimate linkage with the 'inshore' environment, successful HSMPA designation will depend on matching 'inshore' initiatives.

NOTE – *The conservation issues relating to seabirds, cetaceans and trans-boundary fish stocks are of a different scale and nature to those of the seabed environments considered above. An additional specialist report on the former topics is probably warranted.*

9.,10,11) SEABIRDS, CETACEAN & TRANS-BOUNDARY FISH STOCKS

- Many species of oceanic seabirds, cetaceans and fish are already under considerable threat, both from direct exploitation and as a by-catch. HSMPAs could usefully contribute to the protection and re-establishment of these species.
- HSMPA action, however, must be co-ordinated with and matched by (other) legislation and actions within national jurisdictions if the full value of the HSMPA is to be realised.

The status of natural resources on the high-seas

Legal and political considerations[1]

A. Charlotte de Fontaubert, Ph.D.[2]

The author wishes to acknowledge the thorough and helpful comments of Tomme Young, Lee Kimball, Lindy Johnson and Simon Cripps. Any remaining errors, however, whether legal or factual, are the author's alone.

[1] In the context of this paper, high-seas refer to areas beyond exclusive economic zones (EEZs). See explanation of this concept on p.11 of the paper.
[2] Contact: fontaubert@att.net. The views expressed in this paper do not necessarily reflect those of IUCN – The World Conservation Union or the World Commission on Protected Areas.

CONTENTS

Executive Summary

IUCN – The World Conservation Union has long played a leading role in the development and implementation of marine protected areas, particularly through the work of its World Commission on Protected Areas (WCPA). A task force on High-Seas MPAs, a sub-part of the WCPA, brings together experts on this issue from around the world. Most recently, a resolution was adopted at the Amman World Conservation Congress in October 2000, which calls upon national governments, international agencies and the non-governmental community to better integrate established multilateral agencies and existing legal mechanisms to identify areas of the high-seas suitable for collaborative management action, and to reach agreement by consensus on regimes for their conservation and management. It is within this context that IUCN participated in and supported the work of the recent Vilm Meeting of experts on high-seas MPAs. Drawing from the discussions and conclusions of this Meeting of Experts, this paper explores some of the legal, political and institutional issues relevant to the possible establishment of protected areas on the high-seas.

The main points this paper makes are:

- That in view of the current uncertainty as to the state of exploitation of the living resources of the high-seas and the extent of uses (both current and potential), a precautionary approach to the exploitation of these resources is critical;
- That high-seas marine protected areas may be one of the tools available that are called for to address this uncertainty;
- That international law should not necessarily be an obstacle or impediment to the establishment of high-seas MPAs (HSMPAs). Rather, in its present form the international legal regime imposes a duty on States to cooperate in managing resources of the high-seas and does not prohibit or preclude the establishment of marine protected areas on the high-seas;
- That, as the present regime evolves, historical precedent suggests that MPAs will eventually be formally recognised as an instrument applicable on the high-seas;
- That States and other entities with an interest in HSMPAs will need to anticipate and overcome a number of political, legal and institutional obstacles that may arise as MPAs are established on the high-seas; and
- That in view of this uncertainty it might be sensible to launch an experimental MPA around a seamount where fishing has not yet taken place, building on the existing international legal regime, and through intense cooperation and collaboration among all the States with an interest in high-seas resources.

INTRODUCTION: THE RATIONALE FOR HIGH-SEAS MARINE PROTECTED AREAS

WWF and others have demonstrated that marine biodiversity found in the high-seas is abundant, valuable and increasingly threatened (e.g. Baker *et al*., 2001; Koslow, 2001; Cripps and Christiansen, 2001). Currently, 90% of fish harvested is caught within the exclusive economic zone (EEZ) of coastal States, however, this restricted focus has generally been a result of poor understanding of the wealth of resources available on the high-seas, combined with the natural human tendency to exploit resources closer to home before going further afield. But once coastal resources become severely impacted, we can expect exploitation efforts to be directed toward other resources, further offshore and thus more difficult to reach, but where in some measure, freedom of fishing still prevails. This move into the high-seas is already becoming apparent.

Unfortunately, the historical collateral to freedom of fishing has been, and still is, the Tragedy of the Commons, where users engage in a race to harvest resources before others can get to them, often with detrimental effect. In addition to fishing, some other activities impact on high-seas marine biodiversity and emanate from fishing activities, dumping, mining, or even scientific research.[3] Many deep-sea resources are being destroyed even before we have fully explored and assessed their potential value.

Some of the most valuable resources under threat in the high-seas include (Baker *et al*., 2001):

- hydrothermal vents
- seamounts
- deep-sea trenches
- deep-water, reef-forming corals
- submarine canyons
- seabirds
- cetaceans, and
- high-seas fish stocks.

In addition, high-seas biodiversity is at threat from the potential exploitation of the following:

- polymetallic nodules
- cold seeps and pockmarks, and
- gas hydrates.

To-date, the track record of the fishing industry in managing marine living resources is dismal. According to the UN Food and Agriculture Organisation, 69% of the fish stocks world-wide are fully exploited, depleted, or slowly recovering. Fish stocks are becoming depleted, some species disappear before we can even identify them, marine pollution is on the rise, and changing global climate poses significant risks. There seems to be no limit to the extent of human impact on our oceans environment. In most cases, we discover these impacts after the fact.

Along the coast, more often than not, we are able to monitor this impact, and can even put a value (*post hoc* of course) on the resources we have squandered, though that is not always so in some developing countries.

[3] Several papers on the threats to marine biodiversity of the high-seas were presented at the Vilm Meeting of Experts on High-seas MPAs. See for instance the papers submitted by Koslow, Juniper, Donovan, Thiel, Cripps and Gordon (2001).

For most resources of the high-seas, however, this is simply not the case. It is often said that we know more about the surface of the moon than we do about the bottom of our oceans. Certainly, more funds have been devoted to various space programs than to the exploration of our oceans and sea-floors. As a result, we know very little about the resources of the deep. Scientists and the general public have long believed that no life could be sustained on the abyssal plains, only to discover later on that a wealth of species live there. An example that has recently come to light is that of hydrothermal vents, which are veritable oases, teaming with life, rich in biodiversity and often host to endemic species. We have yet to examine or understand fully the extent to which our uses so far (from trawling to dumping of waste) have impacted such biodiversity, and the situation is about to get worse.

"Pulse fishing" is a common fisheries practice, where fishing fleets move into previously un-fished area, over-harvest the resource to the point where it is no longer commercially viable, and then move on to a new, un-exploited area. As ludicrous as it may sound, pulse fishing is still practised by some distant water fishing fleets, but the problem is about to become much more complicated.

As explained in further detail below, international law now recognises that a major portion (perhaps most) of known, exploitable marine living resources are now under the exclusive sovereign jurisdiction of coastal States. A significant part of the marine area that used to be considered "the high-seas" is now regulated by the regime of 200-mile exclusive economic zones (or EEZs), as embodied in the 1982 UN Convention on the Law of the Sea (or UNCLOS). As a result, the same distant water fishing fleets that used to engage in pulse fishing off the coasts of coastal (often developing) States have been displaced beyond these zones of national jurisdiction onto the high-seas. Consequently, we are facing a potential worst-case scenario, where first, we know very little about the resources (and thus are hard pressed to manage them sustainably) and, second, the resources are not under the jurisdiction of any single State, but rather are placed under the so-called regime of the high-seas, where their sustainability is dependent on collective restraint being exercised by all users.

As serious as the fisheries crisis is, the problem is actually much broader, after decades of using the high-seas, abyssal plains, and deep-sea trenches as a repository for the world's unwanted wastes, nuclear and otherwise, under the erroneous assumption that no life could be sustained in such environments and that the waste dumped would be contained in these areas.[4] These same unwise fishing activities not only impact the target fish stocks, but also seriously threaten seabirds, sea turtles, marine mammals and deep-water corals, to name a few. Inappropriate exploitation of the high-seas has already begun, and is unlikely to diminish soon.

Policy makers and resource managers have at their disposal an arsenal of measures to address these threats and to manage resources sustainably, at least in theory. Unfortunately, most of the time these tools are either mis-applied or ineffective. Marine protected areas, though far from being a panacea, are emerging as a flexible, targeted alternative to traditional management measures (Agardy, 1997). As highlighted by Salm and Clark (2000), all MPAs are not created with the same purpose in mind, though they generally aim to regulate the use of a resource that is deemed worthy (and in need) of protection. MPAs are not necessarily marine and coastal areas where all uses are restricted. Rather, MPAs provide a framework in which uses can be regulated and organised. For instance, MPAs are sometimes necessary to organise different, mutually exclusive uses in a limited area. In addition, different uses, and levels of use can be organised within a single MPA. For instance, the Great Barrier Reef Marine Park, which is the largest MPA in the world, is divided in different zones, where different uses are allowed but regulated, including tourism, fishing and other extractive uses of marine resources. Irrespective

[4] Dumping of nuclear waste is now banned under the terms of the London Convention.

of the level of use that is allowed or restricted, the main advantage of MPAs is that they allow to manage an ecosystem rather than a single species, a series of stocks or a mineral resource.

Inter alia, measures taken in MPAs can fulfil the following objectives:

- to help protect vulnerable habitats and threatened species;
- to increase fisheries productivity (including through the export of biomass);
- to protect breeding populations; and
- to reduce the adverse impacts of human activities. (Baker *et al*, 2001)

In addition, MPAs can embody an emerging new principle of international law – the precautionary principle. The principle is worded differently by various international legal instruments but can be interpreted in two ways:

- that the absence of definite scientific information should not be an excuse for inaction in curtailing harmful activities, and
- that the putative new user of a resource should be able to show that the uses intended will not have a detrimental effect on the said resource.

Either interpretation of the principle applies to our current situation on the high-seas, where scientific understanding is inadequate and where many States are:

- either interested in exploiting the resources but are unable to show that theirs will be a *sustainable* use, or
- unwilling to curtail other activities that might have an impact on marine biodiversity.

Within national territorial waters, as well as EEZs, MPAs still represent a relatively recent approach to marine resource management. This initial experience, however, has given us a substantive understanding of how MPAs can and should be established, what we can expect them to accomplish and how to combine them with other, traditional measures. Inherently, MPAs incorporate the precautionary principle, because they provide for the protection of the resource through the restriction (though not necessarily the prohibition) of uses. It is important to note that MPAs usually represent a balance between conservation of the resource (expected benefit of the MPA) and the regulation of the uses of the same resource or others that will have a detrimental impact (the clearest and most immediate cost of the MPA). Along with the benefit of conservation comes a price, which can be very high and tends to be immediate for the displaced or regulated user.

To date, our experience with MPAs has generally been limited to coastal areas and to action taken by a single State or, in exceptional cases, by a handful of adjacent, coastal States.[5] With a few exceptions, which will be examined in more detail later in this paper, MPAs have not been established on the high-seas. One of the main reasons for this state of affairs is that beyond national jurisdiction, no single authority can designate the MPA, adopt the management measures that it requires and see to it that these measures are enforced.

Currently, however, a number of States, along with WWF and IUCN, have expressed a strong interest in exploring the possibilities of MPAs on the high-seas. This effort is a reflection of the dire situation that prevails on the high-seas (and is expected to worsen) and recognises the failure of traditional management measures.[6]

This paper will first determine whether or not high-seas MPAs are permissible in international law. Secondly, it will assess how to make the best use of international law and to modify and build on the existing regime to enhance the recognition of MPAs on the high-seas. Finally, it

[5] Egypt, Israel and Jordan for instance have established a joint "Peace Park" in the Gulf of Aqaba.
[6] See the text of the IUCN Resolution on this issue, in the box below.

will highlight some of the political obstacles that are likely to arise in the process, along with some recommendations on how to overcome those obstacles.

The IUCN Amman Resolution on High-Seas MPAs

Every four years, IUCN – The World Conservation Union holds its World Conservation Congress. The Congress is a forum for all members to guide the work of the Union by adopting resolutions with recommendations to IUCN's Secretariat. In October 2000, IUCN held its Second World Conservation Congress in Amman, Jordan. Resolution 2.20 was adopted on the conservation if marine biodiversity. The resolution was adopted by consensus, though a single State indicated that, had there been a vote, the delegation would have abstained.

The Resolution is based on the framework of the UN Convention on the Law of the Sea, the Convention on Biological Diversity, the FAO Code of Conduct for Responsible Fisheries and past decisions of the UN Commission on Sustainable Development. Inter alia, the Resolution:

- reaffirms IUCN's commitment to the creation of a representative system of marine protected areas at regional and global scales;
- calls on the Director General of IUCN to work with members and multilateral agencies to explore an appropriate range of tools, including high-seas marine protected areas, with the objective of implementing effective protection, restoration and sustainable use of biodiversity and ecosystem processes on the high-seas; and
- calls on national governments, NGOs and international agencies to better integrate established multilateral agencies and existing legal mechanisms to identify areas of the high-seas suitable for collaborative management action and to reach agreement by consensus on regimes for their conservation and management.

1. THE CURRENT INTERNATIONAL LEGAL REGIME OF THE HIGH-SEAS

The current international legal regime can best be described as a mosaic of different instruments (treaties, programmes of action, etc), including global and regional instruments, whether "legally-binding" documents or "soft law" (de Fontaubert, 2000). From this disparate ensemble, a legal regime emerges that regulates who can and should do what, and where. The existing international legal regime that regulates use of the high-seas strongly encourages cooperation among States, does not prohibit the establishment of MPAs, and is furthermore susceptible to evolution and could endorse HSMPAs more explicitly.

1.1. The Framework: The UN Convention on the Law of the Sea

The United Nations Convention on the Law of the Sea (UNCLOS) has been dubbed a constitution for the oceans, because it effectively delineates most of the rights and obligations of all States. Most importantly, it divides the oceans in different zones of jurisdiction, where different States have different rights.

- The territorial sea extends from the baseline up to 12 nautical miles. Within that zone, the coastal State exercises exclusive sovereignty and jurisdiction, almost as it would in its land territory.[7]
- The contiguous zone extends from 12 to 24 nautical miles. There the coastal State may take measures to prevent and punish infringement of national laws as they relate to customs, fiscal, immigration and sanitary matters, as long as these infringements took place within its territory or territorial sea.
- From 12 to 200 nautical miles, the coastal State can declare an exclusive economic zone (EEZ), where it exercises sovereign rights over living and non-living marine resources and jurisdiction over marine scientific research and the protection and preservation of the marine environment.
- From 200 nautical miles outwards, the so-called regime of the high-seas applies, where all States have the right to engage in fishing, subject to treaty obligations and the rights of other States.[8] (In practice, most fishing on the high-seas is now regulated, to some extent, by regional fisheries management organisations). A separate regime will apply to the exploitation of mineral resources on the deep seabed.

UNCLOS represents a very carefully crafted balance between the interests of all States (Churchill & Lowe, 1988). It was negotiated over a 15-year period, following two earlier attempts to reach agreement. As a result, UNCLOS is the bedrock of international law as it relates to ocean uses. One should note that though the Convention was adopted in 1982, it only came into force in 1994, after its regime of deep seabed mining was amended by the so-called 1994 Mining Agreement.[9] In addition, the regime of UNCLOS was further supplemented

[7] For instance, the exclusive rights of the coastal State in the territorial sea are limited by its duty to allow innocent passage by ships from other States.

[8] A separate regime applies to the continental shelf, beyond 200 nautical miles, in very specific circumstances. The Complex regime of UNCLOS is explained in great detail in Kimball, L. "*The United Nations Convention on the Law of the Sea: A Framework for Marine Conservation.*" In IUCN, *The Law of the Sea: Priorities and Responsibilities in Implementing the Convention*. IUCN, Gland, 1995.

[9] Agreement relating to the Implementation of Part XI of the United Nations Convention on the Law of the Sea of 10 December 1982. The Part XI Agreement contains provisions under which deep seabed mining is expected to take place, including environmental considerations.

in 1995 with the adoption of the UN Agreement on Straddling Fish Stocks and Highly Migratory Fish Stocks.[10] The adoption of both the mining agreement and the fish stocks agreement reflect the evolving views of the negotiating Parties. In the former case, the original text was substantially modified to reflect changing economic and political circumstances. The fish stocks agreement, on the other hand, elaborates and supplements the original text, but it has not yet entered into force. In any event, both agreements are a clear reflection that UNCLOS is a living treaty, subject to modifications or elaboration, as reflected by the will of its Parties.

As the Convention stands, the most important and relevant provisions of UNCLOS for our purposes, are divided as follows:

- The provisions that regulate fishing on the high-seas (Articles 116-120), and
- The provisions that regulate the protection of the marine environment (notably, Articles 192 and 194).

The Fisheries Regime

The Law of the Sea devotes a whole section to the conservation and management of the living resources of the high-seas. Under Articles 116 and 117, the States' freedom to fish on the high-seas is limited both by the right of other States to do so and by their duty to cooperate "as may be necessary for the conservation of the living resources of the high-seas." The right to fish is therefore a limited one, and definitely does not stretch to a right to overfish on the high-seas. With the right to fish comes a responsibility to respect the rights of other States and to ensure that the stocks do not become depleted.

To that end, Articles 117 and 118 provide details as to how States should cooperate and the kind of measures they should take to ensure conservation of the resources. *Inter alia*, UNCLOS provides that States shall cooperate to establish subregional or regional fisheries management organisations (or RFMOs), as appropriate, and take measures "which are designed, on the best scientific evidence available..., to maintain or restore populations of harvested species at levels which can produce the maximum sustainable yield." In other words, States have a clear mandate to conserve and cooperate, but the manner in which they achieve that goal is left for them to decide. The reference to the best scientific evidence available is a clear indication that the measures called for will depend on knowledge of the state of the stocks, and must therefore take into account past uses.

One could argue that in cases where the stocks have been severely impacted, strong measures, such as the designation of an MPA (e.g. no take area, closed area) would be completely justified under UNCLOS, *as long as this measure is adopted as a result of the cooperation among the States involved*. In fact, certain regional fisheries management organisations (RFMOs) have already adopted such measures on the high-seas. Whilst UNCLOS does not refer specifically refer to MPAs on the high-seas, it does not prohibit them either, rather the States have carte blanche to adopt any measures they have negotiated and deemed necessary for the conservation of the stocks.[11] In addition, Article 119 of UNCLOS calls on States to take measures on the high-seas that take into account the interdependence of stocks and associated

[10] Agreement for the Implementation of the Provisions of the United Nations Convention on the Law of the Sea of 10 December 1982 relating to the Conservation and Management of Straddling Fish Stocks and Highly Migratory Fish Stocks.

[11] The absence of reference to MPAs is understandable when taken in context. The Convention was negotiated from 1973 to 1982 and at the time MPAs were still being experimented with and not well understood. As their use has become more widespread, reference to MPAs in international legal instruments has steadily increased. See the section on international precedents, below.

species, which can be achieved through the protection of a whole area rather than a mere target stock.

The Environment Regime

Part XII of UNCLOS is devoted entirely to the protection and preservation of the marine environment. Article 192 provides a very clear indication that "States have the obligation to protect and preserve the marine environment." Article 193 also provides that States have the right to exploit their natural resources pursuant to their environmental policies and in accordance with their duty to protect and preserve the marine environment. The duty to protect and preserve is further developed in Article 194, which provides that:

- States shall act individually, or jointly as appropriate to take all measures necessary, *using the best practicable means at their disposal* (including the adoption of MPAs, which are not prohibited here);
- States shall take measures to ensure that activities under their jurisdiction or control are so conducted as not to cause damage by pollution "beyond the areas where they exercise sovereign rights." In other words, the State is responsible for the activities of vessels flying its flag, even when those are on the high-seas and no longer in its EEZ;
- States shall take measures to deal with *all sources of pollution of the marine environment*;
- States also have a duty to take measures to protect and preserve "*rare or fragile ecosystems as well as the habitat of depleted, threatened or endangered species and other forms of marine life*."

Underlying all these measures that States must take is the obligation to cooperate with other States since, "States shall refrain from unjustifiable interference with activities carried out by other States in the exercise of their rights and *in pursuance of their duties in conformity with this Convention*."[12]

By combining the fisheries regime and the protection of the marine environment component, States are therefore in a position to take strong conservation measures on the high-seas, as long as they cooperate with other States, show that the measures they want to take would enhance the conservation of resources and that they are based on the best scientific evidence available. Under these circumstances nothing in the Law of the Sea Convention precludes the adoption of some form of marine protected areas on the high-seas.

1.2. Soft Law vs. Hard Law

As has been noted above, UNCLOS provides the framework within which the whole legal regime rests, but the treaty was adopted close to twenty years ago and international law has evolved since, sometimes in dramatic fashion. New principles have emerged that were not expressly incorporated into the Law of the Sea Convention, including the precautionary principle and the ecosystem approach. Often, this evolution of new legal concepts has been tied to scientific discoveries or experimentation in new management approaches. The emergence of marine

[12] It is important to note here that the Convention strikes a delicate balance since it protects the rights of other States, but still holds them accountable for their obligations under the Convention, which includes the general duty to protect the marine environment set up in Article 192.

protected areas as a management tool has followed that pattern and MPAs are now incorporated into a number of recently negotiated instruments, both in hard law form and as soft law.

Hard law is usually understood as legally-binding, i.e. the rights and obligations of States as incorporated in treaties and conventions. Once a State becomes party to a treaty or convention, it is bound by the measures of that instrument. Other Parties may be able to bring disputes to be solved under binding dispute settlement mechanisms, such as the International Tribunal for the Law of the Sea (ITLOS) in Hamburg.[13] The Law of the Sea Convention, the Convention on Biological Diversity and the International Convention for the Regulation of Whaling are all constitutive of hard law. Soft law, in contrast, is usually adopted when a new principle emerges, where States recognise the value of that principle, but are not yet willing to be bound by it. Agenda 21, the programme of action adopted at the outcome of the UN Conference on Environment (the "Earth Summit" held in Rio in 1992) is a perfect example of soft law, where measures to be taken are suggested but not required. Likewise, the Rio Declaration of Principles contains a series of principles that were adopted and recognised but were not given the force of treaty law. Yet often once States recognise a new legal principle under soft law, that principle is ultimately codified into treaty law.

In the case of marine protected areas, their role in international law has developed informally. The initial stage of their development occurred as a result of national initiatives. As governments became fully aware of the usefulness of MPAs, other area-based mechanisms for protection of species and habitats have found their way into international law, providing a basis for broadening the use of MPAs into EEZs and international waters. Although fully recognised as measures that can be taken in the EEZ, the use of MPAs on the high-seas has yet to be incorporated formally into international instruments. It is important to note that the creation and use of protected areas is in no way prohibited on the high-seas. States recognizing that MPAs are a necessary mechanism for achieving critical international objectives in the realm of biodiversity conservation are within their rights, and arguably under an obligation to start adopting them as one element of their duty to "take all measures necessary to protect and preserve the marine environment" (UNCLOS, Article 193).

To that end, States can also use the following legal instruments.

The Convention on Biological Diversity and its Jakarta Mandate

The Convention on Biological Diversity (CBD) was opened for signature at the UN Conference on Environment and Development (UNCED, or the Earth Summit), which was held in Rio de Janeiro in June 1992. The objectives of the CBD are the conservation of biodiversity, the sustainable use of biodiversity's components and the equitable sharing of benefits derived from genetic resources. State Parties are called upon, *inter alia*, to take measures to ensure the conservation and sustainable use of biodiversity, to monitor biodiversity in their territories, to identify and take measures for the control of destructive activities, and to integrate consideration of biodiversity into national decision making.

[13] In the case of the Law of the Sea Convention, and unlike most treaties, disputes can be brought under compulsory dispute settlement procedures, though not for all matters. For instance, the measures taken by the coastal State in its EEZ for management of marine living resources is not subject to compulsory dispute settlement procedures.

Biodiversity conservation can be achieved though a combination of both *in situ* and *ex situ* conservation. The former is most important and the Convention provides that the Parties, "shall, as far as possible and as appropriate, establish a system of protected areas or areas where special measures need to be taken to conserve biological diversity." The CBD does not refer specifically to marine or terrestrial ecosystems in its discussion of *in situ* conservation, but during the 1995 Conference of the Parties, the so-called Jakarta Mandate was issued, which outlined a programme of action for implementing the Convention with respect to marine and coastal biodiversity. Decisions pursuant to the Jakarta Mandate identify five areas in which the State Parties can take practical steps to apply the Convention to marine habitats. They include: implementing integrated coastal area management; ensuring the sustainable use of coastal and marine living resources; implementing environmentally sustainable mariculture practices; preventing the introduction of alien species; and establishing marine and coastal protected areas. MPAs are therefore one of the five pillars of the Jakarta Mandate (de Fontaubert *et al.*, 1996).

With regards to implementation of the Convention on the high-seas, Article 4 clearly states that the scope of the Convention extends:

- in areas within the limits of national jurisdiction in the case of components of biological diversity, and
- within national jurisdiction or beyond the limits of national jurisdiction for processes and activities carried out by a member State, *regardless of where their effects occur* (i.e. including on the high-seas).

Furthermore, Article 5 calls on States to cooperate with other contracting Parties, as far as possible and as appropriate, in respect of areas beyond national jurisdiction. Article 8 also calls on States to, "establish a system of protected areas or areas where special measures need to be taken to conserve biological diversity."

Under the CBD, Parties are responsible for actions of their nationals that may impact biodiversity on the high-seas, are invited to establish protected areas to conserve biological diversity and are required to cooperate for the conservation and sustainable use of biodiversity on the high-seas. Combined, these requirements present a strong mandate for the establishment of MPAs on the high-seas, constrained only by the need to negotiate with other Parties in areas beyond national jurisdiction.

The UN Fish Stocks Agreement

The UN Agreement of Straddling and Highly Migratory Fish Stocks was adopted in 1995 and aimed to fill some of the gaps that had been left in the framework of UNCLOS.[14] The UN Conference on Straddling and Highly Migratory Fish Stocks was specifically called for in Chapter 17 of Agenda 21. After more than three years of negotiations, the Agreement was adopted and embodies a compromise reached between the interests of coastal States and those of distant water fishing nations. This instrument acknowledges the biological reality that while some stocks straddle EEZs and the high-seas, they nevertheless need to be managed throughout their range (according to the so-called biological unity of the stocks). Efforts to elaborate measures for the conservation of these stocks were unsuccessful during the UNCLOS negotiations, due to the conflict of interest between coastal and distant water fishing States.

[14] Articles 63 and 64 of the Law of the Sea Convention dealt with straddling and highly migratory stocks respectively but merely called on States to cooperate, without solving the disputes that could arise between coastal States and distant water fleets fishing on the high-seas.

The 1995 Agreement takes things further by requiring that Parties settle their differences by adopting compatible measures, but the Agreement does not indicate which measures shall prevail in case of conflict.

The precautionary approach is also given considerable emphasis in the Agreement and the whole of Article 6 is devoted to it. This Article is particularly interesting because it aims to articulate what, in concrete terms, can be undertaken to apply that approach. The adoption of this article represents a major shift in fisheries management, as it reverses the burden of proof between conservation and exploitation objectives. Throughout the history of fishing, remedial measures had been taken following the collapse or severe depletion of stocks and thus were, in essence, reactive. Likewise, conservation measures were only agreed to after managers had shown that a) the stocks were being unduly impacted, and b) the management measures would likely remedy this situation. The precautionary approach, as prescribed under Article 6, requires that the conservation and management measures be based on the best scientific evidence available, that States be more cautious when information is uncertain, unreliable or inadequate and that the absence of adequate scientific information not be used for postponing or failing to take conservation and management measures. Inasmuch as the designation of high-seas MPAs may give effect to the application of the precautionary approach, such designation by the relevant regional fisheries management organisations would be both appropriate and called for.

The Fish Stocks Agreement has not yet entered into force but it is already being implemented by the Parties that have ratified it. Those Parties could conceivably enter into a scheme where they could designate an MPA in an area of the high-seas, under the auspices of the relevant RFMO.[15] Once an MPA is adopted by an RFMO, all Parties to the Fish Stocks Agreement would be bound by this measure since under the Agreement other States should respect the conservation measures taken by the competent RFMOs.

The International Convention for the Regulation of Whaling, 1946

The ICRW was adopted in 1946 to provide for "the proper conservation of whale stocks" and to ensure "the orderly development of the whaling industry." In its more than 50 years of existence, the Convention has evolved dramatically from an instrument that was meant to regulate whaling, to one that currently prohibits it. This evolution reflected the changing political objectives of the majority of its Parties, which have now taken consistent measures to ban most whaling and to restrict it to very few exceptions, notably scientific and traditional whaling. Most noteworthy here is the fact that the Convention provides for the adoption of regulations designed to open and close waters, including the designation of sanctuaries in which no whaling is allowed. These sanctuaries can be declared in all waters in which whaling takes place, and therefore are clearly applicable in areas of the high-seas, beyond national jurisdiction. In this regard, the Convention provides for a very specific type of MPA, where the conservation measure aims to restrict just one use: whaling. Nevertheless, it provides an interesting precedent and is particularly noteworthy in that it was adopted in 1946, long before MPAs became a common tool for management and conservation of marine resources.

Agenda 21

Agenda 21 may well be the most important soft-law instrument that recognises the possibility of enacting MPAs on the high-seas. In the course of the UN Conference on Environment and Development (UNCED) all participating States negotiated and adopted Agenda 21, a blueprint

[15] The whole concept of such a scheme is examined in greater detail, below.

for sustainable development. Agenda 21 is divided into 40 chapters and one of them, Chapter 17, deals with "Protection of the Oceans, all kinds of seas, including enclosed and semi-enclosed seas, and coastal areas and the protection, rational use and development of their living resources." One of the main sections of Chapter 17 deals with integrated management and sustainable development of coastal and marine areas and calls on coastal States to undertake "measures to maintain biological diversity and productivity of marine species under national jurisdiction, ... including ... establishment and management of protected areas."

Agenda 21 also calls for cooperation in areas of the high-seas, beyond national jurisdiction. Paragraph 17.46 calls for States to conserve marine living resources of the high-seas, including through the protection and restoration of endangered marine species and the preservation of habitats and other ecologically sensitive areas.

Agenda 21 is widely recognised as a useful guide for States aiming to achieve sustainable development. Its level of detail also ensures that States can refer to it for practical recommendations of concrete steps to take to that end. In that context, MPAs are clearly marked as a necessary tool for the protection of coastal marine environment and nothing precludes their adoption on the high-seas, as long as this approach is negotiated among all States involved.

Particularly Sensitive Sea Areas Designated under the IMO Regime

The International Maritime Organisation is the UN forum in which shipping issues are discussed and relevant international regulations adopted. Within the IMO a new concept has emerged, that of particularly sensitive sea areas (PSSAs).[16] PSSAs are defined as "areas which need special protection through action by IMO because of their significance for recognised ecological, socio-economic or scientific reasons, and which may be vulnerable to damage by maritime activities." Through these measures, the international shipping community recognises its responsibility to limit the adverse environmental impacts of shipping. A member State or group of States of the IMO may submit an area for designation as a PSSA. This application is reviewed by the Marine Environment Protection Committee (MEPC), the IMO's arm of the organisation that reviews measures designed to limit the impacts of shipping on the marine environment. Guidelines were recently adopted that list ecological, social, cultural and economic or scientific and cultural criteria that must be met for an area to be designated as PSSA. Once a PSSA is designated, special protective measures can be adopted, which must be respected by the vessels flying the flag of all IMO members. Such measures may include traffic separation schemes, pilotage, vessel traffic services and no discharge areas and are designed to avoid the risk of collision, grounding and other adverse impacts resulting from shipping. The measures are then legally-binding and constitutive of hard law.

PSSAs are thus another clear manifestation of the international community's willingness to restrict some uses (in this case shipping) to protect areas that warrant special protection.

[16] The evolving PSSA regime clearly builds on Article 211(6) of UNCLOS, which allows coastal States to designate areas in their EEZs where special mandatory measures are adopted to prevent pollution from vessels as well as the MARPOL Convention, which allows for the designation of *Special Areas*. For more details on PSSAs, see Kimball (2001) and Gjerde (2001).

1.3. Global vs. Regional Approaches

All the instruments reviewed so far, both legally binding and soft-law in nature, are global in scope. In addition, a series of regional approaches have evolved, illustrating the realisation by member States of the importance of adopting regional approaches to the protection of the marine environment and sustainable use of marine living resources.

UNEP's Regional Seas Programmes

Under the auspices of the UN Environment Programme (UNEP), multilateral regional seas conventions have been adopted in eight regions. Each regional seas programme is organised around a framework treaty, under which specific protocols can be adopted to deal with a number of specific issues. Protocols dealing specifically with marine protected areas have been adopted in four regions: the Mediterranean, the South Pacific, East Africa and in the Wider Caribbean.[17] In some of these Conventions, the scope of application includes areas of the high-seas.

The Protocol on Specially Protected Areas and Wildlife (SPAW) to the Cartagena Convention provides a good example of the importance of regional approaches to MPAs.

The 1990 SPAW Protocol is the second protocol to the 1983 Cartagena Convention, which is the major legal instrument of the Caribbean Environment Programme, set-up under UNEP's Regional Seas Programme. Within the structure of the Regional Seas Programmes, the States of the Wider Caribbean collaborated on a substantive aspect through the adoption of an action plan, which was formally adopted by an intergovernmental meeting and then adopted an umbrella regional convention (Freestone, 1992).

The SPAW Protocol refers specifically to the establishment of protected areas and includes a series of protection measures that can be adopted by the Parties to meet the objectives of the Protocol, but the implementation is to be carried out by the States as they see fit. There is, however, a major aspect of the SPAW Protocol, which indicates that the regional marine protected area regime it sets up could amount to more than the sum of its national parts. Marine protected areas serve a wide variety of functions and the Protocol recognises the various objectives that can be pursued. The goal pursued through the designation of an MPA will actually often dictate its shape, size and the means of implementation. If, for instance, a Party intends to protect an endemic and particularly threatened species and the goal is the protection of a single vulnerable habitat type, the design and management of the protected area can be relatively simple. If, however, the goal of the MPA is to protect a wide range of habitats or resources, the protected area established will be more complex. In the case of protected areas where the goal is the protection of the ecosystem and its processes, the underlying ecology in the region dictates the outer boundaries of the area to be protected. In the case of the Wider Caribbean, and given the objectives of the Protocol, marine protected areas planners need to work towards conserving ecosystem integrity and thus to design networks of marine protected areas (de Fontaubert & Agardy, 1999).

Three approaches can be adopted in designating networks of protected areas: preserving ocean or coastal "wilderness" areas; resolving conflicts among users; or restoring degraded or over-

[17] Under the Barcelona, Noumea, Nairobi and Cartagena Conventions, respectively. Convention for the Protection of the Mediterranean Sea Against Pollution, Barcelona 1976, Convention for the Protection of the Natural Resources and Environment of the South Pacific Region, Noumea 1986, Convention for the Protection, Management and Development of the Marine and Coastal Environment of the Eastern African Region, Nairobi 1985, and Convention for the Protection and Development of the Marine Environment of the Wider Caribbean Region, Cartagena de Indias, 1983.

exploited areas. In the case of the Wider Caribbean, choosing one approach over another depends on the state of the resources one aims to protect (and thus whether the approach is proactive, interactive or reactive). There is mounting evidence from physical oceanography in the Caribbean that in order to protect coral reefs in some areas, seed sources of recruits need to be identified and protected in other areas, sometimes hundred of miles removed (Roberts, 1997). This in turn points to the importance of adopting a multilateral approach, which is likely to work more efficiently than the sum total of unilateral efforts that ignore the system dynamics. The SPAW Protocol provides the framework within which a regional network would allow for the protection at the ecosystem level.

Similar models were followed for the Nairobi, Noumea and Barcelona Conventions and all four cases are part of a growing regional approach to MPAs. In all cases, the scope of application of the Conventions is specified in the original forming treaty and it should be noted that they often apply both in areas of national jurisdiction and beyond, when the activities of member States are concerned. As a result, State Parties can agree to restrict their own activities on the high-seas. An even more interesting case in that regard is that of the Noumea Convention because in the South Pacific some areas of the high-seas are enclosed by the EEZs which have been proclaimed by the coastal States in the region. In that case, any State wishing to use resources of the high-seas must first transit through the EEZ of a coastal State, which makes it easier to monitor their activities.

Overall, therefore, the geographical scope of the regional agreements tends to be more limited than the global treaties but conversely, States appear to be more willing to restrict some of their activities if they trust their neighbours in the region to do the same. On paper at least, the potential for networks of MPAs, including some on the high-seas appears greater at the regional than at the global level.

1.4. International precedents

In addition to hard law and soft law as they have been described above, another important source of law is known as customary international law, where law is “made” through the practice of States who may not in theory be legally bound, yet agree to act in a co-ordinated fashion, over a substantive period of time, and with the intent of binding themselves. For instance, the Law of the Sea Convention was adopted in 1982 and did not enter into force until 1994. In the interim, most States had demonstrated by their activities (the so-called State practice) that they recognised most sections of the Convention as binding, even if they had neither signed nor ratified the Convention. The concept of EEZ for instance is now widely acknowledged as being part of customary international law.

In that respect, several examples have emerged that appear to show the willingness of States to see wide areas of the high-seas set aside in order to restrict at least some limited uses. Two such examples occurred within the work of the International Whaling Commission, the other within the UN General Assembly. Under the IWC regime, two sanctuaries were designated on the high-seas, first in the Indian Ocean and then within the Southern Ocean. Through the designation of these sanctuaries, the IWC endorsed the idea that a single use (whaling) can be restricted, and in this case completely banned, in an area of the high-seas (Donovan, 2001). A more remarkable phenomenon occurred when the UN General Assembly adopted a ban on the use of drift-nets on the high-seas, because UN General Assembly Resolutions are not legally binding.

It is very important to note, however, that at least in the case of the IWC sanctuaries some States have expressed their refusal to be bound by the measures. Such a refusal is perfectly legal since the Whaling Convention allows States to object and opt out of measures adopted by the Commission. Any State can also refuse to be bound by *an emerging* legal principle. But the reverse is also true, in that a community of nations is entitled to bind itself under international law, even if it is well aware that its intention is not shared by other States. Legally, therefore, a group of States is allowed to designate an MPA on the high-seas, where it can agree to limit uses for those States willing to be bound. The only limit to such a possibility is that any such measure can only be applied to States willing to be bound.

2. MAKING THE MOST OF THE EXISTING LEGAL REGIME AND FOSTERING CHANGE

As the previous section has shown, the current legal regime should not be viewed as an obstacle to the designation of high-seas MPAs. Although many parts of the legal framework are unclear on the relevant points, it is clear that a lot can be achieved by making full use of its parts. Nevertheless, it is important to identify the areas of the regime that might hamper the establishment of high-seas MPAs since these are clearly a tool that may become more useful as pressure on the resources increases. By identifying what flaws may exist in the regime, States with an interest in high-seas conservation stand a chance to address them, by encouraging change and adaptation in the regime.

2.1. Paving the way for new law: leading by example in customary international law

Marine protected areas are sometimes described as an insurance scheme, a mechanism through which we protect what we know to be of significant value, even if clear impacts cannot yet be identified. In that respect, MPAs can be a true embodiment of the precautionary principle, where we protect a resource either because we are not sure what impacts it is submitted to (as is often the case in the marine realm), or because we are not sure what use would be sustainable. In doubt, the reasoning goes, protect the resource until you know that the use you are planning will be sustainable over time. This approach to MPA management, however, is much more theoretical than practical, and few States have the foresight or resources to protect marine resources in such a way.

This may also be due to the fact that precaution is a very new legal principle, whose implementation is still somewhat random and often inadequate. There is, however, comfort to be drawn from the fact that the new generation of post-UNCED international instruments have, more often than not, incorporated this principle. This outcome is the result of the political will of some States who, when they negotiate international instruments insist on its incorporation. International environmental law rarely emerges spontaneously. MPAs are a balance between conservation objectives and restriction of uses, a State willing to designate, and abide by a high-seas MPA commits to restricting its use on the high-seas where, in theory at least, it could avoid to do so. In this case the benefit of the MPA (conservation of the resource) is greater than the cost (further restriction of uses that might have been permissible) for the State involved.

Because of the inherent nature of international law, no State is bound on the high-seas unless it is willing to do so. The UN General Assembly Resolution was effective only because States agreed to abstain from using drift-nets on the high-seas.[18] Likewise, the IWC Southern Ocean sanctuary measure is not applicable to those members who indicated that they did not want to be bound. As a result, States cannot expect others to follow measures that they themselves are not willing to abide to. Furthermore, the only hope for an evolution in the regime, and for a fuller incorporation of the precautionary and ecosystem approaches on the high-seas, will be through the action of some States willing to restrict their own uses on the high-seas, in the hope that others will follow suit. Some States have already indicated that they would be willing to try and adopt such a strategy and, insofar as their objective is the conservation of high-seas resources, their efforts should be encouraged and supported. Naturally, no one State can hope to end overfishing on the high-seas single-handedly. Like-minded States are likely to cooperate as they restrict their uses but the impact of their effort will be limited unless the main users in the area cooperate. On an equity level, such cooperation also makes sense as few States have an interest in conserving the resources if they know that others will take advantage of their restraint to fish even more, thus undermining any conservation measure.

As far as fisheries are concerned, most States fishing on the high-seas now have a blank slate with the adoption of the Fish Stocks Agreement. The Agreement clearly refers to the duty of States to cooperate, and to set up regional fisheries management organisations where they do not exist and to strengthen existing ones. Within that context, States can demonstrate their commitment to conservation by closing some areas to fishing, for instance around previously un-fished seamounts. If one RFMO is successful in taking such an approach, others are likely to follow suit.[19]

At each level, whether regionally or globally, States have an opportunity to cooperate and develop international law to recognise the unique role that can be played by high-seas MPAs. Another option is to actually modify the existing legal regime through new negotiations.

2.2. The UNCLOS precedents

A number of legal experts have argued that UNCLOS is such a carefully crafted instrument that it cannot and should not be amended lest the balance that it strikes be imperilled (Platzoder, 2001). This view however, is somewhat static and does not take into account the evolution that has taken place since the adoption of the Convention close to twenty years ago. At the very least, one needs to acknowledge that the balance embodied in UNCLOS is actually shifting and that we now know much more than we did then. If UNCLOS were to be negotiated today, it would most certainly look different and more recent concerns that have emerged in the last twenty years would be more specifically outlined and incorporated. In fact, precedent has shown us that when it was inadequate the UNCLOS regime was either amended (in the 1994 Agreement on deep-sea mining) or built upon (in the 1995 Fish Stocks Agreement and in the various Regional Seas Conventions).

The negotiations on straddling and highly migratory fish stocks are a perfect example of an issue that was first tackled during the Law of the Sea negotiations, was then taken up in the course of the Earth Summit and where, after both these efforts failed, the issue was taken up again in the course of a conference called for in Agenda 21. The first two failures were no indication that the issue was not urgent, but rather that most States had not yet reached the

[18] In theory at least. It remains to be seen whether this Resolution will continue to be effective in practice.
[19] As mentioned above, some RFMOs have already established closed areas where fishing is not permitted, though not specifically over a seamount.

point where they were willing to relinquish enough sovereignty over fishing on the high-seas to give birth to a new regime.

The question at this point, then, is to know if enough States are concerned enough about high-seas biodiversity to amend, or build upon the UNCLOS regime to give greater importance to high-seas protection. Even if this is not yet the case, those States with an interest to do so can nevertheless start modifying customary international law through their own State practice.

3. POLITICAL OBSTACLES AND HOW TO OVERCOME THEM

3.1. The lowest common denominator

The designation of MPAs on the high-seas is an eminently political exercise. Establishing any sort of jurisdiction over a high-seas area that is sure to raise the concern of States that have traditionally made the most of the Freedom of the high-seas. The problem here lies in the absence of a centralised, overarching jurisdictional authority that could take action and impose measures on States on the high-seas. As a result, any single State or group of States that refuses an evolution in international law can single-handedly undermine the efforts of the international community as a whole. It is therefore in the common interest to try and focus on approaches that will meet with consensus, or at least quasi-consensus. Several practical steps can be taken to that end.

First, and because they tend to provoke such negative reaction, the adoption of high-seas MPAs should really be restricted to cases where no other traditional measures could achieve the same goal. Again, the UN Resolution on drift-nets is a good example of a measure, in that case gear restriction, that was targeted to the problem at hand.

Second, it might be wise to focus initially on resources that are under direct and actual threat, rather than on those that may (or may not) come under threat in a number of years. With an increased sense of urgency comes the realisation that action must be taken fast.

Third, one should always keep in mind the costs and benefits of MPAs on the high-seas. One of the inherent flaws of MPAs tends to be that the winners and losers are not clearly identified,[20] that the costs tend to overshadow the benefits and that the winners do not always compensate the losers.[21] A perfect illustration of that point would be an MPA established merely to keep an area pristine for future generations, where the current users are ignored and/or fail to be compensated. In such a case, costs could be limited, for instance, by restricting the size of the MPA to that which is strictly necessary or by allowing all other uses that will not adversely impact the resource protected. Another (environmentally undesirable) alternative would be to wait for the pressure on a resource to increase, until the benefit of protecting it overtakes the costs incurred as a result of the protection.

[20] Costs traditionally associated with MPAs include direct costs, indirect costs and opportunity costs. For a clear explanation of costs and benefits of MPAs see Dixon, J.A., and Sherman, P.B., Economics of Protected Areas. A new Look at Benefits and Costs. Island Press, Washington DC, 1990.

[21] The "losers" of MPAs are those users whose use is regulated in the protected area, whereas the "winners" will benefit from the degree of protection afforded. The benefits can be accrued through time, whereas the costs are felt as soon as the MPA is designated.

Fourth, sufficiently strict measures can be taken on the high-seas without incorporating them *stricto sensu* into an MPA. This change in label may appear as a cosmetic measure, but adverse political reaction can sometimes be averted through such modification.

Fifth, if and when a high-seas MPA is established, its management should be carefully monitored and the restrictions on the uses adapted to reflect the status of the resources. In other words, on the high-seas it may not be possible to be as generous with conservation measures (perceived by some as use restrictions) as one might be in the coastal area or in waters under national jurisdiction.

Sixth, any effort to set up an MPA on the high-seas will depend on a careful assessment of the international political climate. This climate in turn can be somewhat influenced by the collection and timely dissemination of relevant scientific information. Some States may be insufficiently informed as to the state of resources on the high-seas and better information may very well sway their opinion as to the necessity of designating MPAs.[22]

Finally, at some point, action may be required even if a State or group of States is still reluctant to see the existing regime in any way amended or strengthened. First, the number of States participating can hope to have a significant impact (albeit one less important than if consensus had been reached). Second, one can hope that once a sub-regime is established among cooperating States, others more recalcitrant will be brought into the fold through a number of diplomatic measures.[23]

3.2. The “Seamount Experiment”

While they wait for the international legal regime to evolve, States should seriously consider an experiment by establishing high-seas MPAs over a seamount where fishing has not yet begun. One of the benefits of such an experiment would be to show other States, who may have another interest in high-seas resources, that a voluntary MPA scheme can work beyond national jurisdiction. In such an endeavor, however, it will be very important to ensure that it can and does work. Where a successful effort will carry a very high value as a demonstration of the value of this mechanism, an unsuccessful one may unjustly doom all future uses of the concept.

Focusing on a seamount also makes sense because history has shown that fisheries in these areas are infallibly unsustainable and recent evidence shows that given the chance fishing fleets will move into un-fished areas where they feel return on their investment will likely be high. (Koslow 2001, Gordon 2001)

From a legal standpoint, States wishing to participate in a seamount experiment can also avail themselves of the Fish Stocks Agreement and establish an RFMO with a declared objective to adopt a precautionary approach, through the designation of an MPA.

An additional benefit of setting up an MPA over an un-fished seamount is that only future uses would be restricted and no current users would be displaced (and no losers would need to be compensated). Access to other users, such as shipping traffic, could remain unrestricted.

In short, a seamount may be the one area where an experimental MPA would be most likely to succeed because of the reality of the threat on the resources, the political will of some States

[22] This collection and dissemination of information is a role for which such NGOs as WWF and IUCN are particularly well suited.
[23] The Fish Stocks Agreement for instance provides for measures that RFMOs can take against non-members if they undermine the conservation and management measures adopted.

who have expressed an interest in the issue and the existence of a usable legal sub-regime to draw from (the Fish Stocks Agreement and possible RFMOs). Paradoxically, however, the designation of an MPA could also be a signal to distant water fleets that valuable resources are found around that seamount and encourage them to start fishing in the area, if they are flying the flag of a State that is not Party to the Fish Stocks Agreement.

Conclusion

As all the scientific evidence points out, urgent action is required to conserve marine living resources of the high-seas. Whether or not such action takes the form of high-seas MPA, action is required now. This action should take place both immediately and over the longer term.

References

Agardy, T.S. (1997). *Marine Protected Areas and Ocean Conservation*, Environmental Intelligence Unit, Academic Press.

Baker, M., Bett, B., Billett, D., and Rogers, A. (2001). *The status of natural resources on the high-seas - an environmental perspective*. WWF / IUCN, Gland, Switzerland

Churchill, R.R. & Lowe, A.V. (1988) *The Law of the Sea*. Manchester University Press.

Cripps, S.J. & Christiansen, S. (2001) A strategic approach to protecting areas on the high-seas. In: *Expert Workshop on Managing Risks to Biodiversity and the Environment on the High-seas, including Tools such as Marine Protected Areas - Scientific Requirements and Legal Aspects*. 27 Feb.-4 Mar. 2001, Vilm, Germany.

Donovan, G. (2001) Legal Aspects of Sanctuaries (Marine Protected Areas) and the International Whaling Commission. In: *Expert Workshop on Managing Risks to Biodiversity and the Environment on the High-seas, including Tools such as Marine Protected Areas - Scientific Requirements and Legal Aspects*. 27 Feb.-4 Mar. 2001, Vilm, Germany.

de Fontaubert, A.C. (2001) *The Convention for the Prevention of Fishing with Long Driftnets in the South Pacific*, Oxford University Press Encyclopedia of Global Change, in Press.

de Fontaubert, A.C. (2000). *Institutional and Legal Framework of Marine Protected Areas*. In: Salm & Clark, Marine and Coastal Protected Areas, A Guide for Planners and Managers, IUCN, Gland.

de Fontaubert, A.C. with Agardy, T.S. (1998). *Critical Analysis of the Protocol on Specially Protected Areas and Wildlife to the Cartagena Convention: the Dilemma of Regional Cooperation*. University of Miami Inter-American Law Review 30:85-98.

de Fontaubert, A.C., Downes, D.R., and Agardy, T.S. (1996). *Biodiversity in the Seas: Implementing the Convention on Biological Diversity in Marine and Coastal Habitats*, IUCN, Gland.

Fonteneau, A. (2001). Potential Use of Protected Areas Applied to Tuna Fisheries and Offshore Pelagic Ecosystems. In: Expert Workshop on Managing Risks to Biodiversity and the Environment on the High-seas, including Tools such as Marine Protected Areas - Scientific Requirements and Legal Aspects. 27 Feb.-4 Mar. 2001, Vilm, Germany.

Freestone, D. (1992) Protection of Marine Species and Ecosystems in the Wider Caribbean – The Protocol on Specially Protected Areas and Wildlife. Marine Pollution Bulletin, Vol.22, No.12, pp. 579-581.

Gjerde, K.M. (2001) Protecting Particularly Sensitive Seas Areas from Shipping: A Review of IMO's New PSSA Guidelines. In: Expert Workshop on Managing Risks to Biodiversity and the Environment on the High-seas, including Tools such as Marine Protected Areas - Scientific Requirements and Legal Aspects. 27 Feb.-4 Mar. 2001, Vilm, Germany.

Gordon, J.D.M. (2001) , Deep-water Fish and Fisheries. In: Expert Workshop on Managing Risks to Biodiversity and the Environment on the High-seas, including Tools such as Marine Protected Areas - Scientific Requirements and Legal Aspects. 27 Feb.-4 Mar. 2001, Vilm, Germany.

Juniper, S.K. (2001). Background Paper on Deep-Sea Hydrothermal Vents. In: Expert Workshop on Managing Risks to Biodiversity and the Environment on the High-seas, including Tools such as Marine Protected Areas - Scientific Requirements and Legal Aspects. 27 Feb.-4 Mar. 2001, Vilm, Germany.

Kimball, L.A. (2001) How to Use International Law and Organisations to Achieve Sustainable Use of Marine Resources: Fishing Sustainably, Controlling Marine Pollution and Preserving Marine Habitat and Ecological Services. IUCN, Gland, In press.

Kimball, L.A. (1995) "The United Nations Convention on the Law of the Sea: A Framework for Marine Conservation." In IUCN, The Law of the Sea: Priorities and Responsibilities in Implementing the Convention. IUCN, Gland.

Koslow, A. (2001). Fish stocks and benthos of seamounts. In: Expert Workshop on Managing Risks to Biodiversity and the Environment on the High-seas, including Tools such as Marine Protected Areas - Scientific Requirements and Legal Aspects. 27 Feb.-4 Mar. 2001, Vilm, Germany.

Osborn, D. (2001) Challenges to Conserving Marine Biodiversity of the High-seas through the use of Marine Protected Areas – An Australian Prospective. In: Expert Workshop on Managing Risks to Biodiversity and the Environment on the High-seas, including Tools such as Marine Protected Areas - Scientific Requirements and Legal Aspects. 27 Feb.-4 Mar. 2001, Vilm, Germany.

Platzoder, R. (2001). The United Nations Convention on the Law of the Sea and Marine Protected Areas on the High-seas. In: Expert Workshop on Managing Risks to Biodiversity and the Environment on the High-seas, including Tools such as Marine Protected Areas - Scientific Requirements and Legal Aspects. 27 Feb.-4 Mar. 2001, Vilm, Germany.

Roberts, C.M. (1997). Connectivity and Management of Caribbean Coral Reefs. Science Magazine, Vol. 278, No. 5342, 21 November 1997, pp. 1454-1457.

Salm, R. and Clark, J., Marine and Coastal Protected Areas: A Guide for Planners and Managers, 3rd edition, IUCN, Gland, 2000.

Thiel, H. (2001). MPAs for Monitoring and Scientific Reference on the High-seas. In: Expert Workshop on Managing Risks to Biodiversity and the Environment on the High-seas, including Tools such as Marine Protected Areas - Scientific Requirements and Legal Aspects. 27 Feb.-4 Mar. 2001, Vilm, Germany.

Warner, R. (2001). Marine protected areas beyond national jurisdiction: existing legal principles and future legal frameworks. In: Expert Workshop on Managing Risks to Biodiversity and the Environment on the High-seas, including Tools such as Marine Protected Areas - Scientific Requirements and Legal Aspects. 27 Feb.-4 Mar. 2001, Vilm, Germany.

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WWF's mission is to stop the degradation of the planet's natural environment and to build a future in which humans live in harmony with nature, by:

- conserving the world's biological diversity
- ensuring that the use of renewable natural resources is sustainable
- promoting the reduction of pollution and wasteful consumption.