State of the World's Oceans

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Preface

The world's oceans cover 70% of the earth's surface and are home to a myriad of amazing and beautiful creatures. However, the biodiversity of the oceans is increasingly coming under serious threat from many human activities including overfishing, use of destructive fishing methods, pollution and commercial aquaculture. In addition, climate change is already having an impact on some marine ecosystems. This book discusses some of the major threats facing marine ecosystems by considering a range of topics, under chapters discussing biodiversity (Chapter 1), fisheries (Chapter 2), aquaculture (Chapter 3), pollution (Chapter 4) and the impacts of increasing greenhouse gas emissions (Chapter 5). It goes on to explore solutions to the problems by discussing equitable and sustainable management of the oceans (Chapter 6) and protecting marine ecosystems using marine reserves (Chapter 7).

Presently, 76% of the oceans are fully or over-exploited with respect to fishing, and many species have been severely depleted. It is abundantly clear that, in general, current fisheries management regimes are to blame for much of the widespread degradation of the oceans. Many policy-makers and scientists now agree that we must adopt a radical new approach to managing the seas – one that is precautionary in nature and has protection of the whole marine ecosystem as its primary objective. This 'ecosystem-based approach' is vital if we are to ensure the health of our oceans for future generations.

The ecosystem approach is one that promotes both conservation and sustainable use of marine resources in an equitable way. This is an holistic approach which considers both environmental protection and marine management together, rather than as two separate and potentially mutually exclusive goals. In this regard, the establishment of networks of fully protected marine reserves is paramount to the application of the ecosystem-based approach. Marine reserves act like national parks of the sea. They provide protection of whole ecosystems and enable biodiversity to both recover and flourish. They also benefit fisheries because there can be spill-over of fish and larvae or eggs from the reserve into adjacent fishing grounds.

Outside of the reserves an ecosystem-based approach requires the sustainable management of fisheries and other resources. It requires protection at the level of the whole ecosystem. This is radically different from the present situation where most fisheries management measures focus on single species and do not consider the role of species in the wider ecosystem. An ecosystem-based approach is also precautionary in nature which, in practice, means that a lack of knowledge does not excuse decision-makers from taking action, but rather they err on the side of caution. To achieve this, the burden of proof must be placed on those who want to undertake activities, such as fishing or coastal development, to show that these activities will not harm the marine environment, before the action is permitted. This will encourage sustainable development of fisheries, while limiting destructive practices.

As a way of implementing an ecosystem-based approach, Greenpeace is advocating the establishment of a global network of marine reserves covering 40% of the world's oceans. Because many marine ecosystems have become degraded and protection of biodiversity is vital, urgent action is needed to implement these marine reserves.

Foreword

I will never forget my first sight of a coral reef. I was 20 and Saudi Arabia my first foray abroad. The July heat in Jeddah topped 40°C as I pulled on mask and snorkel by a dusty roadside. Stretching ahead of me, lagoon waters shimmered inviting hues of green and brown. They darkened suddenly to indigo beyond a ragged line of breakers far offshore where the reef fell away into Red Sea depths. Hot lagoon brine gave scant relief from the scorching sun as I threaded my way among razor edged corals and fragments of storm-tossed rock. I struggled through a blizzard of surf at the reef crest until the water cleared beyond and the reef came alive around me. I had read widely on coral reefs that summer but none of it prepared me for the thrill as I entered a world beyond my imagination.

Fish surrounded me. Blue-sided surgeonfish, striped Abudefduf, clouds of orange Anthias hovering like butterflies, stately unicornfish, goggle-eyed porcupine fish, scowling eels. It was hard to take in even a tenth of what I saw. I felt like the Governor of a Newfoundland colony who wrote in 1620, "the Sea, so diversified with … Fishes abounding therein, the consideration of which is readie to swallow up and drowne my senses not being able to comprehend or expresse the riches thereof." Coral reefs have been around in one form or other for hundreds of millions of years and nature has had plenty of time to experiment. For variety of colour, form and sheer exuberance of life they are unmatched in the sea.

I had little reason to think then that life on this or other reefs would ever be different. The geological durability of rock forged by living coral over hundreds of thousands of years connected me with deep history. It gave the fleeting lives of the fish and invertebrates around me an unshakeable permanence. But I have come to realise that coral reefs have a tenuous hold on life today. Our own species could soon bring this ancient and remarkable ecosystem to an abrupt end. In the 25 years since my first encounter, coral reefs throughout the Indian and Pacific Oceans have lost an average of 1% of their coral cover per year. In the Caribbean, coral cover has declined from around 50% to 10% over the last 3 decades.

The many causes of coral loss are chronicled in this book and include overfishing, pollution, disease epidemics, development, global warming and ocean acidification, among others. They are problems that, to greater or lesser degrees, afflict every place, every habitat and every species in the sea. That the root causes of harm can all be traced to us is testament to the dominance humanity has now achieved over this planet. Even as little as 50 years ago, it was still possible to believe that much of the sea was beyond our reach and therefore wild. Monsters real and imagined lurked in unplumbed depths. Today they are mostly imagined because so many of the titans that once inspired fear and awe in seafarers have been lost to hunting and fishing.

While the challenge of recovering life in the sea is immense, there is much reason to hope. As this book reveals, sea creatures show astonishing resilience when we give them space to live lives free from harm. Where fully protected marine reserves have been established, stocks of food fish increase, habitats rebuild and productivity can be restored. The benefits continue to accrue for decades after protection commences and, like bank deposits, the longest established reserves deliver the greatest dividends.

With power comes responsibility. To date we have exercised much power but little responsibility in the sea. Our predecessors saw marine creatures as commodities and measured their worth in cash. Managers still focus too much on what we take from the sea, to the detriment of the many ways in which intact marine ecosystems benefit our lives. This book explains what we have done to the sea, what ocean life does for us, and why it is vital that we restore the richness and vitality of our oceans.

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Contents

Chapter 1
Biodiversity

Abstract The term biodiversity refers to the total variability of life on earth. In the oceans about 300,000 species are known but it is likely that there are many more, undescribed species. This chapter discusses the biodiversity of a selection of marine habitats including the deep ocean, the open oceans, and, in the coastal zone, coral reefs, mangroves and seagrasses.

Keywords Biodiversity, deep oceans, seamounts, hydrothermal vents, coral reefs, mangroves, seagrasses, conservation

The deep oceans beyond the continental shelf regions are home to many species. For example, underwater mountains, known as seamounts, represent a treasure house of biodiversity. They support corals, sponges, anemones, rock-dwelling invertebrates and huge aggregations of many fish. However, the rich life on some seamounts has been destroyed by the highly destructive practice of bottom trawling, and stocks of some fish species have been severely depleted. To prevent further destruction it has been suggested by some that the United Nations should establish a moratorium on bottom trawling.

The deep oceans are also host to hydrothermal vents – geysers on the seafloor that gush hot water into the cold deep waters. Hydrothermal vents support a diverse array of very unusual life forms. Currently, one of the greatest threats to these life forms is bioprospecting, that is, the exploration of biodiversity for both scientific and commercial purposes. It is possible that mining the deep sea for metal ores may also threaten hydrothermal vent sites in the near future.

Out in the open oceans there are some features that enhance biodiversity. Where warm and cold currents mix, food becomes concentrated and this is a haven for wide-roaming animals such as tuna, sea turtles, seabirds and whales. Other features include upwellings where deep, cooler and usually nutrient-rich water moves to the ocean surface and supports many open-water fish. Drift algae, which floats on the sea surface, and is often associated with fronts and eddies, also provides vital support for many species at some stage in their life-cycle. All these features may ultimately need to be included in plans for marine reserves in order to protect the high biodiversity they support.

Adjacent to coastal regions and supporting high biodiversity are coral reefs, seagrass meadows and mangrove forests. These features are not only important in terms of their biodiversity but they also provide coastal protection from wave and storm impacts. However, all of these ecosystems are threatened by human activities. For example, commercial reef fisheries and overfishing has caused serious degradation of coral reefs and loss of biodiversity. Intense competition means that some fishers have resorted to the use of destructive fishing techniques including explosives and cyanide. Mangroves are threatened by the pressures of increasing populations, industrial and urban development and commercial aquaculture practices. An estimated 35% of the original area of mangroves has been lost in the past 2 decades. In regard to seagrass beds, there is increasing concern about worldwide losses due mainly to coastal development. Threats include dredging operations, nutrient pollution, industrial pollution and sediment inputs. Paramount to the protection of coral reef, mangrove and seagrass habitats will be the establishment of more and effective marine reserves. Moreover, because some species live in-between and use more than one of these habitats, it has been suggested that efforts should be made to protect connected corridors of these ecosystems.

1.1 Introduction to Biodiversity

The term biological diversity, or the shortened form, "biodiversity", refers to the total variability of life on earth. The United Nations Convention on Biological Diversity uses the following definition of biodiversity (UNEP 1995):

> *'Biological diversity' means the variability among living organisms from all sources, including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are a part; this includes diversity within species, between species and of ecosystems.*

The most common usage of the term biodiversity refers to the number of species found in a given area, or species diversity (Gray 1997). For the earth as a whole, most estimates of the total number of species lie between 5 and 30 million. Of these, about two million species have been officially described, and the rest are unknown or unnamed. (Millennium Ecosystem Assessment 2005). More species are known of on land than in the sea. It has been estimated that there are, in total, approximately 300,000 known marine species (Gray 1997). The difference between land and sea is partly due to the very high diversity of beetles (Coleoptera) – 400,000 species are described. The difference may also be due to the fact that more study has been done on land than at sea (UNEP 1995).

At the level of phylum (the classification of all animals into broad groupings) marine diversity is close to twice that on land. For example, of the 33 animal phyla recognized in 1995, 32 occur in the sea; 15 are exclusively marine and 5 are nearly so (UNEP 1995). In contrast, only one phylum occurs exclusively on land. The most diverse ecosystems in the ocean, such as coral reefs, may have levels of species diversity roughly similar to the richest ecosystems on land, such as lowland tropical rain forests (UNEP 1995).

This chapter focuses on biodiversity of the deep oceans (Section 1.2), the open ocean pelagic zone (Section 1.3), coral reefs (Section 1.4), mangroves (Section 1.5) and seagrasses (Section 1.6).

1.2 The Deep Oceans

The deep sea covers about 70% of the Earth and has an average depth of 3,200 m (Prieur 1997). Of the oceans that lie beyond the continental shelves, 88% are deeper than 1 km and 76% have depths of 3–6 km (UNEP 2006a). Despite the darkness of the deep ocean, near freezing temperatures and scarce energetic supplies, the deep ocean supports a surprisingly high diversity of species. This was first discovered by sampling of deep sea sediments in the 1960s by the Woods Hole Oceanographic Institute (Grassle 1991).

About 50% of the deep ocean floor is an abyssal plain comprised mainly of mud flats. Superimposed on the deep sea bed are other deep sea features including submarine canyons, oceanic trenches, hydrothermal vents and underwater mountains called seamounts. This great variety of benthic (sea bottom) habitats support multitudinous life forms (UNEP 2006a). On the sea bed, the large animals (megafauna) are dominated by echinoderms (including brittle stars, sea stars and sea urchins). Other species present are crustaceans (including crabs), giant sized crustaceans called amphipods, sea cucumbers, bristle worms, sea spiders, bottom dwelling fish, sponges, benthic jellyfish, deep sea corals, deep sea barnacles, sea squirts and bryozoa (moss animals) (Gage and Tyler 2001). Koslow et al. (1997) noted that about 2,650 species of demersal (bottom dwelling) deep sea fish are known and suggested that, in total, there are probably about 3,000–4,000 species.

In addition to the marine animals listed above which dwell on or near to the seabed, a very high diversity of small animals are also found within the sediments of the deep sea. These animals are classified according to their size, the largest of which, macrofauna, are those retained by sieves with meshes of about 1 mm while even smaller animals, meiofauna, are retained by the finest screens down to a mesh opening of 62 μm or smaller. Together, the macrofauna and meiofauna comprise the most diverse component of the deep sea benthos (Gage and Tyler 2001). For instance, one study which sampled about 50 m^2 of sediments, identified 707 species of polychaete worms and 426 species of peracarid crustaceans (Grassle 1991). Other species of macrofauna which have been found in deep sea sediments are different sorts of worms, mites, other crustaceans, amphipods and molluscs. Meiofauna include nematode worms, certain copepods and crustaceans and single-celled organisms known as Foraminifera (Gage and Tyler 2001).

It was suggested in the early 1990s that the number of undescribed species in the deep sea may be as high as ten million. However, this was contested by others at the time and a more realistic suggestion of 500,000 was proposed (Gray 1997).

Deep water fisheries, that is fishing at depths of over 500 m, has increased in recent years as traditional fisheries on continental shelves have declined. However, the practice of deep water fishing is known to be extremely destructive to deep water marine ecosystems. Deep water fish species are often long-lived and slow to reach maturity and, hence, breeding potential, which renders them especially vulnerable to exploitation. Further detail on the biodiversity of seamounts and the need to conserve and protect them from deep sea fishing is discussed below.

1.2.1 Seamounts

Seamounts are undersea mountains which rise at least 1,000 m above the sea floor. Smaller undersea features with a height of between 500 and 1,000 m are defined as knolls and those rising less than 500 m high are defined as hills. The term seamount is, however, often also used to refer collectively to seamounts, knolls and hills.

Seamounts are usually formed by volcanic activity and they often occur in chains or clusters. Using the classification of seamounts being over 1,000 m high, it has been estimated that there are over 30,000 seamounts in the Pacific ocean, about 810 in the Atlantic and an indeterminate number in the Indian ocean (Rogers 1994). Kitchingman and Lai (2004) suggested that there may be over 50,000 seamounts worldwide. Plate 1.1 shows the location of known seamounts on a world map.

Despite some 30 years of studies directed at seamounts, the knowledge base on biodiversity remains poor (Johnston and Santillo 2004). For example, of the many thousands of seamounts, animal life has only been studied on almost 200 (Stocks 2004a). However, research to date on seamounts shows that these unique marine habitats represent a treasure house of biological diversity (McGarvin 2005). For example, according to Stocks (2004b), the total number of species found to be associated with seamounts to date was around 2,700. There is generally also a high abundance of life on seamounts, which has led to descriptions of them as 'underwater oases' (Stocks 2004b). Life is abundant at all trophic levels, from tiny plankton to rock-dwelling invertebrates and aggregates of fish populations in their vicinity (Fock et al. 2002; Koslow et al. 2001; Rogers 1994).

Water currents are enhanced around seamounts. Due to these enhanced currents, the animal life forms on the seamounts are dominated by suspension feeders (animals that feed by straining suspended matter and food particles from water) (Koslow et al. 2001). These animals include corals, anemones, featherstars and sponges (Stocks 2004b). They make seamounts visually striking and consequently seamounts have been likened to underwater gardens due to the branching tree-like and flower-like corals and sponges that cover many of them. Some stands of corals which have been discovered on seamounts are several centuries old. In addition to reef-building organisms such as corals and sponges, other invertebrate species common to seamounts are crustaceans, molluscs, sea urchins, brittle stars and polychaetes (bristle worms) (Stocks 2004b).

Many species of fish are associated with seamounts (Rogers 1994) and some are well known for the huge aggregations they form over these features. A study cited by Tracey et al. (2004) described 263 species of fish that were found on seamounts in the New Caledonian region. Perhaps the best-known fish that are associated

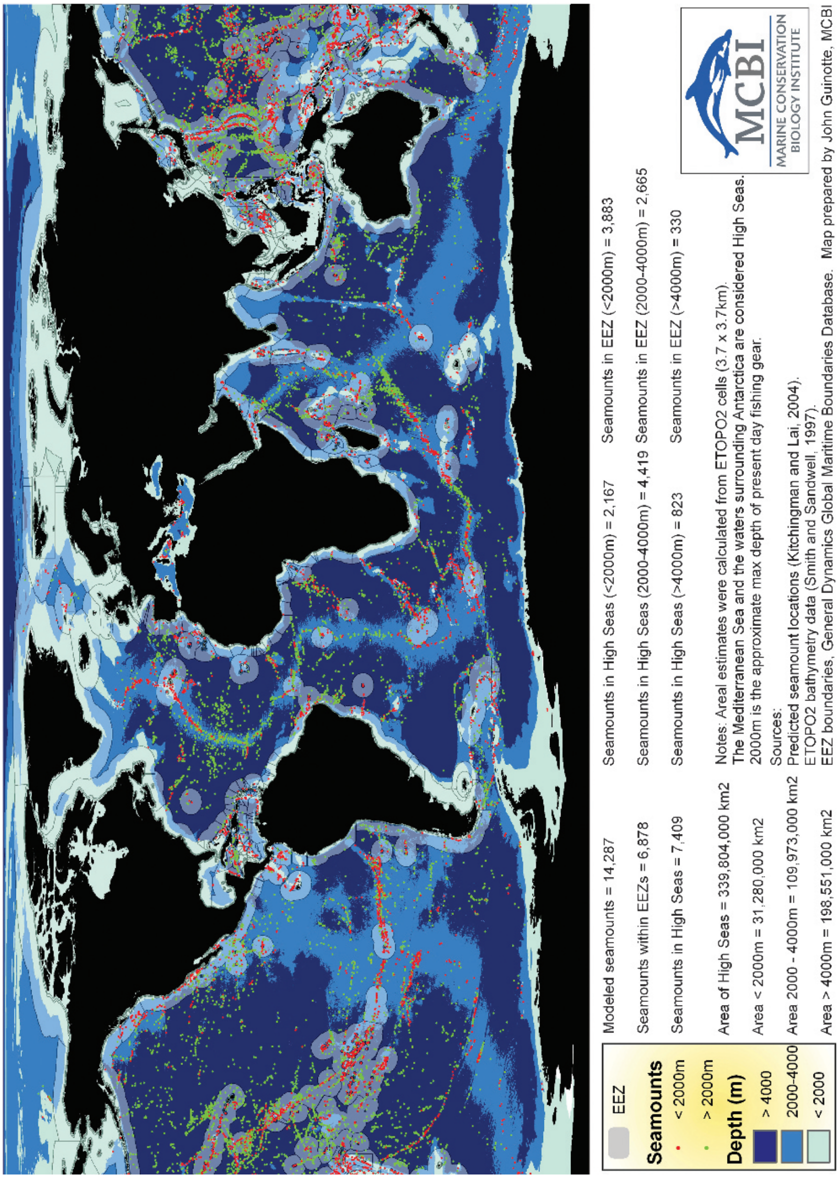

Plate 1.1 Global map of known seamounts

with seamounts are those that have been commercially exploited. These include the orange roughy (*Hoplostethus atlanticus*) which has a global distribution, alfonsinos (*Beryx decadactylus*) in the tropics and subtropics and the pelagic armourhead (*Pseudopentaceros richardsoni*) of the southern Emperor and North Hawaiian Ridge seamounts (McGarvin 2005; Rogers 1994). Migratory species such as tuna, marine mammals and seabirds are known to congregate over seamounts, which suggests they are important for these species (Stocks 2004b).

New species of marine organisms have been found on almost every seamount which has been studied. For instance, one study of seamounts off southern Tasmania found that 24–43% of the invertebrate species collected were new to science (Koslow et al. 2001). It is likely that most unsampled seamounts will also include as yet undiscovered species (Stocks 2004b). On some of the seamounts which have been studied, a high number of species that are endemic have been reported, that is, species which are restricted to only one seamount or seamount chain and have not been found elsewhere in the oceans. Stocks (2004b) cited studies which showed high levels of endemism; for example, 31–36% of species found in seamounts south of New Caledonia were endemic, and in the Pacific off the coast of Chile on two seamount chains, 44% of fishes and 52% of bottom-dwelling invertebrates were endemic. Because knowledge of all species in the oceans is incomplete, it is said that seamounts have 'apparently' high rates of endemism as it is not yet possible to know whether the species present do occur elsewhere in the oceans (Stocks 2004b).

Seamounts have come under intensive exploitation by trawl fisheries since the 1960s. The development of seamount fisheries has taken place in relative ignorance of the biology and ecology of seamounts (Johnston and Santillo 2004). For example, the life history of most seamount species is unknown but research on some species has shown they are generally long-lived (of the order of about seventy to hundreds of years) and slow growing (Koslow et al. 2001). This means that they are vulnerable to depletion by fishing because stocks are not replenished quickly. In addition, where species are endemic to just a single seamount or area of seamounts they rapidly become vulnerable to extinction when exploited (Stocks 2004b).

Fishing on seamounts has led to the depletion of some species and causes damage to communities of corals and other bottom dwelling life-forms (see also Chapter 2, Section 2.5.1.1 on bottom trawling). Stocks of pelagic armourhead (*Pseudopentaceros richardsoni*) over Pacific seamounts northwest of Hawaii were depleted to the point of commercial extinction in less than 20 years. Stocks of orange roughy (*Hoplostethus atlanticus*) have been severely depleted on some seamounts around Australia and New Zealand (Johnston and Santillo 2004). A scientific study of seamounts off the coast of southern Tasmania found that unfished seamounts had 46% more species per sample taken from the surface of the seamount than heavily fished seamounts. In addition, the biomass (weight of living organisms) of samples was 106% greater from unfished seamounts (Koslow et al. 2001). The study also reported that the impact on reefs of the heavily fished seamounts was dramatic, with the coral substrate and associated community largely removed. Other studies on seamount trawling have also shown that coral pieces are a common by-catch of fishing on seamounts. Damage to corals, sponges, anemones and other reef organisms on seamounts is particularly of concern because these species provide habitat for many other organisms (Stocks 2004b).

In summary, seamounts are unique habitats of the deep oceans that support multitudinous species in abundance, some of which are endemic. Seamounts also appear to be important to other migratory species. The fishing practice of bottom-trawling on seamounts is highly destructive to these rich havens of marine life. Greenpeace is campaigning for the UN to impose a moratorium on the practice of bottom-trawling (see also Chapter 2, Section 2.5.1.4). Such a moratorium would provide for the widespread protection of these fragile environments and make it possible to undertake the full scientific assessments needed to develop the permanent solutions necessary to conserve these rich and vulnerable deep sea ecosystems. Key to their long-term protection is the establishment of no-take Marine Reserves. Relatively few seamounts have so far been designated as Marine Reserves or Marine Protected Areas (Johnston and Santillo 2004). Greenpeace is campaigning for the implementation of a global network of Marine Reserves which would protect at least 40% of the world's oceans including particularly vulnerable areas such as seamounts from fishing and other threats such as seabed mining (Roberts et al. 2006) (see Chapter 7).

1.2.2 Deep Sea Hydrothermal Vents

A hydrothermal vent is a geyser on the seafloor which gushes hot water into the cold, deep ocean. These hot springs are heated by molten rock below the seabed (Gage and Tyler 1991). Deep-sea vents have been found in the Pacific, Atlantic, Arctic and Indian Oceans (Little and Vrijenhoek 2003). They are primarily concentrated along the earth's Mid-Oceanic Ridge, a continuous underwater mountain chain that bisects the oceans and is a 60,000 km seam of geological activity. It is thought that hundreds, if not thousands of hydrothermal vent sites may exist along the Mid-Oceanic Ridge but as yet only about 100 sites have been identified because they are very hard to find (Glowka 2003).

In 1977, scientists discovered that vents were populated with an extraordinary array of animal life. This was most unexpected because the environment around vents appears to be hostile to animal life – the fluid coming from vents is hot (up to 390°C), anoxic (without oxygen), is often very acidic and is enriched with hydrogen sulphide, methane and various metals (particularly iron, zinc, copper and manganese) (Little and Vrijenhoek 2003). However, these seemingly toxic fluids are now known to support high densities of animal communities.

After 30 years of research at hydrothermal vent sites, a total of over 550 species have been described (Ramirez-Llodra et al. 2007). The animals at vent sites are unique in that they do not rely ultimately on sunlight as an energy source for food, but on chemosynthetic bacteria which live off hydrogen sulphide in the vent fluids. Animals inhabiting vent sites survive either by consuming the free-living bacteria directly as food or by having a symbiotic relationship with them in which bacteria live within their tissues (Gage and Tyler 1991). It has been reported that vent environments support one of the highest levels of microbial diversity on the planet (Glowka 2003).

Animal species inhabiting vent sites include molluscs, gastropods, tube-dwelling worms, sea anemones and crustaceans (see for example Plate 1.2) (Gage and Tyler 1991; Little and Vrijenhoek 2003). Some species of fish have been found to live within vent environments and more live in their vicinity (Biscoito et al. 2002). Many animal species are exclusively native (endemic) to vent sites (Little and Vrijenhoek 2003). There is variation in the species existing at different vent sites (Van Dover 2005). Although the number of species found at any one vent site is relatively low (low species biodiversity), the abundance of animals is generally high. For example, enormous densities of a giant clam-like organism (*Calyptogena magnificica*) and a giant mussel (*Bathymodiolus thermophilus*) have been found in the area of vents of the Eastern Pacific (Gage and Tyler 1991). Typically, most of the species diversity at vent sites is attributed to small inconspicuous animals, but sites are dominated by a few large and visually striking species such as vestimentiferan tube worms (Siboglinidae), vent clams (Vesicomyidae) and mussels (Bathymodiolinae) and the blind vent shrimp (*Rimicaris exoculata*) (Little and Vrijenhoek 2003).

Plate 1.2 A dense bed of hydrothermal mussels covers the slope of the Northwest Eifuku volcano near the seafloor hot spring called Champagne vent. Other vent animals living among the mussels include shrimp, limpets, and Galatheid crabs (Pacific Ring of Fire 2004 Expedition. NOAA Office of Ocean Exploration; Dr. Bob Embley, NOAA PMEL, Chief Scientist)

1.2.2.1 Protection

The more accessible hydrothermal vents are potentially threatened by a number of human activities such as seabed mining for polymetallic sulphide deposits, submarine-based tourism and marine scientific research (Glowka 2003). Glowka proposed that of these, marine scientific research poses the greatest threat for the most visited vent sites due to, for example, concentrated sampling practices. It was suggested therefore that marine scientific research needs to be placed on a more sustainable footing at hydrothermal vents. Indeed, the unique biodiversity of deep-sea hydrothermal vents needs to be protected from all potentially human-based destructive practices. The most appropriate tool for protecting these environments is their designation as fully protected marine reserves. In this regard, there has been some headway in initiating protection for a few sites, namely the Endeavour Hydrothermal Vents Area (located in Canadian waters on the Juan de Fuca Ridge about 256 km southwest of Vancouver Island) and Lucky Strike and Menez Gwen vent fields in the North-east Atlantic Ocean (within Portugal's EEZ). For Endeavour, a proposal was made in 2002 for it to become a Marine Protected Area and this would mean that nothing could be removed from the area without a relevant license and submission of a research plan (Glowka 2003). In March 2003, the Endeavour Marine Protected Area was legalised by the Canadian government under the Oceans Act (Fisheries and Oceans Canada 2006). For Lucky Strike and Menez Gwen, the Worldwide Fund for Nature (WWF) worked with the Azores regional government to have these relatively shallow vents designated as Marine Protected Areas in 2002 (WWF 2008).

1.2.3 Bioprospecting in the Deep Sea

Bioprospecting is the exploration of biodiversity for both scientific and commercial purposes. There is no internationally accepted definition of bioprospecting. However, it can be summarised as the investigation of an area's biodiversity, and sampling of biological organisms for scientific research or commercial purposes. It is often difficult to differentiate between research on genetic resources for purely scientific purposes, and that for commercial activities. Generally, such resources are collected and analysed as part of a scientific research project, often as partnerships with scientific institutions and industry. At a later stage these resources and findings can enter the commercial arena as products derived from information discovered during these scientific endeavours (Greenpeace 2005a).

With advances in technology, bioprospecting has started to take off in the marine context. There is a realisation that many marine plants, animals and microorganisms contain unique biochemicals which could be integral to developing new products for use in the health, pharmacology, environmental and chemicals sectors.

Compounds that have been isolated from various marine species such as sponges, corals and sea slugs are now being sold commercially (Greenpeace 2005 f).

To date, most bioprospecting in the marine environment has taken place in shallower waters. However, scientists are beginning to appreciate the valuable resources that are housed in the depths of the high seas. Many of these deep-sea species have developed unique biological and physiological properties in which to survive in these extreme environments. These include slow growth, late sexual maturity, the ability to withstand cold, dark and highly pressurised environments, as well as a high level of endemism in many ecosystems. It is these properties that are attracting the interest of the scientific and commercial sectors. Yet these same properties make deep-sea species highly susceptible to disturbance and change (Greenpeace 2005 f).

At the moment, bioprospecting in the deep sea is still restricted to a very select sector – either commercially based or academic – that has both the technical and financial capital to exploit these resources. However, with ever-developing advances in technology, the opportunity to exploit these little-known resources is increasing. Continued scientific research to extend our knowledge of deep-sea ecosystems is important, but there are potentially detrimental impacts of this exploration, including physical disturbance or disruption of ecosystems, pollution and contamination, as well as problems of over-harvesting (Greenpeace 2005 f).

A potential future threat to deep-sea ecosystems from seabed disturbance is deep-sea mining for metal ores. For instance, it has recently been announced that a specialised deep-sea submersible is being developed for intended future use in dredging the seafloor for copper, gold and zinc (Heilman 2006). The submersible will be capable of reaching depths of 1,700 m and is scheduled to be ready for use in 2009. Mining is likely to happen around hydrothermal vents because such areas can contain high levels of mineral sediments. Disturbance by mining operations is a threat to the biodiversity of these regions.

Since much of the deep oceans lie beyond national jurisdiction there is currently no legal regime to regulate bioprospecting in the deep oceans. As such, it poses a threat to deep-sea ecosystems, which due to their unique biological characteristics are particularly vulnerable to habitat disturbance. Greenpeace believes that bioprospecting must be managed in a way that would minimise the potential impact and disruption to deep-sea ecosystems. This requires clear international regulations, which currently do not exist (see also Chapter 6, Section 6.3). What is needed is an integrated, precautionary and ecosystem-based management approach to promote the conservation and sustainable management of the marine environment in areas beyond national jurisdiction, including equitable access and benefit sharing of these resources. This could be provided by a new implementing agreement under the United Nations Convention on the Law of the Sea (UNCLOS). Greenpeace has suggested the necessary prerequisites for a new agreement in a report "Bioprospecting in the Deep Sea" (Greenpeace 2005 f). Only concerted international action by States to put such a legal framework into place will ensure the conservation and sustainable management of the planet's final frontier – the high seas.

1.3 Biodiversity Hotspots at Sea in the Pelagic (Open Water) Zone

The abundance and diversity of biological communities across the open oceans is only just beginning to be understood (Malakoff 2004; Worm et al. 2005). It has been found that some features of the pelagic zone are particularly favourable to enhancing biodiversity. These include areas where warm and cold currents mix. For example, wide-roaming pelagic animals such as tuna, sea turtles, seabirds and whales are known to follow “oceanic fronts”, where cold and warm water masses collide, and to congregate in other areas where food is concentrated. Recently, an area of about 125,000 km^2 off the Baja coast of California was identified where the cool southbound California current collides with a warmer northbound stream. Fishing records showed that this area had supported very high landings of swordfish and striped marlin over the past 35 years and other research showed that blue whales tended to linger in the region (Malakoff 2004).

Other features that are important for many pelagic fish are upwellings where deep and dense, cooler and usually nutrient-rich water moves towards the ocean surface and replaces the warmer, usually nutrient-deficient, surface water. The nutrients may then be used to support the growth of phytoplankton. In turn, phytoplankton may feed zooplankton, which are important in the food-chain for pelagic fishes. Upwelling systems are known to be important to many pelagic fishes and sustain a large proportion of the world’s fisheries (Paramo et al. 2003; Pauly and Christensen 1995; Ward et al. 2006).

A recent study investigated the global diversity of two predatory fish species, tuna and billfish, in the open oceans (Worm et al. 2005). The study revealed that there were peaks of diversity at intermediate latitudes (15°–30° North or South) and lower diversity towards the poles and the equator. The same latitudinal distribution was also found for zooplankton diversity. These results suggested that this global pattern of diversity could be general across several trophic levels (i.e. levels of the food chain from tiny zooplankton animals to fish that prey on the zooplankton to predatory fishes). The study also showed that the species diversity of zooplankton, tuna and billfish was linked closely to sea surface temperature and oxygen concentration, such that optimal habitats were characterised by warm waters (about 25°C) with sufficient oxygen concentrations. Fronts and eddies were also found to be important in supporting high diversity due to the concentration of food in these areas. The protection of such areas of high biological diversity in the pelagic zone is discussed below (Section 1.3.1).

Another pelagic habitat of great importance to marine biodiversity is drift algae. Drift algae accumulations float on the sea surface in some areas of the open oceans, existing as occasional clumps, expansive mats of up to several kilometres, or elongated lines. It provides vital support for many species at some stage in their lifecycle. This includes at least 280 species of fish, many invertebrates, 4 species of turtle in early life and some seabird species. Drift algae is thus an important habitat to many species in the open oceans. However, in some areas it is under threat from commercial harvesting for food, livestock fodder, fertiliser and medicine. Other threats to drift algae include commercial fishing, which is in direct association with algal mats, vessel traffic through drift algae habitat, and pollution (Hemphill 2005).

Paramount to the protection of open water features such as drift algae, upwellings and oceanic fronts is the establishment of marine reserves (see Chapter 7, Section 7.4.3).

1.4 Coral Reefs

Coral reefs are distributed in shallow seas throughout the tropics (Fig. 1.1). About one third of tropical coastlines are made of coral reefs and they occur in over 100 countries. Globally, coral reefs are estimated to occupy 284,300 km^2, an area which represents less than 1.2% of the world's continental shelf area. There are two distinctive regions of coral reefs worldwide, one centred around the wider Caribbean (the Atlantic), and the other reaching from East Africa and the Red Sea to the Central Pacific (the Indo-Pacific) (Spalding et al. 2001).

The majority of corals require a solid surface on which to grow, and this limits their formation to rocky substrates in the tropics. They cannot grow on fine muds or mobile sediments, so they are largely absent from river mouth areas and along stretches of sediment-laden coastlines (Spalding et al. 2001). Living coral is only a thin veneer, measured in millimetres, often covering the thick limestone structures (reefs) that the corals have laid down over very long periods. Archipelagoes consisting of hundreds of atolls, such as the Marshall Islands and the Maldives, are formed from coral reefs. The Great Barrier Reef in Australia is over 2,000 km long (Birkeland 1997).

Reef corals build calcium carbonate (limestone) skeletons and most derive at least some of their nutrition from photosynthesis by algae which live within their tissues (Sebens 1994). The ability of corals to construct massive calcium carbonate frameworks sets them apart from all other marine ecosystems (UNEP 1995). The resulting reef structure is complex and contains a superabundance of surfaces and spaces, many of them internal (Adey et al. 2000). This provides habitat and shelter for numerous species. For example, at the times of night or day that fish are inactive, many retreat into the reef to take shelter (Sale 1991).

1.4.1 Biodiversity of Coral Reefs

Coral reefs are the most biologically diverse ecosystems of the entire oceans. Their high species diversity has led to them being called "rainforests of the sea". As many as 100,000 reef-dwelling species may have been named and described to date (Spalding et al. 2001) although estimates of the total number of species

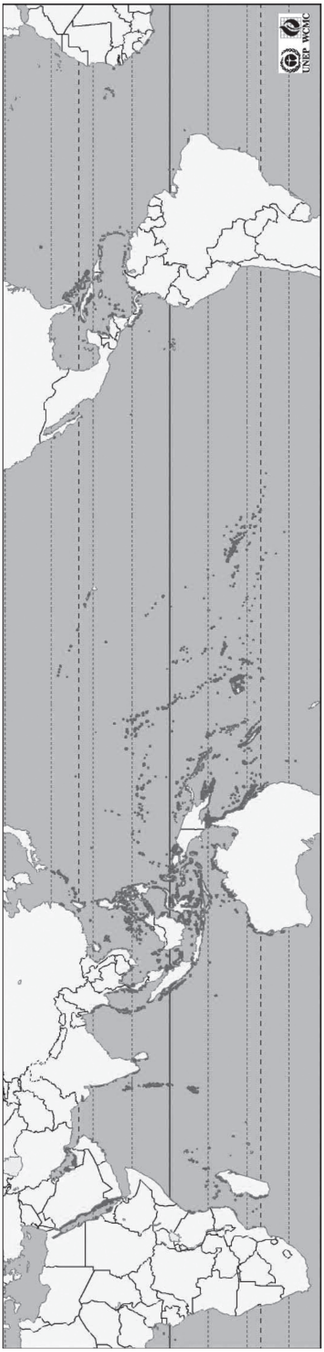

Fig. 1.1 World distribution of scleractinian corals (Spalding et al. 2001a, reproduced with permission from UNEP)

on the world's coral reefs of both one million and three million species have been proposed (Adey et al. 2000). The species diversity of corals and reef-dwelling organisms differs geographically, such that diversity declines going northwards and southwards of the equator (Sebens 1994). However, at a global scale, reefs appear to support high diversities of fish regardless of latitude (Ormond and Roberts 1997). Centres of particularly high biodiversity of coral reefs are located in the tropical Indo-West Pacific Ocean, called the East Indies Triangle (Briggs 2005).

Reefs in the Atlantic have a lower diversity of species than Indo-Pacific reefs. In the most biologically diverse coral reefs centred in the Philippines, Indonesia, Malaysia and Papua New Guinea there are 500–600 species of coral (Spalding et al. 2001). There are many other species inhabiting coral reefs including sponges, hydrozoa, jellyfish, anthozoans, worm-like animals, crustaceans, molluscs, echinoderms (such as starfish and sea urchins), sea cucumbers and tunicates (Spalding et al. 2001). It has been estimated that there are at least 4,000, perhaps even 4,500 species of marine fishes inhabiting the world's coral reefs. This represents more than a quarter of all marine fish species (Ormond and Roberts 1997). Sea turtles often make use of reefs as a source of food, and a number of seabird species are found regularly in coral reef environments. Several species of marine mammals can also be found in close proximity to coral reefs; for instance, dolphins regularly take shelter in bays and lagoons near reefs and sometimes feed on reef animals. Humpback whales breed close to coral reefs in Hawaii, the Great Barrier Reef and the Caribbean (Spalding et al. 2001).

Some coral reef organisms are also dependent on neighbouring seagrass beds and mangroves. For example, some coral reef fish use seagrass beds and mangroves as nursery grounds and some herbivorous fish forage in seagrass habitats by day and shelter on the reefs at night (Moberg and Folke 1999; Valentine and Heck 2005).

New species are still being discovered on coral reefs: in 2006, research by Conservation International in a region known as the Bird's Head Seascape off the coast of Indonesia's Papua Province, found more than 50 new species (Conservation International 2008; ENN 2006). This included 24 fish species and 20 species of coral that are new or likely to be new to science. Among the new fish discovered were two species of bottom-dwelling sharks, which use their pectoral fins to 'walk' across the seafloor. Biodiversity in the area is very high and Conservation International are now helping to establish a regional network of community and government-endorsed marine protected areas.

Figure 1.2 shows a diagrammatic representation of a healthy coral reef. A healthy reef contains species that perform critical functions for the maintenance and survival of the reef. For instance, herbivorous fishes can be divided into three different functional groups, namely scrapers, grazers and bioeroders. Scrapers remove algae and sediment from the reef and facilitate the settlement and growth of new corals. Grazers remove seaweed and thereby reduce coral shading and overgrowth by such species (Bellwood et al. 2004). Without herbivores the reef would be overgrown by faster-growing algae (Moberg and Folke 1999). Bioeroding fishes and urchins remove dead corals and expose the hard reef matrix for settlement by new corals and coralline algae (Bellwood et al. 2004). Besides herbivorous species, there

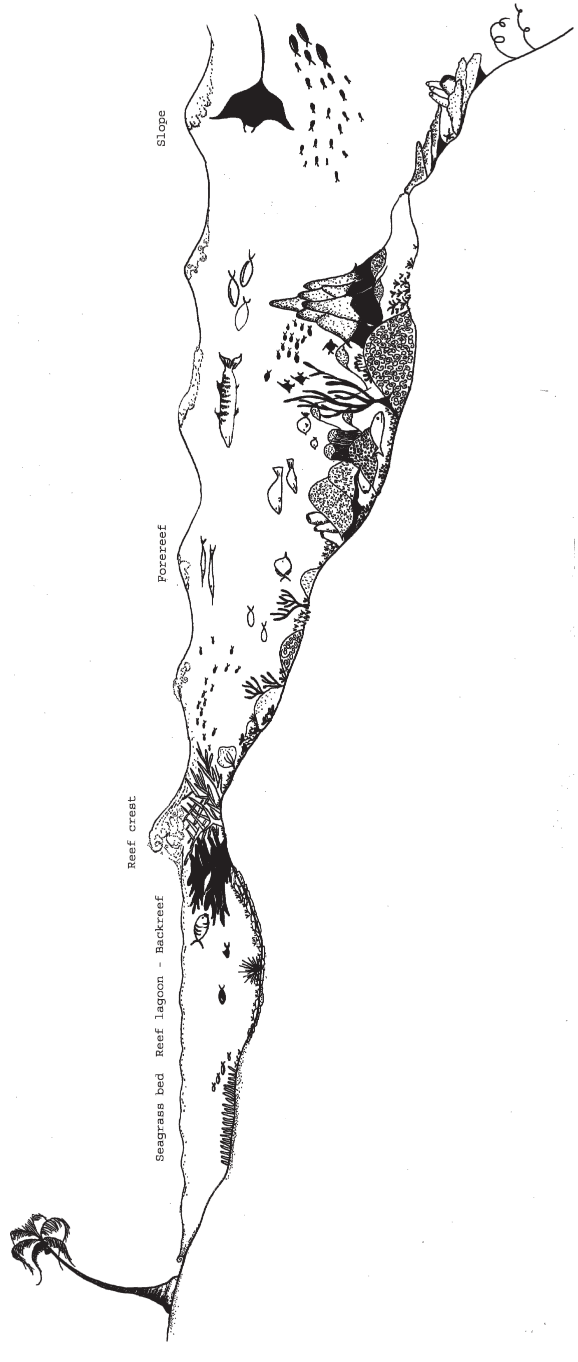

Fig. 1.2 Diagrammatic representation showing a profile through a typical healthy coral reef from slope to lagoon, including associated seagrass beds and sandy beach (Prepared by Sonja Bejarano)