Roadmap to Recovery:
A global network of marine reserves

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1. Summary

The high seas lie beyond the 200 nautical mile limits that define the extent of national sovereignty by countries of the world. They cover 64% of the area of the oceans, and nearly half the surface of the planet. They are a global commons, under the stewardship of the United Nations Law of the Sea for the benefit of all nations. But human pressures on the high seas are increasing fast, and urgent action is needed to protect them from harm. Recent research shows that industrial fishing has reduced populations of large, predatory fish, like tunas and billfish, by ninety percent or more in the last fifty years. Some particularly vulnerable species, like sharks, have been reduced by factors of a hundred, or even a thousand. In the process of capturing these fish, industrial fishing methods are killing untold numbers of other wildlife, endangering birds, turtles and marine mammals. In the deep sea, heavy bottom trawling gears are destroying seamount habitats that have taken thousands of years to develop and may be irreplaceable on human timescales. Much of this activity is illegal, unregulated or goes unreported.

In this report we present a design for a global network of high seas marine reserves. Marine reserves are highly protected areas that are off limits to all extractive and destructive uses, including fishing. They are the most powerful tool available for the conservation of ocean wildlife and may also benefit fisheries by promoting recovery and reproduction of exploited species. The network we propose aims to protect places that are biologically rich, supporting outstanding concentrations of animals and plants. It also seeks to protect places that are particularly threatened or vulnerable to present or possible future human impacts, like fishing or seabed mining. Our overarching aim is for a network that is representative of the full variety of life in the sea.

To achieve these aims, we brought together many different kinds of biological, physical and oceanographic data. Data on oceanographic features like water temperature gradients and upwelling areas, together with fishery and tracking data on oceanic megafauna, enabled us to identify places that are hotspots of activity on the high seas for large-bodied and vulnerable species. They included tunas and billfish, albatrosses, turtles, pinnipeds (seals and sea lions) and penguins, animal groups whose ranges cover the seas from pole to pole. To this we added maps of cetacean diversity. To ensure that our network is representative, we used data on the distribution of different biogeographic areas, depth zones, seabed sediment types and ocean trenches to represent the variety of habitats and their variation across the globe. We paid particular attention to highly sensitive deepwater habitats, using maps of seamount distribution and bathymetry to identify places vulnerable to harm by bottom fishing. We also used bathymetric data to calculate seabed complexity, which helps in identifying biologically rich places in the deep sea. All data were mapped using a geographic information system and gridded into 5° latitude by 5° longitude cells, the size of the smallest marine reserves that we considered to be viable in the high seas.


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An effective reserve network must be large enough to sustain species and ecological processes in perpetuity. Research indicates that protecting between twenty and fifty percent of the sea will maximise benefits to fisheries. It will also enable the creation of networks of reserves that represent the full spectrum of life and replicate it in different reserves. Larger figures in this range are warranted for environments that support highly mobile species and where habitats are particularly sensitive to damage. To be viable over the long term, populations protected by reserves must be large enough to be self-sustaining or must interconnect with others in the network. These factors argue for a high level of protection on the high seas, and we set a target of protecting forty percent of the area of all habitats and biogeographic zones. We also set a series of subsidiary targets for inclusion of places identified as important for different species groups. We used the computer program Marxan to help develop network designs that met these targets with the minimum coverage of marine reserves. The design presented in this report includes twenty-nine separate marine reserves that together encompass 40.8% of the area of the world's oceans. This network met all the targets set and is representative of biodiversity on the high seas. All the marine reserves identified incorporate places that are biologically important based on available data. However, their boundaries may be refined as more data become available.

It is our view that this network of marine reserves is essential to safeguard life on the high seas for the sake of our own and future generations. Implementing the network represent a challenge to the will and cooperative spirit of the world's nations. But time is short as the scale and severity of harm are growing day by day. In order to reverse the precipitous decline of the life in our oceans and fulfill the targets set by the Convention on Biological Diversity (CBD), we call on the United Nations to take urgent action to establish and protect a global network of marine reserves on the high seas.

2. Introduction

Our Earth is an ocean planet. The sea covers nearly three quarters of its surface. Long ago, before tribes wrestled control of patches of land from one another, and before tribes gave way to nations, people were free to roam the world, taking what they needed where they found it. The land was a commons for use by all. Today, the land has long since been privatised and fenced, and few places remain where such freedom applies. But on the oceans – beyond the 200 nautical mile limits of national waters – the seas are still a global commons. The high seas, as these regions are known, cover 64% of the area of the oceans, and nearly half of the planet's surface. On the high seas, our freedom to exploit still takes precedence over our duty to protect.

The high seas are the least regulated and least protected places in the world. Lying beyond the limits of national jurisdiction, they are governed by the United Nations Law of the Sea. This convention only came into force in 1994, and has yet to be signed by some of the most influential nations in the world. The Law of the Sea enshrines the right of access and use of the high seas for all. It allows for nations to fish, lay submarine cables and pipelines, or create other installations such as rigs and even artificial islands, for example. While signatory nations are obliged to conserve and manage the resources they exploit, including fish, in reality few exercise much control over their high seas fleets. Many do not monitor fishing operations, leaving their fleets to exploit high seas resources unhindered, to the detriment of all.

High seas fisheries have grown rapidly in the last thirty years as a result of declining nearshore stocks and the escalating value of prime fish like tuna on world markets. Those fisheries have had dramatic impacts on populations of large, ocean-going fish like swordfish, tuna, marlin and sharks. Populations of these open water predators have plummeted, falling on average to one tenth of their abundance in the 1950s (Myers and Worm 2003). Some species, like the large oceanic whitetip shark (Carcharhinus longimanus) could be a hundred to a thousand times less common than they were fifty years ago (Baum and Myers 2004).

Fisheries have also moved into the deep sea. Trawls and gillnets now penetrate to depths of 2000m, while longlines can fish to 3000m. In the cold stillness and dark of the deep, these fisheries are targeting species that live slowly and reach great ages. Because their population growth rates are so slow, deep-sea fish are extremely vulnerable to overfishing, far more so than their shallow water counterparts that support traditional fisheries near our coasts. High seas fishing fleets are more accurately characterised as mining vessels since they are removing fish at rates far beyond those at which populations can replace themselves. In the process of removing these animals they are doing untold damage to seabed habitats, tearing up corals, sponges and seafans and levelling myriad other species.

An increased awareness of these problems has resulted in some positive developments. In 1992 the United Nations global moratorium on high seas driftnets came into force, so ending the horrendous collateral damage inflicted every year on thousands of marine mammals, seabirds and turtles by these so-called 'walls of death'.

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More recently the value of marine reserves as a key tool in preventing the loss of marine biodiversity has been widely recognised. The UN Millennium Project calls for 10% of the oceans to be covered by marine reserves in the short to medium term, with a long-term goal of 30%. Furthermore in 2004, echoing pledges taken at the World Summit on Sustainable Development (WSSD), the Convention on Biological Diversity's 7th Conference of the Parties (CoP 7) committed to the establishment of a global network of marine protected areas by 2012 (Decision VII/28).

These are admirable targets but given the current rate of designation there is little to suggest that they will be achieved. A recent study indicated that the World Parks Congress target of creating a global system of marine protected area networks by 2012 – including 'strictly protected areas' amounting to at least 20-30% of each habitat will not be reached until at least 2085. The 2085 date is even more alarming given that it is based on an assumption that all marine protected areas from now on will be strictly protected i.e. no-take marine reserves and that all existing marine protected areas will be converted to strictly protected marine reserves. Similarly the Convention on Biological Diversity 2012 target will not be met until 2069 (MPA News 2005).

The current rate of progress is simply not going to deliver what the world's governments have already agreed is needed to protect our oceans and the marine life that they harbour.

3. Aims of this report

The collapse of life in the high seas has led to calls for urgent action to reverse the decline, including the establishment of a global network of high seas marine protected areas (World Parks Congress Resolution 23, Gjerde 2003, Balmford et al. 2004). In this report we present plans for such a network. Our objective is to identify candidate sites for a representative network of marine reserves that would afford protection to the full spectrum of life on the high seas. Marine reserves are places that are protected from all fishing and other extractive use (Roberts and Hawkins 2000). They are the most effective means available for the conservation of marine life, but have yet to be used on the high seas. In fact, as yet there are few marine protected areas of any kind on the high seas, and none that are effective. Urgent action is needed if we are to reverse loss of biodiversity across the world's oceans.

4. Life on the high seas

4.1 The pelagic realm

Observed from a boat, the high seas can seem like an endless waste of barren water, empty but for the occasional bird or flying fish. Far from land the ocean is clear blue of startling intensity. The clarity is because there is so little matter, either living or inert, suspended in the water. Without nutrients plankton doesn't grow, and without plankton nothing else can survive. But amid the rolling plains of blue emptiness, there exist oases where nutrients brought to the surface enrich the sea. These fuel plankton that feed glittering shoals of tiny baitfish and armadas of squid. Upon them large and swift predators are able to sate their hunger.

In the Pacific Ocean, west of the Galapagos, in years when there is no El Niño, a current flows west along the equator. Passing by the islands, it kicks up spinning eddies and entrains nutrient-rich water brought up from the deep. Flowing west, planetary rotation twists water to the right, north of the equator, and left, south of the equator. Known as the Coriolis force, this parting of the surface draws up water and nutrients from below. Satellite images of the Pacific reveal a streak of plankton growth along this line of upwelling. In the early 19th century, these waters supported vast groups of sperm whales

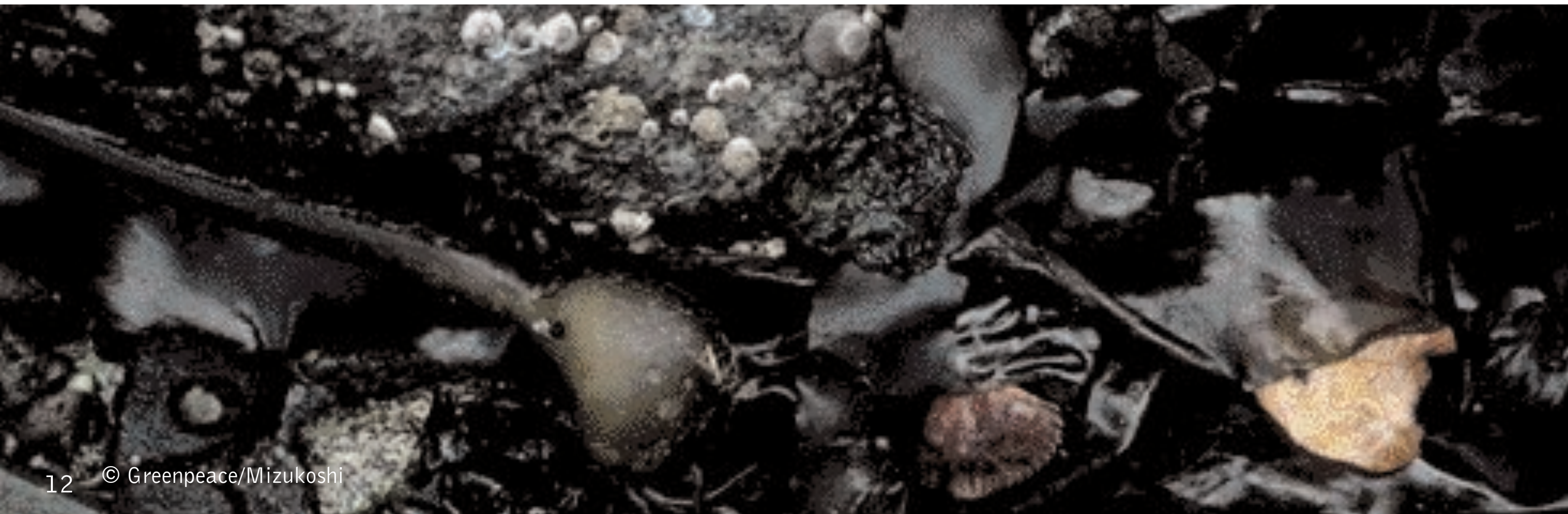
(Physeter macrocephalus), sometimes five hundred strong, and attracted whalemen in search of fortune from the other side of the world. Today the upwelling still attracts animals: tuna, albatross, terns, billfish and pods of dolphins all travel vast distances to exploit this rich feeding ground.

Convergence zones where warm and cold currents press together and mix also trigger dramatic plankton blooms. East of South Africa, the Agulhas Current spills down the west of the continent from the tropics, mixing as it does with the cool, dense water of the Southern Ocean in a region known as the Subtropical Convergence. These seas are the haunts of southern elephant seals (Mirounga leonina), several species of albatross, penguin and dozens of other seabirds.

In the North Atlantic there is an immense circling current gyre powered in the west by that great 'river in the sea', the Gulf Stream. In the east, the Canary Current flows south along the African coast before turning west above the equator and heading for the West Indies. Coriolis forces push water to the right from these circling currents, piling it up to the left of centre of the gyre in a region known as the Sargasso Sea. This sea is a giant convergence zone that accumulates drifting material from coast and main. It is named after the floating strings of Sargassum weed that dot its surface and sometimes coalesce into vast floating mats. Species like loggerhead (Caretta caretta) and green turtles (Chelonia mydas) ride the gyre and feed among the relative bounty of the Sargasso.

In 1992, astronauts in the space shuttle spotted a line in the sea drawn across the mid-Pacific. By chance, oceanographers were in the region and able to investigate. They found a convergence zone that had concentrated plankton in a streak ten kilometres wide and several hundreds long. The line marked the boundary between the North and South Equatorial Currents. At sea, it was visible as a region of breaking, turbulent waves and bright green water rich in diatoms. William Beebe, the explorer and naturalist of the early 20th century described crossing such a convergence zone in the Pacific in his book The Arcturus Adventure (Beebe 1926):

"At seven-thirty, after sounding, temperatures, and breakfast, I went on the bridge and saw a very distinct line in the water to the north. The captain said we had been steaming parallel to it since dawn. I had the Arcturus turned toward it at once, and found the Sargasso Sea of the Pacific, only in this instance it was a wall of water, against which all the floating jetsam for miles and miles was drifted and held. ...When we first detected the rip we were in 2^{o} 36' North Latitude, and 85^{o} West Longitude, which placed us about two hundred miles southeast of Cocos Island.
When I approached within the possibility of more accurate examination, I saw that the line, which stretched from horizon to horizon, extended in a northeast and southwest direction. On our side, the south, the water showed dark and rough, but much lighter and smoother to the north. When the Arcturus was at last actually astraddle of the rip, I saw it as a narrow line of foam, zigzagging across the placid sea, with spouting white-caps shooting up through the froth that marked the meeting place of the great ocean currents."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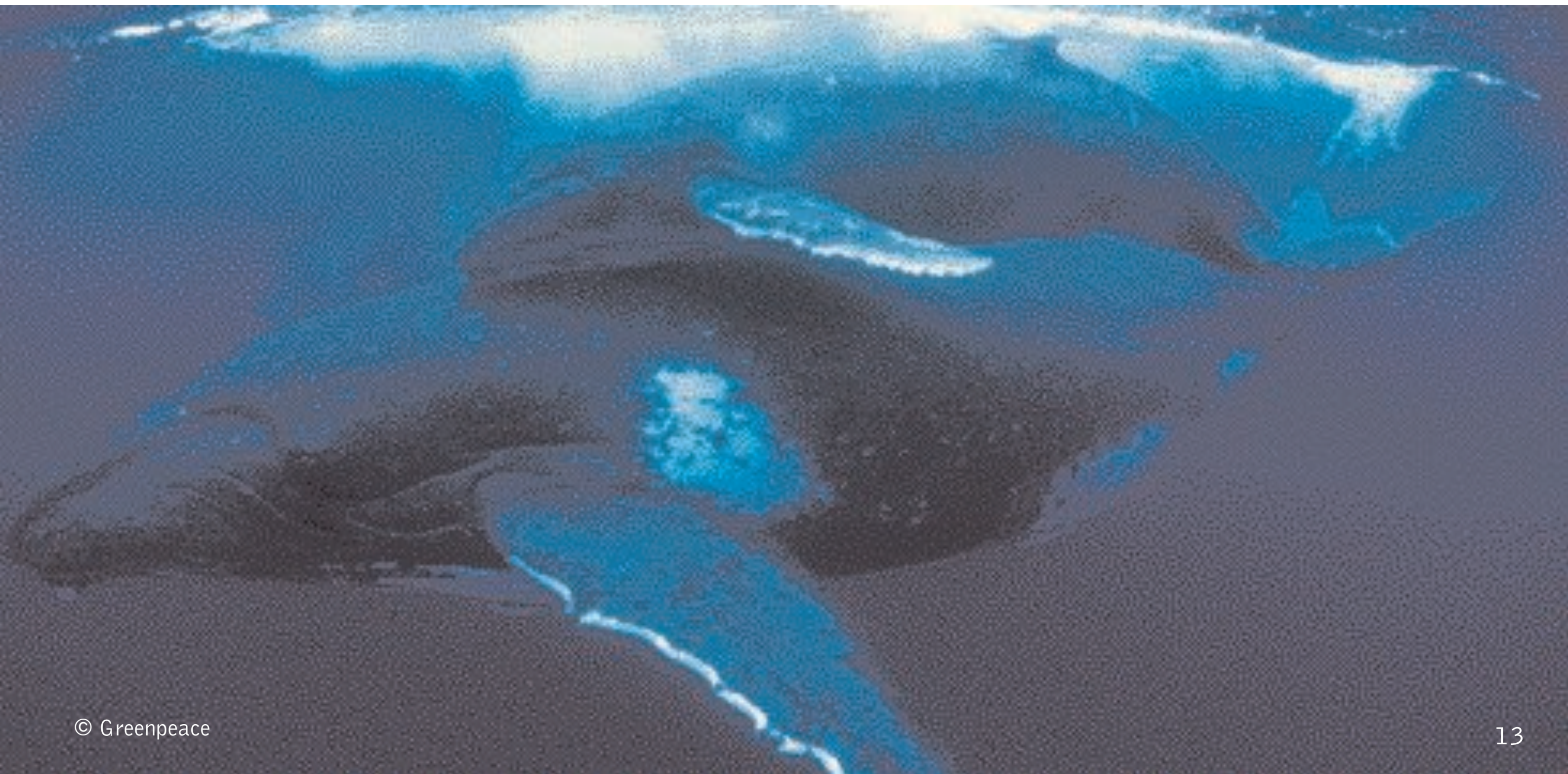
Today convergence zones like this also concentrate less natural debris. A person sailing through a convergence zone would see bobbing chunks of hardened tar, plastic bottles, discarded rubber shoes and lumps of Styrofoam. Although such rubbish is troubling, it seems benign compared to the great floating bales of monofilament netting that were once drift nets, and endless kilometres of twisted longline bristling with hooks. Some of this junk still remains lethal to marine life, entangling and often killing birds, mammals, turtles and fish.

Hotspots of life on the high seas attract fishers who home in on places teeming with fish in search of a good catch. Boris Worm and his colleagues from Dalhousie University in Canada have analysed data from the Japanese longline fishery to see what they tell us about the distribution of animals in the high seas (Worm et al. 2005). They reveal concentrations of marine life, picking out regions where animals are abundant and diverse. Not surprisingly, some of these places coincide with regions where productivity gets a boost, such as convergence zones between warm and cold currents. The findings of Worm's team are shown in Appendix 1, Figure 6. But the places with the greatest variety of big fish are not necessarily the same as those with the most fish. Productivity and variety are not closely coupled. According to these authors, this offers a way of finding places to protect that are critical to high seas species without needing to shut down the fisheries that exploit them. Examples of biodiversity hotspots include the western Sargasso Sea north of the Bahamas; the region south of Hawaii; the southeast Pacific, and the northwest Pacific bounded by the Kuroshio Current. Later in this report, we use Worm et al.'s findings to help design our global network of marine reserves.

4.2 The deep sea

The deep sea is the most widespread habitat on Earth. Waters more than a thousand metres deep cover 62% of the planet, or 87% of the sea (Gage and Tyler 1991). Creatures that inhabit the deep sea live in permanent inky darkness. Many of them communicate with flashes of light produced by bioluminescent organs, which makes this form of communication, according to the oceanographer Sylvia Earle, the most common means of animal signalling on the planet. Much of the deep sea is blanketed in sediment. Sediments accumulate in areas close to continents where rivers pump mud into the sea. They also build up as a result of the sinking bodies of organisms that live in the sunlit surface waters where photosynthesis takes place. Beneath regions where surface productivity is high sediment can build up relatively fast. But some areas – especially far offshore over the vast abyssal plains – have extremely slow rates of sediment accumulation, amounting to only a few millimetres per million years.



Animals that live in mud dominate the deep sea. Endless ranks of delicate crinoids wave their primordial tentacles across grey ooze. Sea cucumbers creep over the bottom, sifting mud for nourishment like submarine earthworms. Countless worms – flat ones, round ones, feathered ones and serrated – conduct their business unseen beneath the monotonous surface. The supremacy of mud is only broken occasionally; where mountains rise from the ocean floor, along the spreading ridges where oceans are created, and in hotspots where volcanoes break through the crust. In these places sediment yields to rock. At seamounts, normally sluggish deep-sea currents accelerate as they pass over and around the obstacles. These currents keep the slopes clear of sediment, exposing rocks that are colonised by corals, sponges, seafans, hydroids and multitudes of other encrusting invertebrates. Illuminated by the beams of a submersible, these coral gardens wrap the rocks in gorgeous cloaks of great antiquity.

Life in the deep is slow. With few exceptions, animals that live on the deep-sea bed are dependent on scraps trickling down from sunlit waters far above. This rain of organic matter affords them meagre fare. The water in which they live is icy cold, a few degrees above zero at most, and their metabolic rates are correspondingly slow. Growth rates are glacial, but for most creatures, their creeping pace of life is compensated by great longevity. Seafans and corals attached to seamounts may only grow millimetres per year, but ages of hundreds sometimes thousands of years have been estimated for corals that tower metres above their rocky plinths.

As well as providing for coral growth, seamounts have a great influence over other life in the high seas. Where they rise near to the surface they can throw off circling current gyres that drag nutrients from the deep toward sunlit waters. This stimulates plankton growth, and these patches of high production attract fish, birds and marine mammals to feed. Tunas use seamounts as waypoints and refuelling stations in their transoceanic crossings. For deepwater animals too, seamounts provide a boost to productivity. The continuous flow of water over their slopes and summits brings nutrients and food that can sustain large populations of firm-fleshed fish.

Underwater hot springs – hydrothermal vents – are often found in close association with seamounts along spreading ridges where new rock wells to the surface, like that in the mid-Atlantic. Hydrothermal vents shocked scientists when they were first discovered near the Galapagos in 1977. Spewing fountains of black, mineral laden water superheated to 300^{o}C, they create extreme conditions amid the frigid sea. The greatest surprise of these toxic oases was the abundance of life they support. Crabs and shrimps seethe among the belching chimneys while tall waving worms with blood red gills, stark white clams and mussels crust the rock. Such animals prove an exception to the rule that there is no primary production in the deep sea, as they harness microbes to synthesise energy from the breakdown of hydrogen sulphide.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Since the discovery of hydrothermal vents, scientists have found other exotic habitats. They include methane seeps where microbes harness energy from methane to sustain extraordinary communities of creatures. In northern seas, cold-water coral reefs and sponge beds have amazed researchers by their richness, supporting as many species of coral as reefs in the tropics. The new discoveries have turned on its head the long held idea that the deep sea supports only a few species and that they are very widespread. Sampling of seamounts in the southwestern Pacific showed that a quarter to a third of species were unique to closely spaced mountain ranges (Richer de Forges et al. 2000). Different seamount ranges, hydrothermal vent fields and deep ocean trenches all support unique collections of species, many with narrowly restricted distributions.

The time has come to end the popular misconception that the high seas are a barren salt wilderness. We now know that they support extraordinary communities of creatures, bizarre, beautiful, grotesque, diverse, alarming and succulent. The high seas are places that are worthy of protection and should be cherished for our own and for future generations.

5. History of exploitation of the high seas

For most of human history, the high seas have been of little interest to fishers. While there were plenty of fish in shallow seas close to coastlines, there was little point in venturing into the open oceans to fish. Why risk the danger, not to mention the greater expense of fishing far out at sea, especially when the rewards were generally less than could be obtained closer to home? The high seas were places to cross, not to go fishing. Nevertheless, some animals were hunted there.

The first high seas fisheries were for great whales. These began in the late 18th century once coastal populations had been depleted around the northern rim of the Atlantic Ocean. United States whalers operating from New England were the first to venture into the mid-Atlantic in pursuit of sperm whales. By the end of the 1700s voyages lasted three to four years, as boats literally circled the planet to fill their holds with oil, whalebone and ambergris. For most of the 19th century, whalers scoured the high seas in search of their quarry. But then whales grew scarce and with the development of cheap mineral oils and gas in the late 1800s, the industry began to decline. However, the rise of steam power and diesel in the late 19th and early 20th led to a revival of whaling by enabling boats to increase their speed and so catch the faster swimming fin whales, which had previously been inaccessible. Subsequently, the whaling industry embarked on a suicidal course of eliminating its quarry, species by species, place by place, until a halt was called to all commercial whaling in 1986[1].

Catching fish from the high seas only became commercially viable with the development of canning technology in the late 19th century. The early fisheries were conducted seasonally when migratory species like tunas and swordfish came near to coasts to feed and breed. In California and New England, the fisheries targeted animals like bluefin tuna and albacore. Zane Grey, the American author and avid big game fisherman, described the scenes around California's Santa Catalina Island in the summer of 1917:

"Barracuda and white sea-bass showed up in big schools; the ocean appeared to be full of albacore; yellowtail began to strike all along the island shores and even in the bay of Avalon; almost every day in July sight of broadbill swordfish was reported, sometimes as many as ten in a day; in August the blue-fin tuna surged in, school after school, in vast numbers; and in September returned the Marlin, or roundbill swordfish that royal-purple swashbuckler of the Pacific." (Grey 1919)

[1]The global moratorium on commercial whaling came into effect in 1986. Japan and more recently Iceland, have undertaken limited commercial whaling since then under the guise of scientific research. Norway holds an objection to the moratorium and continues to hunt commercially.

But in Zane Grey's time, it was for sporting interest rather than for meat that big fish were highly prized. It is hard to believe today, when individual blue-fin tuna can sell for tens of thousands of dollars, that the meat then fetched only a few cents per pound and was often used for pet food. The real spread of fishing into the high seas came after the Second World War when post-war food shortages bit hard. Soviet and Japanese wartime shipping fleets were converted for high seas fishing, and began to fan out across the Pacific in pursuit of tuna, swordfish and marlin. By the mid-1950s the Japanese fleet fished the entire western Pacific, from the Sea of Japan to the Australian coast, east to Hawaii and French Polynesia. By 1960, they had crossed the Indian Ocean and penetrated the Atlantic, fishing a swathe of equatorial water from Brazil to West Africa. By 1970 they fished the entire globe, spanning the Pacific from west to east, the Indian Ocean, and the Atlantic from Newfoundland to the Falkland Islands.

Surface living fish were not the only ones to attract interest. During the 1960s and 1970s, Soviet and Japanese fleets experimented with deep water fishing technology. Specially adapted trawls probed deep slopes flanking the edge of continents and raked the summits of seamounts in waters more than a thousand metres deep. Deepwater fishing proved hugely lucrative, and at its peak, trawl fleets landed tens of thousands of tonnes per year of valuable species like pelagic armorhead (Pseudopentaceros wheeleri) and orange roughy (Hoplostethus atlanticus). Over the last twenty years of the 20th century, deepwater bottom trawling expanded across the planet. Bottom trawlers were joined by deepwater longliners and gillnetters, allowing fishers to penetrate into new areas and catch new species.

6. Present status and threats to life on the high seas

6.1 Fishing

Fishing is by far the greatest threat to biodiversity on the high seas today. Since the end of the Second World War, the high seas have been subject to increasing levels of fishing. Both bottom fish in deep water and shallow water pelagic species like tuna and billfish have been targeted and stocks of both have plummeted. Tuna and billfish numbers have collapsed, falling by 90% or more since the 1950s (Myers and Worm 2003). A recent assessment showed that the high seas are being impoverished and the diversity of these fish has declined by between 10 and 50% since the 1950s, depending on the area (Worm et al. 2005).

All over the planet, deep seamounts and continental slopes now bear scars marking the passage of trawls. Seamounts subjected to bottom trawling have been stripped of rich and delicate coral and sponge forests that may have taken thousands of years to develop. In the case of these hard bottom habitats, the damage done is extremely slow to recover and it may be centuries before the scars heal. Even over muddy bottoms, biological and physical processes operate so slowly in the deep sea that scars are apparent for years or decades. Devine et al. (2006) recently found that declines in deep-sea fish stocks had been so severe since the onset of fishing off the Canadian east coast that many target species qualify as being Critically Endangered according to criteria developed by The World Conservation Union (IUCN).

Fisheries on the high seas are governed by a bewildering array of Regional Fishery Management Organisations (RFMOs). These organisations have different remits in terms of the fish species and depth range over which they have jurisdiction. Some have a mandate to manage stocks from the surface to the seabed, while others are only tasked with managing migratory species such as tunas. Some areas of the high seas lack any governance by a RFMO. The performance of RFMOs in protecting even the fisheries they


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are tasked with managing, has been disappointing, on the whole. For example, the International Commission for the Conservation of Atlantic Tunas has presided for the last twenty-seven years over a more than ninety percent decline in the abundance of bluefin tuna (Thunnus thynnus).

Most RFMOs suffer from serious problems of illegal, unreported and unregulated fishing within their areas. Vessels flying flags of convenience compromise efforts to conserve fish stocks, and it has been estimated that as much as half of the total catch of species like the Patagonian toothfish (Dissostichus eleginoides) may be taken illegally. It is surprising then that some RFMOs have repeatedly failed to prosecute known infringements by vessels operating under their oversight. Management by many RFMOs is failing to safeguard either fisheries or the environment.

6.2 Global warming

Global change is affecting the high seas like every other habitat on the planet. Rising temperatures and changing salinity patterns are leading to alteration of ocean currents. For example, increasing freshwater runoff into the Arctic Ocean north of Europe and Russia is reducing sinking of seawater into the deep planetary circulation and weakening the Gulf Stream. Changes in current patterns like this may have major feedback effects on climate, but they are also certain to affect marine life. Another impact of great concern is the acidification of the ocean as a result of rising concentrations of CO_2 in the atmosphere. Higher acidity could interfere with calcification by zooplankton, with unpredictable but probably detrimental consequences. Marine reserves will not prevent such impacts occurring but they may mitigate some of the negative consequences. Protection from exploitation may help organisms maintain larger populations that can offset the added stress or mortality from global change processes. It may also be possible for us to move marine reserves over time, tracking shifts in current patterns and other oceanographic features, as we discuss below.

6.3 Disposal of CO_2

Worryingly some countries have proposed dumping liquid CO_2 in the deep ocean as a technical solution to curbing the levels of CO_2 entering the atmosphere, despite no real idea of how this will impact the marine environment. What we do know is that any CO_2 dumped in the ocean will eventually make its way back to the atmosphere, it's just a question of when. This could take thousands of years or happen almost immediately.

6.4 Oil and mineral exploitation

Until very recently, deep-sea areas, which mean most of the high seas, have been too expensive to exploit for their mineral wealth. For mining and petroleum companies, there seemed little point looking for minerals and oil in deep water while more accessible resources were readily available from continental shelves. But many oil and gas fields on continental shelves, like those of the North Sea, are nearing the end of their productive lives and other sources must be found. Oil companies are also taking an interest in new resources from the deep sea that could supply energy, like methane gas hydrate deposits.

It may soon become cost effective to mine from the deep sea when terrestrial sources of minerals become scarce. In particular, mining companies have their eyes set on hydrothermal vent fields. Ancient hydrothermal vents uplifted from the ocean floor, in places like Canada and Cyprus, represent some of the richest sources of metals in the world. Underwater vent fields, both active and inactive, are tempting targets.

6.5 Bioprospecting

Recent technological advances have caused bioprospecting – the exploitation of genetic resources for both scientific and commercial purposes – to take off in the marine context with a special interest being taken in the properties of those organisms inhabiting the depths of the high seas. Many of these deep sea species have developed unique biological and physiological characteristics that enable them to survive in very cold, dark and highly pressurised environments. The biochemicals found in these animals and micro-organisms could prove to be integral in developing new products for use in the health, pharmacology, environmental and chemical sectors. However these organisms and ecosystems are highly vulnerable to potential detrimental impacts including over-harvesting, pollution and habitat disturbance.

6.6 Noise

Noise levels in the sea have increased by several orders of magnitude since just a century ago. Where sailing ships once caught the wind, today's ships throb their way across the waves, booming out low frequency noise that travels tens or hundreds of kilometres. Sonar pings – much louder than the term suggests – fill the oceans. Oil and gas companies explode seismic charges in intermittent barrages that can kill or permanently deafen marine mammals, and perhaps other species, that come too close. The world's navies are testing ever more powerful sonar to detect submarines, with little thought for the consequences to marine life. Even if an animal is not exposed to injurious levels of noise, the sheer background clamour may interfere with communication or smother signals that may be critical to navigation or survival. Nowhere in the oceans is free of human generated noise any more and marine reserves will not change that. However, reserves could provide havens from which the most injurious forms of sound production are excluded.

7. Designing a global marine reserve network for the high seas

7.1 Marine reserves and why they are needed

Fully protected marine reserves are places that are protected from all fishing and other extractive or harmful human uses, such as mining and drilling for oil. They are also protected from harm by other causes, so far as it is possible, such as pollution. Recreational boating, passage of shipping etc. are permitted up to levels that do not harm the environment. Marine reserve status does not interfere with the right of innocent passage embodied in the UN Law of the Sea. However, reserves may require additional restrictions on shipping where such areas are also designated as Particularly Sensitive Sea Areas. High seas marine reserves are unlikely to attract much recreational use since they are generally inaccessible and lack the easily approachable animal life that shallow coastal seas often possess. The main source of harm that high seas marine reserves must offer protection against is fishing, in both its legal and illegal, unreported and unregulated (IUU) forms. In future, as more accessible oil, gas and mineral resources are depleted, they will also need to offer protection from drilling and mining. There are, however, some kinds of harm that marine reserves cannot counter, such as global warming and highly mobile pollutants from distant sources. It will require action at regional or global scales to benefit species and habitats occurring in the high seas, though healthier ecosystems such as those protected by large-scale marine reserves are likely to be more resilient. As outlined in Sections 5 and 6.1, fishing impacts on the high seas and deep sea are severe and growing. Since the onset of industrial scale fishing a little over fifty years ago, high seas fish stocks have been plundered. Fewer than one in ten of the big, pelagic fish at large on the high seas at the end of the Second World War are present today. Figures are closer to one in a hundred, and even one in a thousand for the most severely depleted species. The same scales of loss apply in the deep sea. The isolation of the high seas and deep sea no longer put these environments beyond human harm. They urgently need protection.

Some decision makers, fisheries managers and scientists have questioned whether marine reserves are the right way to protect life and habitats on the high seas. Would other measures that restrain fishing be better? For example, the United Nations implemented a global moratorium on the use of drift nets on the high seas that came into effect in 1992[2]. A large number of conservation organisations, including Greenpeace, have joined together in the last two years to call for a global moratorium on bottom trawling on the high seas (www.savethehighseas.org). Their contention, supported by extensive and detailed evidence, is that this fishing method is destructive and wasteful. A global moratorium on deep sea bottom trawling would indeed be better than protecting some areas in marine reserves and trawling the rest to oblivion. However, the response to this proposal at the United Nations has been mixed. Some countries favour a moratorium, while pro-fishing nations such as Iceland and Japan oppose it. In the centre ground, some nations favour a partial ban. This would prohibit bottom trawling on a case-by-case basis in areas of the high seas proven to have habitats that are vulnerable to damage by trawling, and in places where there is no competent regional fisheries management organisation that can regulate deep-sea fishing. Such a proposal would essentially mean identifying vulnerable areas for protection as partial marine reserves. To make this proposal work would certainly mean introducing an interim moratorium on high seas bottom trawling while vulnerable areas are identified. If it were not, many sensitive areas would be destroyed before protection could be given to them because the pace of damage by trawling is so great.

One problem with implementing fishing restrictions like the UN drift net ban, is that they can have unintended consequences. Since this ban came into force, the intensity of high seas longline fishing has greatly increased with the result that it has put leatherback and loggerhead turtles at risk of extinction. So parlous is the plight of the leatherback that in 2005 some conservationists called on the United Nations to introduce a moratorium on high seas longlining to prevent its extinction. The call attracted sympathy from many country delegations but was rejected due to concern for and pressure from the fishing industry. In the case of longlining, arguments for a complete ban on the practice are less clear-cut than for deep sea bottom trawling. Again, there is greater support for a partial ban, which would mean identifying areas where turtles are particularly vulnerable and giving them protection from fishing through time and area closures.

7.2 Will marine reserves protect species on the high seas?

The most frequent criticism of using marine reserves on the high seas is that species there are too mobile to gain sufficient protection. Animals like tunas, for example, are the ultimate planetary wanderers. Bluefin and albacore cross oceans and in the Pacific undertake an eighteen thousand kilometre round trip every year. Albatrosses wander the oceans for half the year covering tens of thousands of kilometres. Single provisioning trips for their young may span several thousand kilometres. Not all species are this mobile, but many range over hundreds to more than a thousand kilometres. How then can anything other than impractically large marine reserves offer sufficient protection?


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[2]The moratorium applies to all drift nets greater than 2.5 miles long.

The key to success is to protect species in the places and times that they most need it. Marine reserves can safeguard species where and when they are aggregated or are otherwise particularly vulnerable to human impact, such as breeding sites, nursery grounds or migration bottlenecks. On land we are very familiar with the idea of using protected areas to safeguard highly migratory species. Dozens of migratory birds arrive and depart each year as they move between breeding and over-wintering habitats. We protect their breeding sites and their resting and refuelling spots along the way. This strategy is also used in the sea. For nearly a century, fishery managers have protected the breeding sites of migratory species like herring and capelin when they gather in coastal shallows to spawn. They also protect juvenile nursery habitats to ensure that animals are able to grow undisturbed to marketable sizes.

Many high seas migratory species come close to coasts at some stage of their lives. Birds, turtles, seals and sea lions (pinnipeds) must come to land to breed. They can benefit from protected areas in national waters and on land. But there are also places on the high seas that support remarkable and predictable concentrations of life. Some of them are fixed, such as zones of high productivity around seamounts. Others are mobile, snaking around some general area of ocean at the whim of weather and currents or, like spinning eddies, may simply drift off then dissipate. These areas, as we described in Section 4.1, can be highly productive, such as upwellings and convergence zones between currents, and can draw animals from far afield to feed or breed. In other places, phenomena like downwellings, may concentrate plants and animals passively. Drifting rafts of plants, flotsam and jetsam can become important features enhancing productivity, acting shelters and nurseries for animals, which in turn attract others to feed on them.

Protecting mobile features on the high seas presents more of a challenge than protecting fixed locations like seamounts or fields of hydrothermal vents. In some places it may be feasible to create large enough marine reserves to incorporate most of the temporal variability in the location of these features. In others, this may not be possible. However, today's technologies provide the means by which we can both identify and protect important places as they move. Satellite sensors highlight areas of high chlorophyll concentration that indicate blooming plankton. Measures of sea surface height pick out currents and convergence zones, as do steep gradients in sea surface temperature. Thermal data also show upwellings and coiling eddies. At present, satellite data are fed to fishing fleets either by national governments or private companies to guide boats to the places where it is known that fish will be concentrated. In the same way it would be a simple matter for governments to inform fishing fleets about that day, week or month's position of designated mobile high seas marine reserves (Norse et al. 2005). In the same way, mobile marine reserves could be used to protect migrating species like turtles that follow predictable routes across the oceans. Fixed and mobile marine reserves would also benefit species such as birds that risk being killed in places where fishing operations are underway. In some places, marine reserves may promote the creation of oceanic hotspots of life, by allowing forage species to build in abundance and thereby attracting migratory animals to feed on them.


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Marine reserves will meet some of the conservation and management needs of highly mobile and migratory species, but in most cases will not be sufficient on their own. Where species remain subject to moderate or high levels of threat outside protected areas, there will need to be supplementary management, such as additional fishing restrictions implemented by Regional Fishery Management Organisations.

7.3 Identifying candidate sites for protection

In this report we identify candidate sites for a global network of high seas marine reserves. In seeking suitable places to protect, our primary objective has been to find and prioritise for protection places with high intrinsic biological value. Complementing this search for the places most prolific in quantity and variety of life, we sought to achieve representation of the full spectrum of biological diversity. To attain these ends, we employed three main data gathering approaches:

(1) We assembled maps of physical and biological data and brought them into a common format using the ArcInfo 3.3 ® Geographic Information System (GIS) program;
(2) We created our own maps of use of the high seas by aquatic megafauna, drawing on data in numerous separate studies and reviews;
(3) We consulted with experts in marine science and management, requesting them to nominate sites they believe should be afforded protection.

All the above sources of information were used to identify candidate sites for protection and to design a global network of high seas marine reserves. Full details of data layers are given in Appendix 1. We offer a few comments on each approach below.

(1) Mapping physical and biological data

We have brought together information from a wide variety of sources pertaining to the high seas. They include data showing species richness and species density of large pelagic fish species (billfish and tunas, Worm et al. 2005), sea surface temperature gradient (which identifies areas of mixing of cold and warm water masses), and the location of upwelling and downwelling areas, and bottom sediment types. We also obtained data on seamount distribution (www.seaaroundus.org), marine biomes and bathymetry. From the bathymetry data we calculated bottom complexity, a measure of habitat heterogeneity thought to relate to high benthic biodiversity (Ardron et al. 2002), and have identified ocean trench habitats.

(2) Air-breathing aquatic megafauna

Large and mobile animals seek out places on the high seas that are rich in their prey. Their movements can guide us to concentrations of marine life. We gathered and mapped data from dozens of studies of the movements of air-breathing aquatic megafauna, including albatrosses, pinnipeds, penguins and turtles. In particular, we sought data from studies using satellite, radio-tracking or data loggers to reveal high seas movements of these species. However, since there are insufficient data to be fully comprehensive, we concentrated on species for which there were good data and that spend significant amounts of their time on the high seas. We also developed maps showing species richness of cetaceans (whales, dolphins and porpoises) across the world.

(3) Expert consultation

We wrote to 404 experts on marine science and conservation asking them to nominate one or more candidate sites deserving high priority for protection on the high seas. We also requested they provided justification for their choice and send us supporting documentation, if any was available. We received replies from around sixty-six

(Appendix 2). Experts nominated a wide range of sites (Appendix 3), but there was also considerable consistency in their suggestions. In particular, seamounts and convergence zones between currents received multiple nominations for protection.

7.4 The grid

We entered our data into the ArcInfo 3.3 ® GIS and gridded on a 5^{o} latitude by 5^{o} longitude grid. We chose this grid size for two reasons. Firstly, we think that 5^{o} x 5^{o} corresponds to the minimum viable area for a high seas marine reserve, although we accept that the area included in cells of this grid do vary with latitude. One grid cell corresponds to an area of approximately 560 x 560 km at the equator, or 314,000 km^{2}, with the longitudinal dimension diminishing towards the poles. Between 70^{o}N and 75^{o}N, for example, each cell covers 93,600 km^{2}. To facilitate easy identification, compliance and enforcement, it is essential that reserves on the high seas have straight edges and are demarcated based on latitude and longitude. This way the boundaries can easily be located with the global positioning systems used on boats. The only exceptions to this will likely be in areas adjoining the exclusive economic zone(s) of one or more countries.

The second reason for choosing a 5^{o} grid is because some of the data layers we used have a relatively coarse resolution. In addition, many processes important to generating biological patterns on the high seas vary in space over time. Fine scale mapping, for example on a 1^{o} grid, would be unjustified. The 5^{o} resolution is relatively robust to data errors and temporal variation.

At its edges, many cells of the grid incorporate parts of national exclusive economic zones. In addition, we have included grid cells across large parts of the high seas that lie within the exclusive economic zones of island nations or island dependencies of other countries. We believe that much of the seas surrounding these islands are virtually indistinguishable in biology from areas further offshore. Many of these islands, especially isolated and often uninhabited places in the Southern Ocean, are critical habitat for species that use the high seas. Protecting these species will require conservation strategies that include the islands as well as regions of the high seas used by the species.

8. Principles of marine reserve networking

A network (1) should be representative of the full range of biodiversity, (2) should replicate habitats in different marine reserves, (3) should be designed so that populations in different marine reserves can interact and be mutually supporting, (4) should be sufficiently large to ensure long-term persistence of species, habitats, ecological processes and services, and (5) should be based on the best available scientific, local and traditional information.

8.1 Site selection

Protected area selection must aim for broad representation of the full spectrum of biodiversity. It should not be driven, as it has been to date, simply by the need to protect threatened species or habitats. Habitat representation and protection of threatened species are dual objectives for protected area networks, not mutually exclusive ones. Fishing and other human activities have highly modified habitats and their associated ecological communities on the high seas and in the deep sea. Therefore, in selecting representative sites, the emphasis must be on seeking to recover and restore those sites to a more natural, little disturbed state, not on maintaining them in their present condition. At the network scale, the aim should be to provide the conditions for expansion in the ranges of species that have previously been seriously depleted, and to accommodate changes in range as environmental conditions change.

8.2 Networking and connectivity

A protected area network needs to be greater than the sum of its parts. The emphasis in coastal seas, with a few notable exceptions such as the Australian Great Barrier Reef, has so far been on selecting sites to protect specific attributes with little consideration given to how those sites interact with others. Management has been site specific rather than taking into account how a protected area affects and is affected by others. A central objective for a network is to ensure ecological connectivity among protected area units. For species that move or disperse widely, populations in marine reserves should be mutually supporting. Levels of coverage, replication, size and spacing of marine reserves need to be set taking connectivity considerations into account.


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8.3 Level of replication

Habitats should be replicated in more than one protected area in order to buffer against human or natural catastrophes that may damage or destroy populations in individual marine reserves. Furthermore, marine reserves cannot be mutually supporting unless there are similarities in the habitats and species they contain. The aims of replication are to spread the benefits of protection throughout the region, to provide insurance against human and natural impacts, and to ensure ecological connectivity among marine reserves. How much replication is enough? At present this question has not been adequately resolved by science. Roberts and Hawkins (2000) suggested that all habitats should be replicated in at least three marine reserves. This level of replication was adopted in the recent rezoning of the Great Barrier Reef Marine Park, and was applied within three biogeographic subdivisions of the park. However, when very large areas are involved, low levels of habitat replication in different marine reserves will fail to secure adequate connectivity. This is because the resulting marine reserves will tend to be very widely spaced and the distances between them may exceed the dispersal abilities of most resident species. Clearly, however, there are constraints on replication. It may only be possible to attain low levels of replication for rare and isolated habitats. Higher levels of replication can be achieved by creating smaller marine reserves, but this could be self defeating if such areas are not sufficiently large to sustain populations of resident species (see Size of Marine Reserves, below).

8.4 Spacing of marine reserves

Scales of ecological linkages in the high seas – i.e. the movement of juveniles and adult organisms, dispersal of their offspring, and transport of materials – extend from metres to thousands of kilometres. Seamount invertebrates, for example, may disperse only metres, while migratory tunas can undertake journeys of 20,000 kilometres in a year. To ensure ecological connectivity in the network, marine reserves with similar habitats should generally be spaced from a few hundreds to a few thousand kilometres apart.

8.5 Size of marine reserves

There are no hard and fast rules governing protected area size. Protection goals, habitat distribution, heterogeneity and patchiness, mobility of species, together with social constraints that limit options for protection, must all be considered in decisions on protected area size. However, sizes of marine reserves must be matched to the scales of mobility of the species in the habitats being considered. At a minimum, marine reserves must be large enough and numerous enough to support long-term viable populations of the majority of species at a network level. For some species, populations will be viable at the level of individual marine reserves. For more mobile and widely dispersing species, the aim is to achieve viability across the sum of marine reserves making up the network. Two rules of thumb are that marine reserves should be as large as possible given social constraints, and they should generally increase in size from nearshore to offshore environments. High seas marine reserves should therefore be at the large end of the size spectrum to encompass movement scales of the organisms that inhabit the offshore realm. In this study, we have adopted a minimum reserve size of 5^o latitude x 5^o longitude. At the equator, this represents a size of approximately 560km x 560km, or 314,000km^2. We recognize in doing this that the size of 5^o x 5^o cells will decrease approaching the poles. While the latitudinal dimension remains unchanged regardless of latitude, the longitudinal dimension decreases polewards.

8.6 Coverage of marine reserves

The World Parks Congress in 2003 recommended that at least 20-30% of all marine habitats should be included in networks of marine reserves (World Parks Congress Recommendation 22, 2003). There are good scientific arguments for taking an even more precautionary approach, since higher levels of protection can be required to maintain the integrity of marine ecosystem processes. Gell and Roberts (2003) reviewed nearly forty studies examining how much of the sea should be protected. The majority of studies concluded that between 20 and 50% of the sea should be protected to achieve the conservation of viable populations, support fisheries management, secure ecosystem processes and assure sufficient connectivity between marine reserves in networks. Given the large scales of oceanic processes and species' movements on the high seas, a high level of protection is warranted. In this report, we have adopted the goal of protecting 40% of all habitats on the high seas.

Some habitats will require greater proportional protection than others. A larger fraction of habitat should be protected for isolated and regionally rare habitats, than for regionally extensive and widespread habitats. This is because the former will be more dependent on self-recruitment to sustain populations. If habitats are damaged or species' populations collapse, more widespread habitats have greater opportunities for recovery by recolonisation from distant source populations than do isolated or rare habitats.

Some habitats warrant total protection. They include places for which the nature and degree of threats to them mean that any areas left unprotected will be destroyed or damaged beyond recognition, and where the recovery time following damage is lengthy. Deep-water habitats such as seamounts, ridges and canyons are among those that warrant complete protection (Merrett and Haedrich 1997, Roberts 2002, MCBI 2004). Their resources are currently being mined as if they were non-renewable resources. Any areas left unprotected will be destroyed by present fishing practices. There is little prospect of reforming deep sea fishing practices to try and achieve sustainability, since industrial scale fisheries are so expensive to run that they would be unprofitable at the levels required for a sustainable fishing effort (Roberts 2002).

Text in this section adapted from: Roberts, C.M., F.R. Gell, and J.P. Hawkins (2003) Protecting Nationally Important Marine Areas in the Irish Sea Pilot Project Region. Report to the Department of the Environment, Food and Rural Affairs, UK. www.jncc.gov.uk/page-2847

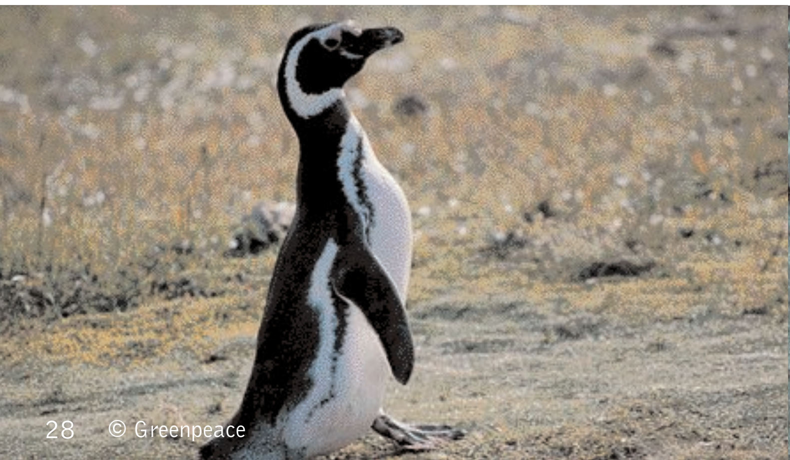
9. Procedure used for computer-assisted design of a network of marine reserves

Marxan is the most widely used computer program for designing networks of marine reserves and has been instrumental in rezoning the Great Barrier Reef Marine Park in Australia and the California Channel Islands National Marine Sanctuary in the United States (Airame et al. 2003). Marxan works by selecting sites for protection to create networks that meet user-defined conservation targets while trying to minimise costs. The costs included are generally proxies for real financial costs and include measures of the area and boundary length of reserves within the network. Costs increase with area to be protected but there are economies of scale that can be achieved by creating fewer, larger reserves, compared to many small reserves that cover the same area (Balmford et al. 2004). Adding the total boundary length of marine reserves in a network represents a proxy for this economy since as reserves increase in area, the boundary length increases less quickly. The less boundary there is for a given total area protected, the more clumped reserves are and thus the less expensive the network is to create and manage.

To use Marxan, the area being considered for protection has to be split into units of area, referred to as planning units. Features that are to be represented in the reserve network are then mapped, such as seamounts, presence of species of conservation interest, and biogeographic zones. Undesirable qualities can also be mapped, such as fishing intensity or pollution levels. For each planning unit the amount of each feature is calculated. In some cases direct area measures can be used, while for other features, such as use by birds or turtles, scoring systems may be developed and each planning unit scored for the feature (such as that used in this report for air-breathing aquatic megafauna). The Marxan user then sets a target for how much of each feature is required in the network. If the network does not meet a particular target then a penalty is applied. Any penalties are ultimately added to the total cost for a reserve network. Hence network designs that do not meet the conservation targets can be considered as expensive options.

Marxan works towards 'good' network solutions iteratively. It begins with a 'seed solution' which is usually a random pick of planning units. It then adds and subtracts planning units in a pre-determined number of iterations (usually several thousand). For each iteration the cost of the network is calculated, which is the area, plus the boundary, plus any penalty for not meeting the conservation targets. Advantageous changes are retained. In this way the program seeks to meet the conservation targets with the smallest total area protected and the smallest boundary length.

In Marxan a 'Boundary Length Modifier' can be set to limit the overall boundary length of sites that are selected. This forces the program to seek less expensive network solutions with fewer, larger marine reserves rather than many small areas.
At the outset of a Marxan run, priority sites for protection can be locked in, and undesirable areas locked out. Marxan can be run many times to provide alternative marine reserve network designs for any given set of targets. From these, a selection frequency or 'irreplaceability value' can be calculated for each planning unit, indicating its relative importance to meeting the given targets. This value may be useful in deciding which planning units are high priorities for protection.



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9.1 Features and targets used for Marxan analyses

The aims of the network design process outlined below are to select sites that will protect the richest and most vulnerable concentrations of high seas marine life, represent the full spectrum of high seas biodiversity, represent all habitat types in different marine reserves, and include forty percent of the high seas in marine reserves.

Oceanographic Features

1. Upwellings and downwellings: We calculated the area of three upwelling and downwelling types: major upwelling zones, areas where intermediate waters form and sink, and areas where deep and bottom waters form and sink. We then set a target of representing 40% of the area of each type in the network.
2. Sea surface temperature gradient: used to identify fronts, convergence zones and upwellings. We took the top 10% of cell scores for steepness of their temperature gradient, and then set a target of representing 40% of these cells in the network.

Physical features

1. Bathymetry: Depth data were divided into five strata: 0-200m (continental shelves/epipelagic zone); 201-1000m (mesopelagic zone); 1001-4000m (bathypelagic zone); 4001-6000m (abyssopelagic zone); > 6000m (hadalpelagic zone). We then set a target of representing 40% of each depth zone in the network.
2. Bathymetric complexity: We scored each cell for its bathymetric complexity then split the scores into four categories (high to low complexity) and identified all the cells that contained high complexity (see Ardron et al. 2002 for method). We then set a target of representing 40% of the total number of high complexity cells in the network.
3. Seamounts: We calculated the number of seamounts in each cell then set a target of including 40% of all seamounts in the network.
4. Bottom sediments: We calculated the area of different bottom sediments in each cell and then set the target of representing 40% of the total area of each sediment type in the network.
5. Ocean trenches: We calculated the area of ocean trenches (places > 6250 m deep) and aimed to represent 40% of their area in the network.

Biological data

1. At sea movements of albatrosses, turtles, pinnipeds and penguins: We scored each cell for use by each of the four different taxa. The scores were then normalised to a range of 0-1, added across the four taxa, and then divided by the number of taxa contributing to that score. We then set a target of representing 40% of the top scoring 25% of cells in the network.
2. Biodiversity distribution of cetaceans: we scored each cell for species richness of three groups of cetaceans (baleen whales; toothed whales excluding dolphins; dolphins) and ranked them by score. We then set a target of representing 40% of the top scoring 25% of cells in the network for each taxon.
3. Billfish and tuna species richness: We identified cells within the top quartile of values for species richness and aimed to represent 40% of them in the network.
4. Billfish and tuna species density: We identified cells within the top quartile of values for species density and aimed to represent 40% of them in the network.
5. Marine biomes: We calculated the area of each of 12 marine biogeographic zones in each cell. We set a target of representing 40% of the area of each biome in the network.

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Expert consultation

1. We used the results of the expert consultation to lock in certain areas at the out set of the Marxan analyses.

For each network design calculated by Marxan we ran the simulated annealing model 1000 times. We repeated this 10,000 times to generate 10,000 different network designs. They were then compared with each other to find the designs that met the targets set most efficiently. At the end of each run of 10,000 network designs, we calculated the irreplaceability metric for each cell, i.e. the number of times that cell was picked to be part of a network. We used this irreplaceability statistic to identify high scoring cells which should be locked in to the network prior to the next run of Marxan. In this way, we ran Marxan iteratively, progressively working towards a final network design that met all targets set. In the final step, locked in cells covered 36% of the oceans, and the program was run to select cells to make up the final approximately 4% coverage needed to complete the network. For this final run, we also locked out a small number of cells to prevent Marxan amalgamating nearby protected areas that we preferred to keep separate.

10. Design of a network of high seas marine reserves

Figure 1 shows the final design of the candidate network of marine reserves. It covers 40.8% of the global oceans and includes twenty-nine separate candidate reserves. These cover every ocean and include representatives of all twelve ocean biogeographic zones. The network met all of the targets we set (Table 1).

In the Mediterranean, the high seas begin at the boundary of territorial waters, 6 or 12 nautical miles from the coast. We have identified two areas in the Mediterranean Sea that have particularly high biodiversity values, but they are not the only places that warrant protection. To adequately protect Mediterranean biodiversity a regional network of marine reserves will have to be developed at a finer scale. This is to take account of the finer scale distribution of ecological features and associated human uses compared to the high seas.

Like the Mediterranean, Antarctica has no Exclusive Economic Zone, nor does it have territorial waters. The high seas thus begin adjacent to the coast. We have identified several areas of the Antarctic that are high priorities for protection based on their rich marine wildlife. However, there is a case for extending protection to all waters south of 60^{o}S, the area covered by the Convention on the Conservation of Antarctic Marine Living Resources. Such a protected area could safeguard one of the most pristine environments left on this planet for the benefit of all humanity.

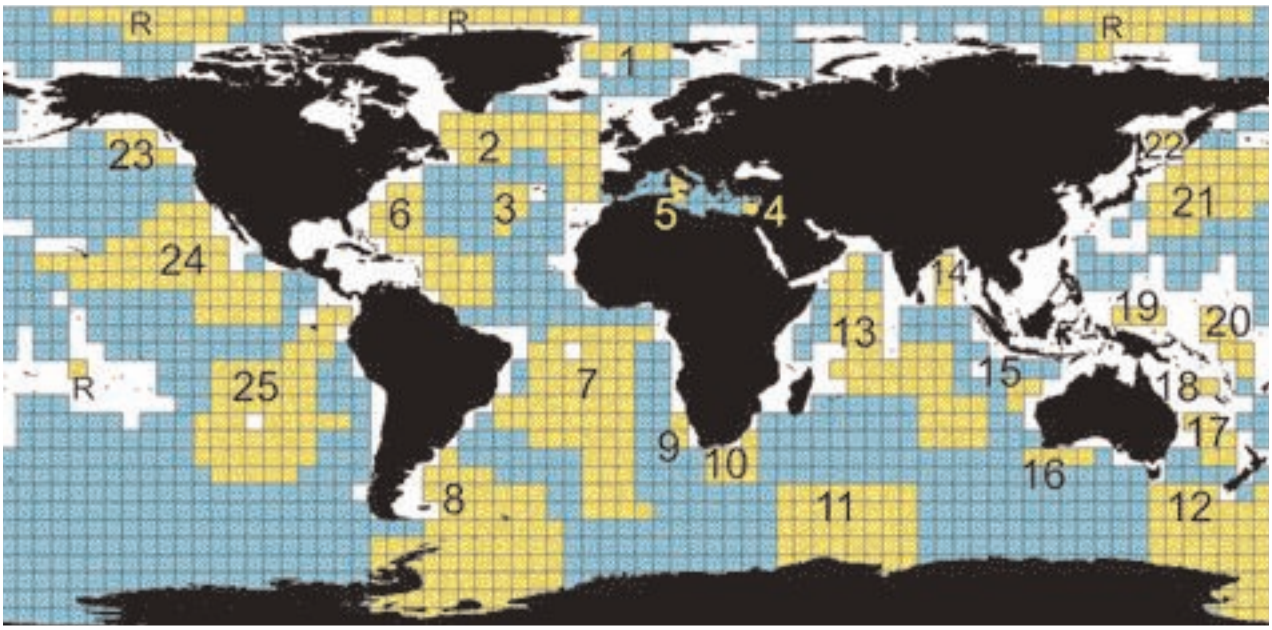

Figure 1: Proposed global network of marine reserves. Numbers refer to descriptions given in Section 11.

Table 1: Targets set for the global network of marine reserves and performance of the network show in Figure 1 against these targets.

Feature	Target	Amount included in network	Number of grid cells with the feature
Ocean Area	40% of world ocean coverage	40.8%	549
Biogeographic Zones			
Pacific westerly winds	40% of area	46.7%	59
Pacific trade winds	40% of area	37.2%	99
Pacific polar	40% of area	54.6%	3
Pacific coastal	40% of area	51.7%	29
Indian Ocean trade winds	40% of area	47.5%	50
Indian Ocean coastal	40% of area	49.5%	13
Atlantic westerly winds	40% of area	46%	39
Atlantic trade winds	40% of area	53.7%	72
Atlantic polar	40% of area	32.4%	66
Atlantic coastal	40% of area	56.8%	23
Antarctic westerly winds	40% of area	28.1%	91
Antarctic polar	40% of area	37.2%	139
Bottom types			
Sediment Clays	40% of area	39.8%	146
Sediment Glacial deposits	40% of area	39.6%	105
Sediment Continental margins	40% of area	39.1%	134
Sediment Siliceous diatom ooze	40% of area	36.5%	86
Sediment Siliceous radiolarian ooze	40% of area	31.9%	13
Sediment Calcareous ooze	40% of area	43.9%	237
Depth 1-200m	40% of area	33.3%	140
Depth 201-1000m	40% of area	51.6%	237
Depth 1001-4000m	40% of area	51.1%	488
Depth 4001-6000m	40% of area	34.8%	437
Depth 6000m+	40% of area	44.1%	79
Bathymetric complexity	40% of the top 25% of cell values (397 cells)	401 cells	401
Ocean trench area	40% of area	42.3%	35
Seamounts	3829 seamounts = 40% of global total	3862	363
Fauna			
Tuna and billfish species richness	40% of the top 25% of cell values (21 cells)	22 cells	22
Tuna and billfish species density	40% of the top 25% of cell values (24 cells)	25 cells	25
Baleen whale diversity	40% of the top 25% of cell values (111 cells)	102 cells	102
Toothed whale diversity (excl. dolphins)	40% of the top 25% of cell values (83 cells)	97 cells	97
Dolphin diversity	40% of the top 25% of cell values (48 cells)	51 cells	51
Importance for air breathing megafauna (albatross, turtles, penguins and pinnipeds)	40% of the top 25% of cell values (75 cells)	112 cells	112
Oceanography			
Sea surface temperature gradient	40% top 10% of cell values (10 cells)	9 cells	9
Major upwellings	40% of area	46.7%	28
Zone of deep and bottom water formation	40% of area	47.9%	37
Zone of intermediate water formation	40% of area	43.2%	16

Deepwater fishing, as we discussed earlier, is one of the major threats to high seas biodiversity. To examine how effective the network would be in protecting deep-sea habitats from fishing we superimposed the 800 – 3000 m depth stratum over the map of proposed marine reserves. This represents the zone of greatest sensitivity to deepwater fishing. Bottom trawls and gillnets regularly work to 2000m deep, while longlines penetrate to at least 3000m.

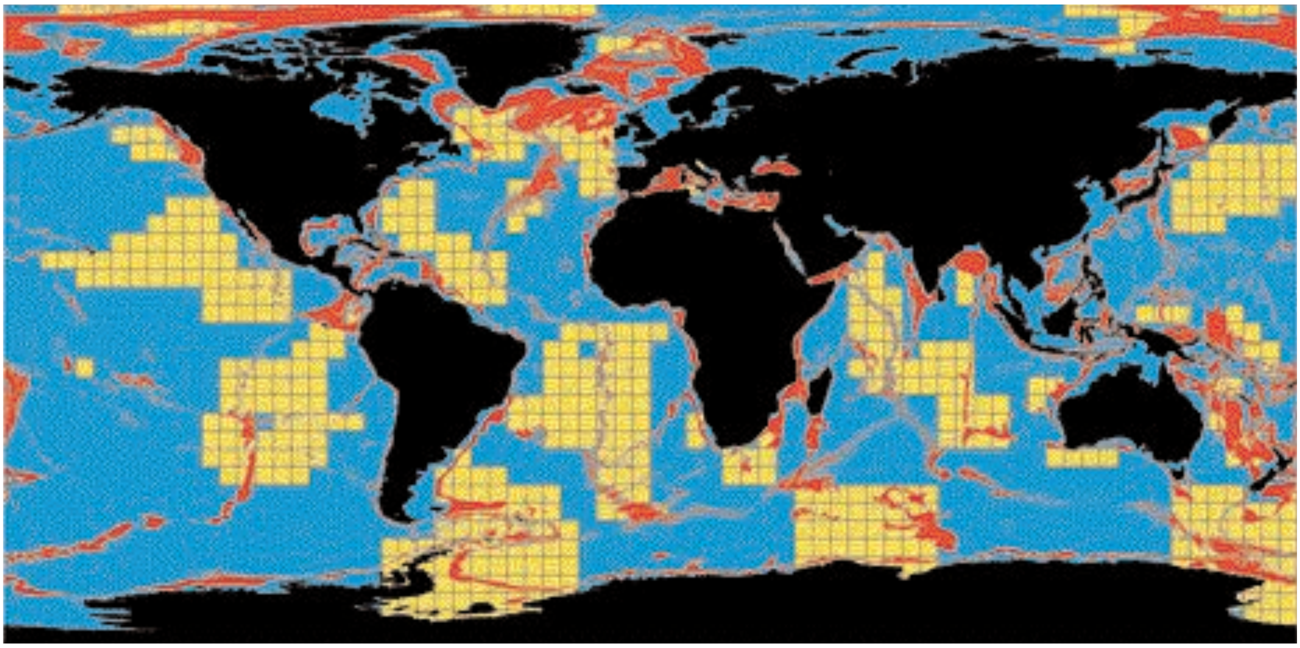

Figure 2: Distribution of places sensitive to deep-sea fishing impacts in relation to candidate marine reserves. Red areas are places where the bottom depth lies between 800 and 3000m. Yellow areas are proposed marine reserves.

11. Features of selected areas identified for protection

Greenland Sea (1): This candidate marine reserve incorporates a swathe of the Greenland Sea between Svalbard and Eastern Greenland. It supports high levels of summer productivity and is an important feeding area for a variety of whales, seals and walrus, including hooded and harp seals (Crystophoca cristata) and (Phagophilus groenlandicus).

North Atlantic (2): This candidate marine reserve spans the North Atlantic from western Britain to Eastern Canada, including a southward extension west of Spain and Portugal. It includes a significant section of the mid-Atlantic ridge between 50^{o}N and 60^{o}N, incorporating the Charlie Gibbs Fracture Zone, making it important for deep-sea bottom life. It also includes the Rockall, Hatton and Porcupine Banks, deepwater areas to the west of the British Isles around 50^{o}N to 60^{o}N. Further south, it incorporates the Josephine and Gorringe Banks off the coast of Spain. Josephine Bank is a current swept seamount, rising from 3200 m from the abyssal plain to within 170 m of the surface. It supports a diverse assemblage of fish, corals and other invertebrates and is a possible stepping-stone in tuna and turtle migrations. Deep water trawling is seriously impacting this and other deepwater banks and seamounts that support important deepwater coral and sponge communities. Preliminary video surveys are showing that some banks still have pristine coral and other deep-water habitats but the fishing fleets are moving in fast and there is a high risk of these habitats being destroyed imminently.

The proposed reserve also holds the sub-polar front, a rich summer feeding area for many migratory fish, birds and mammals, as well as leatherback turtles (Dermochelys coriacea). The reserve includes two shallow water regions off Eastern Canada, the 'tail' of the Grand Banks and Flemish Cap. The 'tail of the bank' is an important nursery area for cod (Gadus morhua) and other shallow water fish and currently supports a high intensity international fishery with significant removals of undersized fish. Flemish Cap is a shallow water shelf covering a total area of 58,000 km2 situated outside the Canadian EEZ. It supports the most heterogeneous offshore Atlantic cod population and is a foraging ground for northeastern and western Atlantic bluefin tuna populations (Thunnus thynnus). It is also visited by sperm whales (Physeter macrocephalus) among others and may be an important wintering area for great shearwaters (Puffinus gravis). Flemish Cap is currently intensively trawled.

Azores/Mid-Atlantic Ridge (3): This candidate reserve includes a section of the mid-Atlantic ridge that is rich in deep seamounts. It also covers the Rainbow Hydrothermal Vent Field which is located at 2270-2320 m depth. This comprises more than thirty groups of active small sulphide chimneys over an area of fifteen square kilometres. About thirty-two different vent species have so far been recorded in the Rainbow area. The small spatial extent and site-specific communities make the vent field highly vulnerable to the increasing levels of scientific and commercial exploitation, including scientific sampling, bioprospecting and mining. Overlying waters of this region also supports significant populations of whales and fish, including sperm whales.

Eastern Mediterranean (4): The area to the south, east and west of Cyprus is important for loggerhead (Caretta caretta) and green turtles (Chelonia mydas). The area to the south, extending to the Egyptian coast, contains the Eratosthenes seamount, an isolated and near pristine mount with a likely highly endemic fauna. It also includes an area of biologically important deepwater cold-seeps off the Nile Delta.

Central Mediterranean (5): The Ligurian Sea between France, Northern Italy and Sardinia is already a multi-nationally managed marine protected area, the Pelagos reserve for marine mammals. The outstanding values and importance of this area for cetaceans was recognised in designating it as the first high seas MPA in the Mediterranean. However, the cetaceans of the Ligurian Sea need to be protected from the impacts of fishing and other activities. To the immediate south, the Tyrrhenian Sea contains a significant concentration of seamounts, and has important migration routes for bluefin tuna, and is thought to be a major spawning area for the species in the Mediterranean.

Sargasso Sea/Western Atlantic (6): The Sargasso Sea lies to the west of the centre of the North Atlantic Gyre and is bounded on the west by the Gulf Stream. The Sargasso is a region of light winds and little rain. Coriolis forces acting on currents in the North Atlantic Gyre push water inward toward the centre of the gyre and planetary rotation offsets it west. The Sargasso is thus a region of convergence of currents and gentle downwelling. It supports a high level of endemism among plankton species. Converging currents bring together flotsam and jetsam and higher nutrients foster growth of seaweed mats that can cover huge areas. The western Sargasso and adjacent Gulf Stream is a hotspot for aquatic megafauna, including fish, turtles and marine mammals. Young


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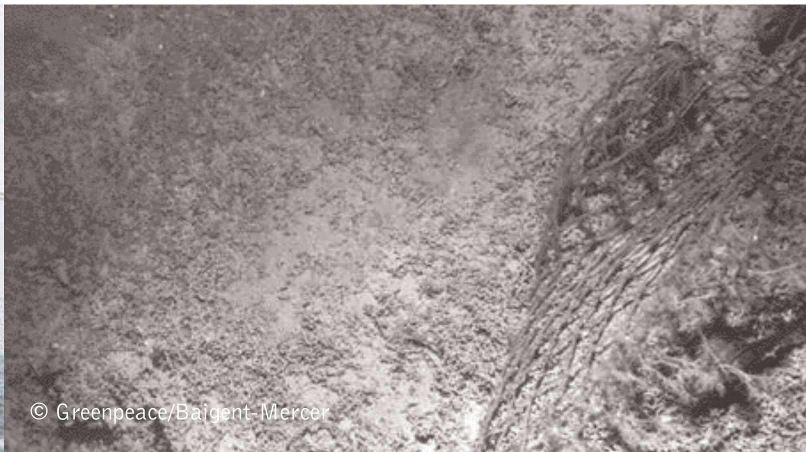
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juveniles of several species of turtle spend their time on the high seas in the Sargasso, feeding and sheltering among the seaweed mats. It is the breeding ground for threatened European eels (Anguilla anguilla) and is a migration route for whales, fish and turtles. Atlantic leatherback turtles migrate across the Sargasso from nesting beaches in Guyana to feeding grounds off Nova Scotia.

The southern spur of this candidate reserve also includes a section of the mid-Atlantic ridge that holds the Logatchev Hydrothermal Vent Area. Logatchev-1 field is characterised by three distinct sites: (i) a large sulphide mound with smoking craters; (ii) an active chimney complex called Irina-2; and (iii) an area with soft sediment and diffuse flow. These have a diversity of biotopes including thick bacterial mats, diffuse flow areas, and two different types of smokers – 'creeping' or horizontal smokers, and the more common vertical structures that resemble chimneys. Logatchev-1 also hosts an abundance of fauna, including swarms of shrimp at black smokers, clam beds in the sediment biotopes, mussels from the genus Bathymodiolus on sulphide chimneys and sulphide base areas, as well as sea anemones. Logatchev-2 has six sulphide mounds and extensive massive sulphide deposits containing high concentrations of copper, gold, zinc, uranite (uranium), and the highest concentration of cobalt of any hydrothermal vent field recorded to date. The main present threat is scientific research; future threats are mining and bioprospecting.

South-Central Atlantic (7): This proposed reserve includes a large section of the mid-Atlantic ridge that is rich in seamounts, as well as a ridge spur that extends from the coast of Brazil into the Atlantic, the Trindade ridge. This ridge extends west to east at a latitude centred on 20^{o}S, terminating at the islands of Trindade and Martin Vas. It has high endemism of species such as fish and is currently being damaged by deep sea trawling. The proposed reserve also includes a critical migration route for green turtles at approximately 5^{o} to 10^{o}S, between breeding beaches in Ascension and feeding grounds off South America. The candidate reserve also supports exceptional species diversity of tuna, billfish and toothed whales. The far southern part of the region includes a transition area between South Atlantic and Southern Ocean waters and is a critical feeding area for albatrosses, penguins and pinnipeds that breed on remote islands of the South Atlantic.

Antarctic-Patagonia (8): This proposed reserve incorporates the Antarctic Peninsula, the entire Weddell Sea and Bellingshausen Seas, much of the Scotia Sea, and parts of the South Atlantic. It includes the Patagonian Shelf edge, a region of exceptionally high productivity. This is the convergence zone between the south flowing warm Brazil current and the northward-flowing cold water Malvinas-Falklands current. The proposed reserve incorporates transitional waters between the warmer southern Atlantic and cold polar seas, which also support high productivity. It is a key area for aquatic megafauna, including albatross, seals, penguins and whales. It supports eight species of baleen whales and a further twenty species of toothed whale and dolphin. There is an important deep-sea fishery for Patagonian toothfish and a highly productive shallower water fishery for squid both of which have serious impacts on wildlife.

Vema Seamount-Benguela (9): This proposed reserve includes Vema Seamount which lies approximately 500km off the coasts of Namibia and South Africa. It is an isolated seamount, rising from a deep abyssal plain that supports a high diversity of fish and invertebrates, probably with significant endemism. It has suffered badly from overexploitation of rock lobsters. The reserve also includes part of the Benguela current ecosystem which sustains highly productive fisheries for pelagic and bottom living species, but increasingly deepwater species like those on the seamount, are being targeted.

South Africa-Agulhas Current (10): This proposed reserve incorporates the confluence between the warm, south-flowing Agulhas Current and cool, nutrient rich waters from the Southern Ocean. The mixing area includes large warm core eddies that propagate eastwards from the tip of South Africa, promoting high productivity throughout the area. This productivity sustains many resident and migratory species, including southern right whales (Eubalaena glacialis), sharks, billfish, penguins and

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albatross. The proposed reserve also includes migration routes for leatherback turtles that nest on the South African and Mozambique coasts.

Southern Ocean (11): This proposed reserve incorporates waters between approximately 45^{o}S to the edge of Antarctica. These waters are dotted with small islands that are critical breeding sites for seabirds and marine mammals, including the likes of Prince Edward, Crozet, and Kerguelen. From the map of high seas use by air-breathing megafauna shown in this report, it is clear that the region is very important to such species. Hotspots of use of the ocean by these species are concentrated around several of these sub-Antarctic islands. The region also has a complex of seamounts including the Afrikaner II Rise (ca. 46^{o}S, 42^{o}E), which straddles the edge of the South African EEZ boundary. This is the site of a large amount of illegal fishing activity. It is also a favoured foraging site for many top predators, especially albatrosses, breeding both on the Prince Edward Islands and the Crozets. The area also contains the isolated Ob and Lena Tablemounts.

Southern Ocean-Australia/New Zealand (12): This region of the Southern Ocean is critical for wildlife. It includes the area between Australia, New Zealand and Antarctica, centred on Macquarie Island. This incorporates Campbell Islands, The Antipodes Islands and Balleny Islands as well as the western half of the Ross Sea. In addition, the proposed reserve covers a large area of seamounts that are subject to bottom fishing, including the Macquarie Ridge and South Tasman Rise. Collectively the islands, several hundred seamounts and the comparatively shallow surrounding seas represent a strong physical barrier in oceanographic terms. The marine environment is thus one of a slow-moving water mass rich in nutrients. The region shares similar features of high productivity and high concentration of air-breathing megafauna as the Southern Ocean Reserve, described above. It supports five species of penguin, for example, of which two are endemic, the snares (Eudyptes robustus) and royal (Eudyptes schegel). It is also important for New Zealand sea lions (Phocarctos hookeri) and has a rich but poorly described underwater biota, including fragile seamount communities. The Ross Sea is distinct from the wider Antarctic marine ecosystem. Its highly productive and healthy food web includes such charismatic megafauna as whales, seals and penguins, but it is imminently threatened by the rapid growth of toothfish fishing and hunting of minke whales (Balaenoptera acutorostrata). Potential threats may arise from bioprospecting, tourism and the introduction of invasive marine species from ship hulls.

Central Indian Ocean-Arabian Sea (13): This region incorporates the central-western Indian Ocean. It includes the Saya de Malha Banks, a part of the Mascarene Plateau between the Seychelles, Madagascar, Mauritius and Chagos. The proposed reserve supports deep and shallow water fauna, including diverse coral reefs. The area contains the largest coral reef and seagrass habitat in the world in international waters and is a stepping stone providing connectivity across the entire Indian Ocean. As such it is crucial to gene flow and migratory stocks. The area around Saya de Malha is a major whale calving ground. The proposed reserve incorporates a region of high tuna and billfish diversity as well as major seamount areas such as the Ninetyeast Ridge, Broken Ridge and the seafloor-spreading zone of the Mid-Indian Ridge. Much of the proposed reserve is subject to high fishing intensities including trawling, longlining and purse-seining. Distant water fleets from many nations, such as those of Europe, Sri Lanka and Asia, go there to fish. The Chagos Islands, which the reserve bounds, are uninhabited and almost unpolluted and little affected by direct human impacts except fishing. The proposed reserve surrounds these and islands of the Maldives and Lakshadweep groups, providing an offshore conservation buffer. The western part of the reserve extends north into the Arabian Sea, encompassing a region of seasonal upwelling driven by monsoon winds.

Bay of Bengal (14): This region supports a high diversity of large pelagic fishes, including tunas, billfish and whale sharks. It is an important migration route for turtles breeding on the coast of India's Orissa coast and is intensively fished.

Northwestern Australia (15): This proposed reserve incorporates a region of exceptional richness of tunas and billfishes. It is a spawning area for southern bluefin tuna (Thunnus maccoyii). It is also a critical feeding and juvenile habitat for highly migratory whale sharks.

South Australia (16): This region supports very high productivity and is the meeting place of the warm, south flowing coastal Leeuwin Current and the cool water of the Southern Ocean. The Leeuwin spills around Cape Leeuwin into the Great Australian Bight, mixing as it does with cooler, nutrient rich water, fuelling plankton growth. This mixing zone attracts large concentrations of aquatic megafauna to feed. It is home to over fifteen species of toothed whale and dolphin, and eight species of baleen whale.

Lord Howe Rise and Norfolk Ridge (17): This area supports extensive seamount chains of the Lord Howe Rise and Norfolk Ridge. Recent scientific studies indicate they support a highly endemic fauna, with a quarter to a third of species sampled found nowhere else. Many appear to be relict species. Deepwater bottom trawlers intensively exploit the seamounts. This region supports a high diversity of large pelagic fishes.

Coral Sea (18): This proposed reserve incorporates a region of exceptional richness of tunas, billfishes and other large pelagic animals, as well as being a global centre of endemism for coral reef fauna. It contains significant deepwater seamount and slope habitats, also supporting high levels of endemism.

Northern New Guinea (19): This area represents an important migration corridor for critically endangered Pacific leatherback turtles. It also incorporates the Eauripik Rise, a significant seamount area in one of the most biologically diverse regions of the world oceans.

Western Pacific (20): This area is bounded by the Exclusive Economic Zones of Federated States of Micronesia, Papua New Guinea, Solomon Islands, Tuvalu, Kiribati, Nauru and Marshall Islands. It represents an important spawning area for tunas, including Bigeye Tuna (Thunnus obesus).

Kuroshi-Oyashio Confluence (21): This proposed reserve covers the area of convergence between the warm north-flowing Kuroshio Current and the cold south-flowing Oyashio Current. It is a highly productive region that is rich in fish and aquatic megafauna, including whales, dolphins, tuna and albatross. These seas are a productive fishing ground for sardines, squid, bonito, and mackerel. In deep water, the proposed reserve includes sections of the Japan and Kuril Trenches.

Sea of Okhotsk (22): The Sea of Okhotsk is a highly productive semi-enclosed sea that supports large populations of fish and shellfish, together with high concentrations of marine mega-fauna, including the critically endangered western population of Pacific gray whales. It is an important bird and fish migration route, especially for salmon spawning in rivers of eastern Russia. In winter, large areas of the sea are ice-bound, making for highly seasonal productivity. Overfishing and illegal fishing are widespread, and the region is being rapidly developed for oil production, threatening wildlife.

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Gulf of Alaska (23): This region in the Gulf of Alaska is highly productive and is a key area for migrating salmon, salmon sharks, whales e.g. gray whale, (Eschrichtius robustus), fur seals (Callorhinus ursinus) and Steller's sea lions (Eumetopias jubatus), among others. It also contains a significant concentration of seamounts.

Northeastern Pacific (24): This large equatorial/sub-equatorial area extends from to the southwest towards the North American coast. It supports high pelagic fish diversities and abundance and lies on a major trans-Pacific pathway for tuna migration. It also contains key migration corridors for leatherback turtles across the Pacific from New Guinea, and from nesting beaches in California and Mexico to feeding grounds that the proposed reserve largely includes. It also is important for loggerhead turtles, blackfooted albatross (Phoebastria nigripes) and northern elephant seals (Mirounga angustirotris). In deep water, the region includes the Clarion-Clipperton Fracture Zone, an area with high concentrations of manganese nodules. These nodules support a hard substrate fauna on an otherwise sediment covered abyssal plain. Without protection they are likely to be impacted by future mining operations.

Southeastern Pacific (25): This proposed reserve incorporates the region bounded by Galapagos-Cocos-Panama-Costa Rica-Columbia-Ecuador. There is considerable potential for cooperative protection of high seas areas adjacent to the EEZs of these countries and an initiative is already underway, coordinated by Conservation International, to secure such cooperation. The Humboldt Current bounds this region to the east before flowing away from the Peruvian coast toward the Galapagos. Consequently this is an area of high aquatic productivity, but it is also a convergence between very different bodies of water, including North and South Equatorial Currents. The area is intensively fished but it supports a diverse and still abundant megafauna. It includes a migration route for the critically endangered Pacific leatherback turtles from breeding beaches in Costa Rica to feeding grounds (which the proposed reserve largely encompasses). To the southwest, the region is a hotspot of tuna and billfish diversity. The region also contains important and vulnerable deepwater habitats, including the Galapagos Rise, Sala y Gomez Ridge and Challenger Fracture Zone.

Representative areas (marked 'R'): The global network of marine reserves presented here has been designed to be fully representative of high seas habitats and biodiversity. Some of the areas included are not described separately here, and are simply marked 'R'. These areas include important representatives of particular ecosystems, such as bottom types, depth zones and biogeographic regions, needed to achieve targets of coverage and representation of habitats.

12. Implementing the network

Although the value of establishing a global network of marine reserves is widely recognised, there is currently no mechanism under the existing international framework provided by UNCLOS and the CBD for implementing such reserves on the high seas.

The CBD is the primary instrument providing direction to states for the establishment of marine protected areas and marine reserves under their jurisdiction, and also explicitly acknowledges the need for protective measures in areas beyond national jurisdiction. Article 4 of the convention obliges Parties to apply the convention to all processes or activities under their jurisdiction or control, including those taking place on the high seas. However, the Convention on Biological Diversity does not oblige states to take collective measures to protect the high seas and does not contain the necessary provisions to implement its 2012 goal of a comprehensive global network.

It is Greenpeace's view that in order to implement the CBD commitment and provide the necessary mandate to establish and manage marine reserves on the high seas, a new implementing agreement under UNCLOS is required. Such an implementing agreement would not require any amendment to the text of the Convention and would be consistent with article 22 (2) of the CBD which already obliges parties to implement the convention "with respect to the marine environment consistently with the rights and obligations of States under the Law of the Sea". The agreement would provide formal recognition of the need to protect biodiversity on the high seas, and a mandate to protect high seas areas for conservation purposes. Such an implementing agreement could be modelled on the UN Fish Stocks Agreement – which was itself negotiated in order to implement some of the Articles of UNCLOS, and could be used to address a number of gaps in the current governance of high seas biodiversity in addition to those relating to the establishment of high seas marine reserves.

Other advantages of developing such an implementing agreement under UNCLOS include:

- **UNCLOS is regarded as the framework agreement that delimits ocean areas and details state rights and duties in the high seas and the 'Area', and it is recognised as customary international law;**
- **UNCLOS' broad remit already covers most or all of the activities that impact on marine biodiversity, including emerging issues such as bioprospecting and noise pollution;**
- **UNCLOS provides a binding dispute settlement mechanism**

Such an agreement would build on and provide for the implementation of existing provisions in UNCLOS relating to the protection and preservation of the marine environment and the 'Area'.

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Appendix 1: Data layers used

Bathymetry

Global sea depths were obtained from the GEBCO One Minute Grid (The GEBCO Digital Atlas published by the British Oceanographic Data Centre on behalf of Intergovernmental Oceanographic Commission and International Hydrographic Organization, 2003), which provide the data on a one-minute interval global grid. For use with Marxan the depth values were reclassified into five categories:

0-200m	Epipelagic
201-1000m	Mesopelagic
1001-4000m	Bathypelagic
4001-6000m	Abyssopelagic
6001m+	Hadalpelagic

Bottom complexity

High species diversity is often associated with high habitat complexity. More complex habitats provide greater refugia, which can support a greater variety of life stages and also interrupt predator-prey relationships, so allowing more species to co-exist. All of the above can lead to greater ecosystem resilience. To identify features associated with varying and complex habitats such as sills, ledges and rocky reefs, Ardron (2002) developed a method of calculating bottom complexity. The measure gauges how convoluted the seabed is from how often the slope of the sea bottom changes in a given area (Ardron 2002). It is estimated by exaggerating the depth scale and calculating the density of changes in the 'slope of the slope' of the (exaggerated) depth. We followed this method, but due to the large grid size used and the global coverage (which meant a broad range of values) it was not necessary to exaggerate the depth in order to cause a greater spread of values. We then classified the results into four equal categories of high to low bottom complexity. Global sea depths were obtained from the GEBCO One Minute Grid (GEBCO 2003), which provide bathymetric data on a one-minute interval global grid.

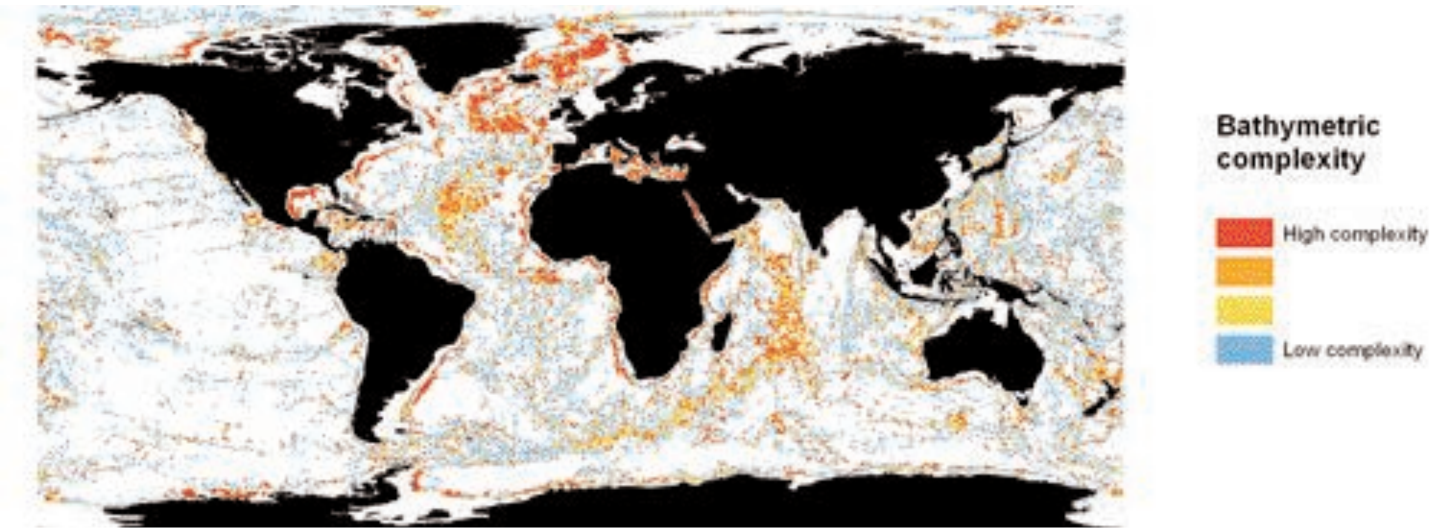

Figure 3: Map of seabed bottom complexity.

Ardron, J.A., 2002. A Recipe for Determining Benthic Complexity: An Indicator of Species Richness. Chapter 23, Marine Geography: GIS for the Oceans and Seas. Edited by Joe Breman, ESRI Press, Redlands, CA, USA. Pp 169-175

Seamounts

A global point database of more than 14,000 seamount locations was obtained from The Sea Around Us Project (www.seaaroundus.org). The seamounts were identified from depth differences on a digital elevation map (Kitchingman and Lai 2004). The locations were mapped, overlaid with a five-degree grid, and the number of seamounts per grid cell calculated.

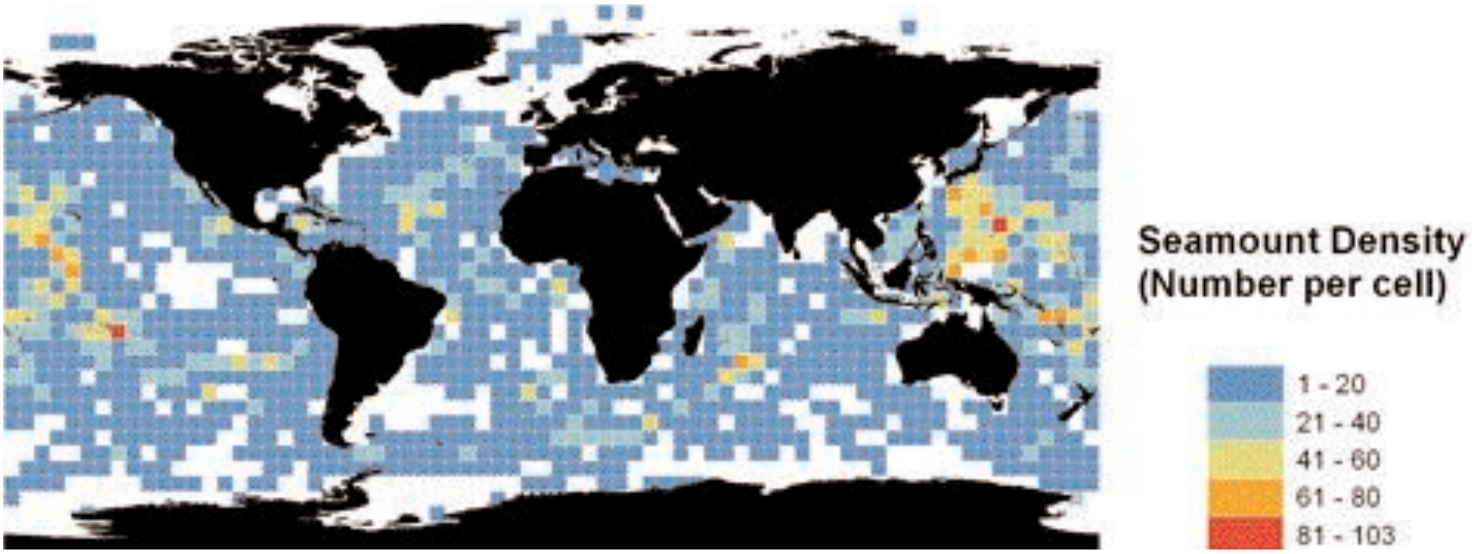

Figure 4: Density of seamounts (number per grid cell).

Kitchingman, A., and Lai, S., (2004) Inferences on potential seamount locations from mid-resolution bathymetric data. Pp 7-12 In: Pauly, D., and Morato, T. (eds). Seamounts: Biodiversity and Fisheries, 2004 Fisheries Centre Research Reports 12(5).

Upwellings and Downwellings

We created a data layer showing ocean areas where deep and bottom waters form and sink, zones where intermediate waters form and sink, and major upwelling zones. We created a GIS polygon layer of these zones that could be used within Marxan as features for selection.

Source: Segar, D. A., 1998. Introduction to Ocean Science. Wadsworth Publishing Co., Belmont, CA.

Sea surface temperature gradient

The steepness of the gradient in sea surface temperature from one place to another provides an indication of places where warm and cold water meet, including upwellings and convergence zones between warm and cold currents. These data are markers of high productivity and the presence of higher concentrations of marine life (Worm et al. 2005). Sea surface temperature (SST) gradient data were kindly provided by Boris Worm (Worm et. al. 2005). Five-day maps of sea surface temperature at a resolution of 0.5^{0} were provided by the NOAA/NASA Advanced Very High Resolution Radiometer, Oceans Pathfinder Project from 1998-2002. The maximum slope of each data point (at original resolution of 0.5^{0}) to its eight surrounding points was calculated and then averaged across 5^{0} x 5^{0} grid cells, to give an estimate of the spatial gradients in SST ($^{0}C.km^{-1}$).


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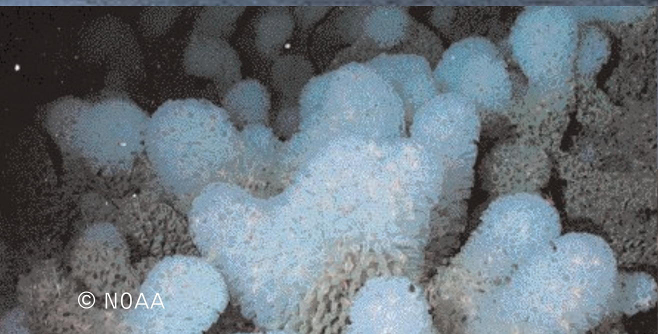
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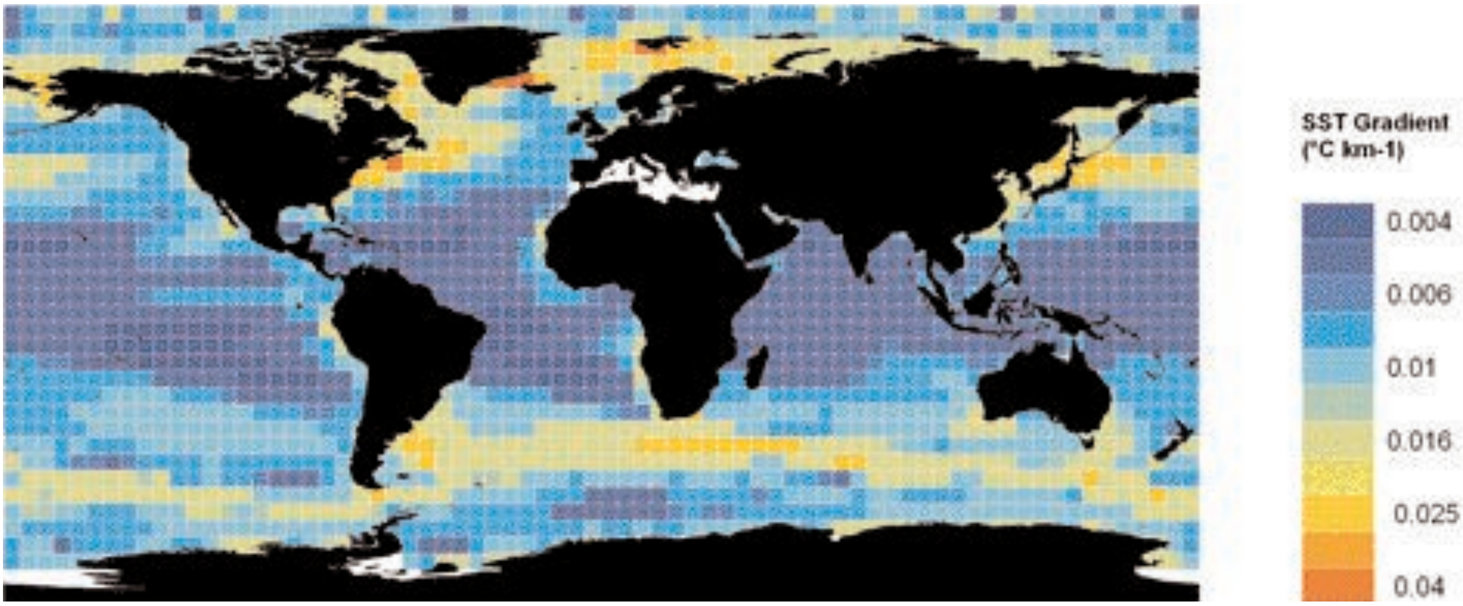


Figure 5: Map showing the intensity of the sea surface temperature gradient

Worm, B., Sandow, M., Oschlies, A., Lotze, H.K. and Myers, R.A., 2005. Global Patterns of Predator Diversity in the Opens Oceans. Science 309: 1365-1369.

Tuna and Billfish data

Tuna and billfish diversity data were kindly provided by Boris Worm (Worm et. al.2005). Global 5^0 x 5^0 gridded Japanese longlining data from 1990-99 were used to estimate two measures of species diversity in each grid cell: species richness (the number of species per 50 individuals caught) and species density (the number of species caught per 1000 hooks).

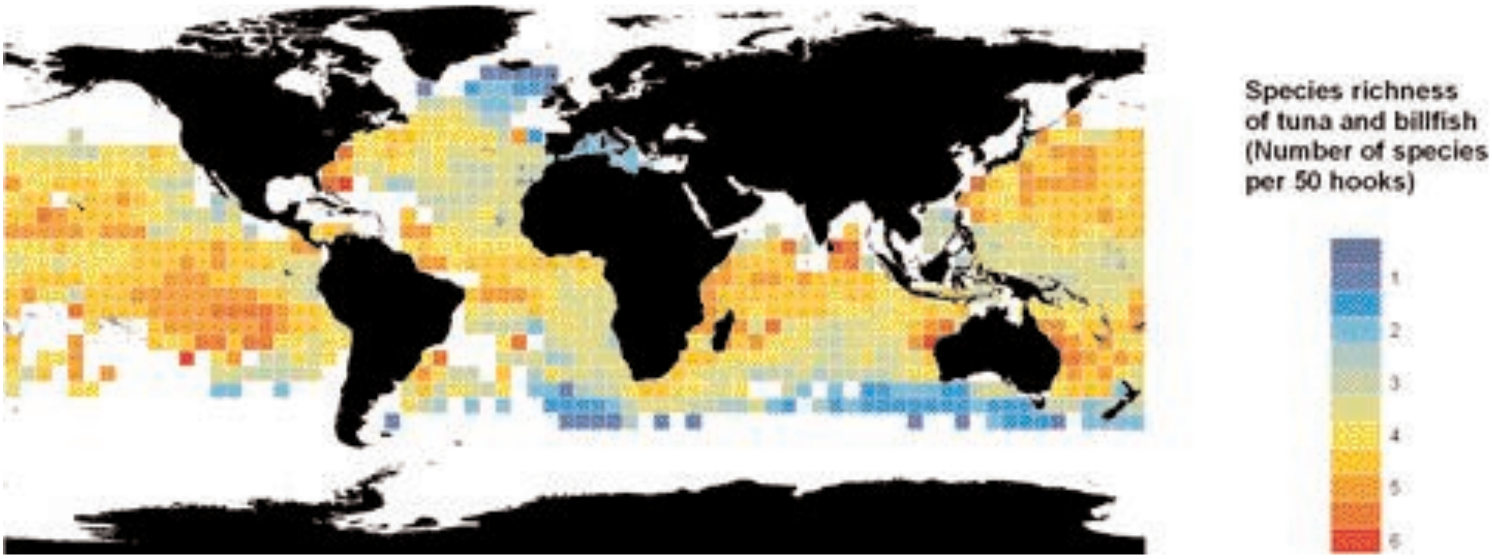


Figure 6: Map showing the species richness of tunas and billfish (number of species per fifty fish caught).

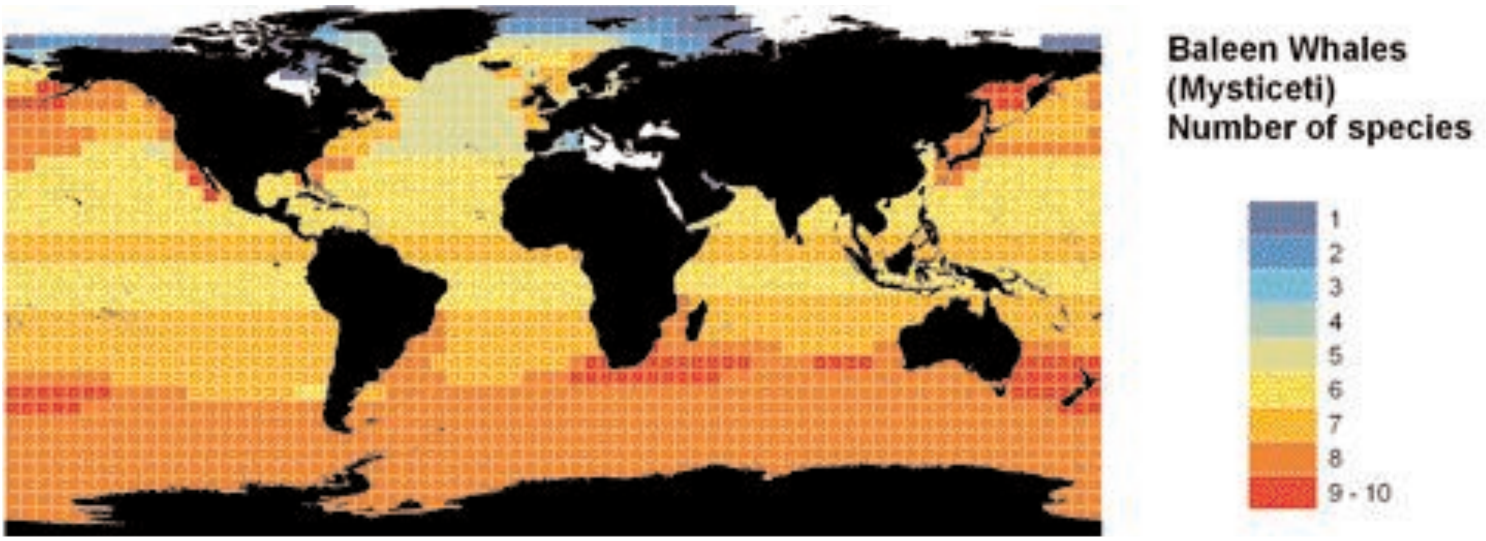
Worm, B., Sandow, M., Oschlies, A., Lotze, H.K. and Myers, R.A., 2005. Global Patterns of Predator Diversity in the Opens Oceans. Science 309: 1365-1369.

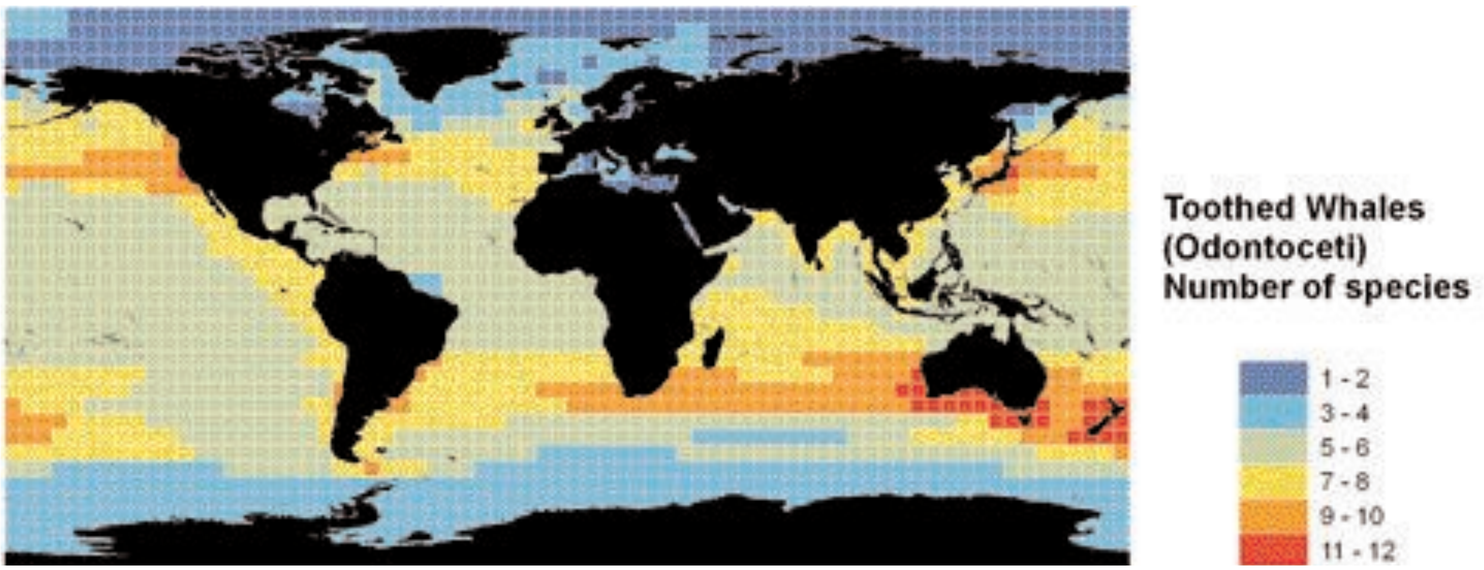
Bottom sediments

The distribution of sea-floor sediments was taken from http://soconnell.web.wesleyan.edu/courses/ees106/lecture_notes/lecture14_106ocean_cir2/sld034.htm. The original source of the image is: Segar, D. A., 1998. Introduction to Ocean Science. Wadsworth Publishing Co., Belmont, CA. The image was then digitised to create a GIS polygon layer.

Cetaceans

Maps of the geographic distribution of 73 cetacean species were obtained from http://en.wikipedia.org/wiki/Cetaceans. They represent the majority of the world's cetaceans, but we excluded river dolphins. Maps were digitised into polygon coverages which were compiled into distribution maps of three groups: baleen whales (Mysticetes), toothed whales (Odontocetes) excluding dolphins (Delphinidae), which are the largest family within the Odontocetes and were mapped separately. A 5^0 x 5^0 grid was then overlaid and the number of species present per grid cell calculated for each group and collectively.





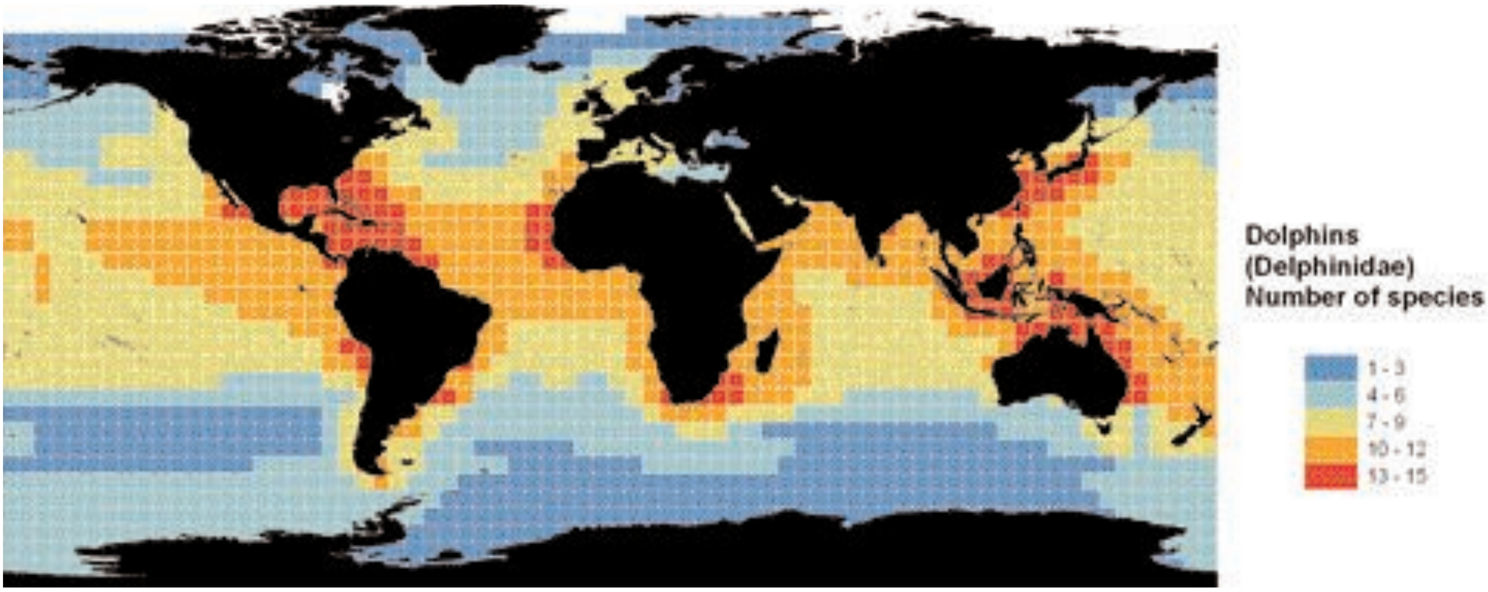


Figure 7: Species diversity of cetaceans.

Biogeographic zones

A map of the world oceans biogeochemical provinces (Pauly et al. 2000, downloaded from http://seaaroundus.org/report/method/pauly02.pdf) was used to create a GIS layer of the world's 12 ocean biomes that are to be used as a selection feature representing biogeographic zones in Marxan.

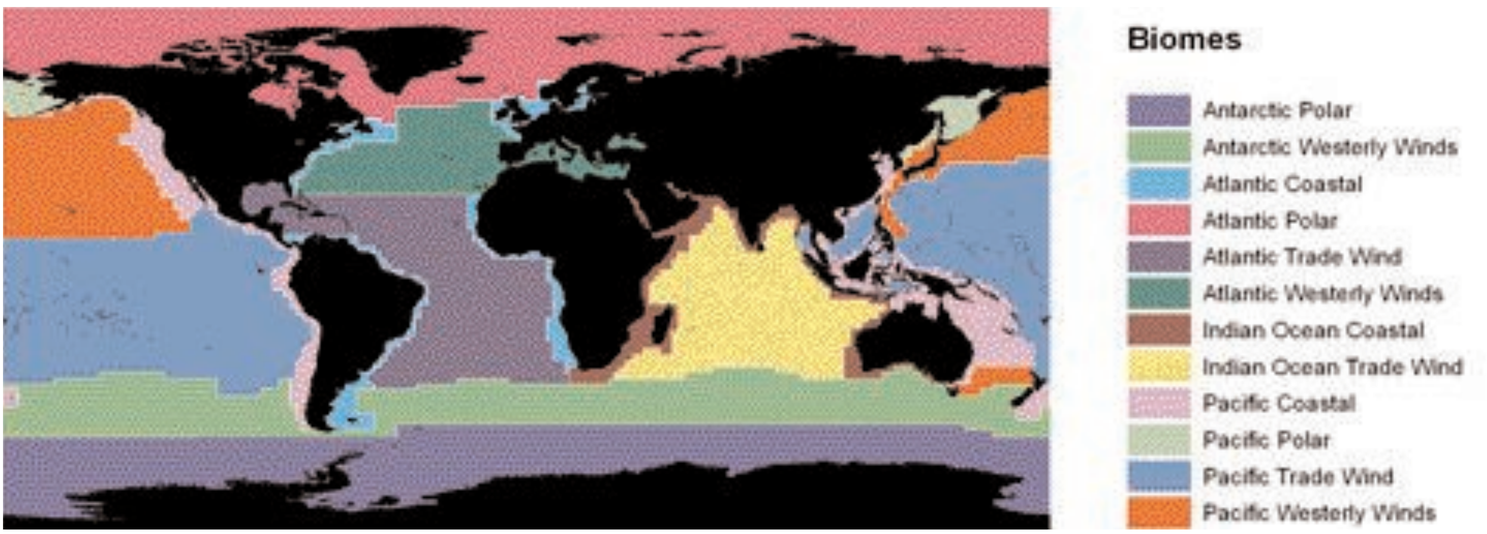


Figure 8: Biogeographic zones of the global oceans.

Pauly, D., V. Christensen, R. Froese, A. Longhurst, T. Platt, S. Sathyendranath, K. Sherman and R. Watson. 2000. Mapping fisheries onto marine ecosystems: a proposal for a consensus approach for regional, oceanic and global integration. Pp 13-22. In: Pauly, D. and T.J. Pitcher (eds). Methods for Evaluating the Impacts of North Atlantic Ecosystems. Fisheries Centre Research Reports 8(2).

Longline and purse-seining catches

Fishing operations represent a threat to biodiversity of both target and non-target species on the high seas. Average recent yearly catches of tuna and billfish (tonnes) were obtained on a 5^0 x 5^0 grid basis. We used data averaged from 2000 to 2003 inclusive, separated by gear type, i.e. longlining and purse-seining.

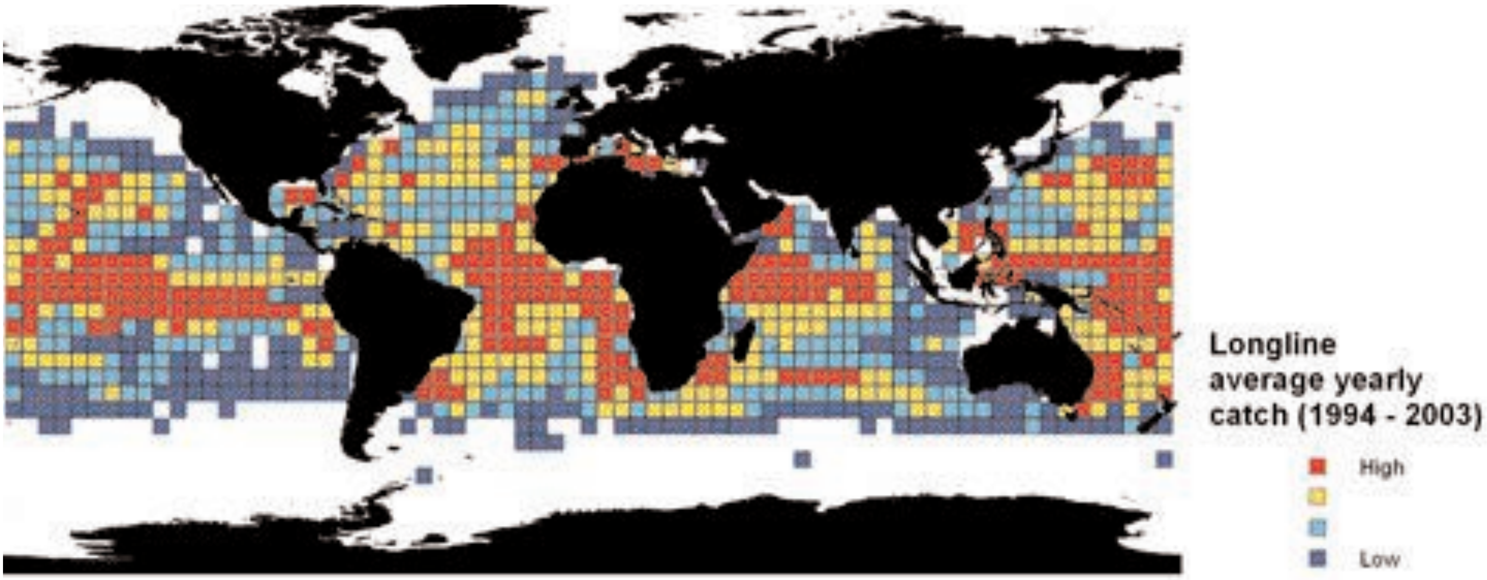


Figure 9: Distribution of longline and purse-seine catches.

Reference
Fisheries Global Information System (FIGIS). Atlas of Tuna and Billfish Catches. http://www.fao.org/figis/servlet/static?dom=root&xml=index.xml.

Distribution of aquatic megafauna

An extensive data search on the abundance, at-sea distribution and foraging ranges of penguins, turtles, pinnipeds and albatross was carried out. The data were digitised into separate GIS layers for each species. To identify areas on the high seas that were important to marine megafauna, we divided the high seas into five-degree grid-cells. Cells that fell entirely within the exclusive economic zones were excluded, however cells around small islands such as the sub-Antarctic islands were included on the basis of being so remote they were essentially high seas in all but name.

Cells were scored from 0-3 on a species-by-species basis, depending on the use:

Score	Definition
0	No individuals present
1	Little use
2	Intermediate use
3	High use and/or a breeding colony present

These scores were then summed across the species within the taxonomic groups to produce a composite score for each grid-cell for each of the four taxa. To ascertain an overall importance for each taxon, the scores were standardized onto a common scale of zero to one, to give them equal weighting. The scores were then summed to produce a combined score for all taxa. The score for each grid-cell was divided by the number of taxa present so as not to over-represent cells where data were available for multiple taxa.

We were unable to obtain data on all species or regions because of the incomplete coverage of scientific research to date. Consequently, where data indicate high importance of an ocean area to one or more of the taxa, it is taken as a positive indication that protection of that area would be worthwhile. However, absence of data from an area is not used as an indication that the cell does not warrant protection. Its value to aquatic megafauna is simply indeterminate. Data on albatrosses are the most complete due to the existence of a detailed review of at-sea movements that includes data for 16 of the 21 existing species (BirdLife International 2004).

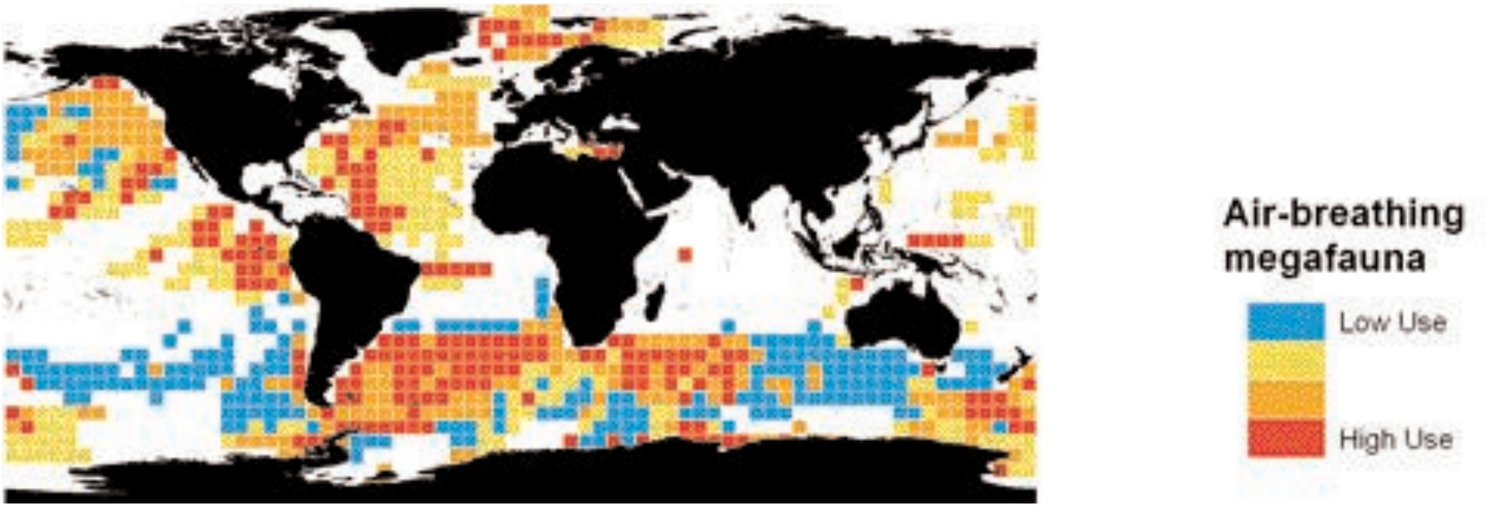


Figure 10: Distribution of at-sea movements of air-breathing aquatic megafauna (albatrosses, turtles, pinnipeds and penguins).

Appendix 2: Respondents to the expert consultation on high seas marine reserves.

Rob Ahrens, University of British Columbia, Canada;
Jeff Ardron, German Federal Agency for Nature Conservation;
Peter Batson, Deep Ocean Expeditions;
Giovanni Bearzi, Tethys Research Institute, Italy;
Maria Beger, University of Queensland, Australia;
Doug Biffard, British Columbia Parks, Canada;
Barbara Block, Stanford University, USA;
P. Dee Boersma, University of Washington, USA;
George Branch, University of Cape Town, South Africa;
Chris Caldow, NOAA, USA
Claudio Campagna, National Research Council of Argentina
Jim Carlton, Williams College, USA;
Nick Conner, Environment Department, New South Wales Government, Australia;
Helen Cross, University of East Anglia, UK;
Paul Dayton, University of California, San Diego, USA;
Lyndon Devantier, Australia;
Nick Dulvy, Centre for Fisheries and Aquaculture Science, UK;
Carlos Eduardo Leite Ferreira, Dept of Oceanography, Arraial do Cabo, RJ, Brazil
Kate Eschelbach, NOAA, USA
Marta Estrada, Departamente de Biología Marina, Institut de Ciències del Mar, Spain;
Sergio Floeter, University of California, Santa Barbara, USA;
Rod Fujita, Environmental Defense, USA;
Caleb Gardner, University of Tasmania, Australia;
Fiona Gell, Isle of Man Government, UK;
Stuart Green, Reefcheck, Philippines;
Ben Halpern, University of California, Santa Barbara, USA;
Indu Hewawasam, World Bank, USA;
Cheryl Hislop, University of Tasmania, Australia;
Sascha Hooker, St. Andrews University, UK;
Mike Kaiser, University of Wales at Bangor, UK;
Les Kaufman, Boston University, USA;
Graeme Kelleher, Australia;
Stephen Kellert, Yale University, USA;
Nicola King, University of Aberdeen, UK;
Stuart Kininmouth, Australian Institute of Marine Science;
Heather Leslie, Princeton University, USA;
Helene Marsh, James Cook University, Australia;
Aileen Maypa, Philippines
Laurence McCook, Great Barrier Reef Marine Park Authority, Australia;
Paul McNab, Department of Fisheries and Oceans, Canada;
Camilo Mora, University of Windsor, Canada;
Ivan Nagelkerken, Radboud University, The Netherlands;
Deon Nel, WWF, South Africa
Giuseppe Notarbartolo di Sciara, Tethys Research Institute, Italy;
John Ogden, Florida Institute of Oceanography, USA;
Bob Paine, University of Washington, USA;
Steve Palumbi, Stanford University, USA;
Dominique Pelletier, IFREMER, France;
Simon Pittman, NOAA, USA
Andrew Price, University of Warwick, UK;
Murray Roberts, Scottish Association for Marine Science, UK;
Rod Salm, The Nature Conservancy, USA;
Dominique von Schiller, University of East Anglia, UK;
Stephen Schneider, Stanford University, USA;

Charles Sheppard, University of Warwick, UK;
Chris Smyth, Australian Conservation Foundation;
Jason Spencer-Hall, Plymouth University, UK;
Daniel Suman, Rosenstiel School of Marine and Atmospheric Sciences, USA;
John Terborgh, Duke University, USA;
Virginie Tilot, France;
Carl Walters, University of British Columbia, Canada;
Dianne Williams, University of Western Australia;
David Williamson, James Cook University, Australia;
Alan White, Tetra Tech, Honolulu, USA;
Dirk Zeller, University of British Columbia, Canada;

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Appendix 3: Results of the expert consultation

Area recommended for protection	Justification
Gulf of Maine shelf edge/central Atlantic	Convergence zone between warm Gulf Stream and cold Labrador current; summer feeding site for highly migratory species, including whales, tuna, billfish and leatherback turtles.
Northwest Atlantic - Grand Banks	The 'tail of the bank' outside Canada's EEZ. Important nursery area for cod and other shallow water fish; high intensity international fishery.
Northwest Atlantic - Flemish Cap (47°N, 45°W)	A shallow water shelf covering a total area of 58,000 km^2 situated outside the Canadian EEZ; supports the most heterogeneous offshore Atlantic cod population; foraging ground for north eastern and western Atlantic bluefin tuna populations; leatherback turtle summer foraging area; visited by sperm whale; may be an important wintering area for Great Shearwaters. The area is intensively trawled.
Eastern Canada - the Gully submarine canyon (approx 43.5° - 44.5°N, 58.5° - 59.5°W)	On the Scotian Shelf off eastern Canada, this large submarine canyon supports an unusually high abundance and diversity of cetacean species. This region appears to be particularly important for deep-diving species, possibly due to high squid biomass in the area.
Sargasso Sea, Western Central Atlantic 3 nominations	Downwelling region in the centre of the North Atlantic Gyre; large floating mats of seaweed; critical habitat for juvenile turtles, eels and other migratory species; especially rich for tuna and billfish species; high planktonic endemism; important for birds and cetaceans.
Mid-Atlantic ridge between 49° and 53°N 2 nominations	This section of the mid-Atlantic ridge contains the Charlie Gibbs Fracture Zone and is rich in seamounts. High levels of illegal as well as legal deep sea fishing using trawls and gill nets causing depletion of target species and serious habitat damage. The area also holds the sub-polar front which is highly productive and supports prolific pelagic life, including large bodied species such as whales.
Rockall, Hatton and Porcupine Banks, Northeast Atlantic – 3 nominations	Support highly diverse deepwater coral reefs and fish fauna; currently subject to intensive trawling pressure; location is ideally suited for enforcement.
Mid-Atlantic Ridge Rainbow Hydrothermal Vent field - located in international waters at 2270-2320 m depth on the Azorean segment of the Mid-Atlantic-Ridge – 2 nominations	Comprises more than 30 groups of active small sulphide chimneys over an area of 15 square kilometres. About 32 different species so far recorded in the Rainbow area; small spatial extent and site-specific communities make the vent field highly vulnerable to the increasing levels of scientific and commercial exploitation, including sampling, bioprospecting and mining.
Mid-Atlantic Ridge Logatchev Hydrothermal Vent Area –Logatchev-1 field is located at 14°45'N 44°58'W Logatchev-2 is located at 14°43.22'N 44°56.27'W Covers approximately 200,000 m^2 at a depth of 3050 m. Most isolated in mid-Atlantic. - there were 2 other more general nominations for hydrothermal vents	The Logatchev-1 field is characterised by three distinct sites: (i) a large sulphide mound with smoking craters; (ii) an active chimney complex called Irina-2; and (iii) an area with soft sediment and diffuse flow. These areas are further characterised by a diversity of biotopes including thick bacterial mats, diffuse flow areas, and two different types of smokers – 'creeping' or horizontal smokers, and the more common vertical structures that resemble chimneys. Logatchev-1 also hosts an abundance of fauna, including swarms of shrimp at black smokers, clam beds in the sediment biotopes, mussels from the genus Bathymodiolus on sulphide chimneys and sulphide base areas, as well as sea anemones. Logatchev-2 is characterised by six sulphide mounds and extensive massive sulphide deposits containing high concentrations of copper, gold, zinc, uranite (uranium), and the highest concentration of cobalt of any hydrothermal vent field recorded to date. Main current threat is scientific research; future threats are mining and bioprospecting.

Eastern Atlantic - Josephine Bank (36°45′N, 14°15′W)	Current swept seamount, rising from 3200 m depth to within 170 m of t he surface. This seamount is situated in international waters between the EEZ of continental Portugal and Madeira; and is located on an abyssal plain. Supports a diverse assemblage of fish, corals and other invertebrates; possible stepping stone in tuna and turtle migrations. Seriously threatened by deep water trawling.
Atol das Rocas/Fernando de Noronha Ridge, Brazil	Submarine mountain ridges extending east-west from the coast of Brazil; rich in deep sea endemic species and sensitive to damage from bottom trawling.
Vitoria-Trindade Spur, Brazil	Very important for deepwater endemic species; strong fishing pressure from the Asian fleet (e.g. Korea, Japan). The chain has shallow peaks that are currently subjected to trawling and very deep parts as well.
Patagonian Shelf Edge – 3 nominations	Convergence zone between the cold Falklands-Malvinas Current and warm Brazil Current; exceptionally high pelagic productivity attracts and supports large concentrations of aquatic megafauna; an internationally critical area for endangered whales, seals and sea lions; high intensity shallow and deep sea fisheries operate for toothfish and squid.
Vema Sea Mount - 500km off Namibia	High diversity, high vulnerability deep seamount; has suffered badly from overexploitation of rock lobsters.
Afrikaner II Rise (ca. 46°S, 42°E) in the Southern Ocean.	This deep rise straddles the edge of the South African EEZ boundary, and is the site of a large amount of illegal fishing activity. It is a favoured foraging site for many top predators, especially albatrosses, breeding both on the Prince Edward Islands and the Crozets.
Mediterranean: The National Park of the North Dodecanese, currently in the process of being established, is situated in Greece, in the southeastern Aegean, including 44 islands and islets (the island groups of Agathonisi, Arki and Lipsi, as well as isolated islets further south)	Sparsely populated with limited human impacts; has a rich biodiversity of marine and terrestrial ecosystems, supporting numerous protected and endangered species: marine mammals and turtles including Mediterranean monk seals, bottlenose, striped, common and Risso's dolphins and loggerhead turtles; extensive Posidonia seagrass beds and diverse littoral ecosystems; the islands support numerous important breeding birds and are critical way stations for migratory species.
Ligurian Sea, Mediterranean 2 nominations	Contains a permanent frontal system that promotes higher productivity; important region for marine mammals; currently declared a protected area between France and Italy – the Pelagos Sanctuary – but little real protection as yet.
Eastern Mediterranean – area of cold seeps off the Nile Delta. Location of the core area is: 31°30′-31°50′N, 33°10′-34°00′ E.	The area harbours an exceptionally high concentration of cold hydrocarbon seeps between 300 and 800 off the continental slope of North Sinai (Egypt) and the Palestinian Authority Gaza strip; supports unique living communities of chemosynthetic organisms such as polychaetes and bivalves.
Eastern Mediterranean - Eratosthenes Seamount is located between the Levantine Platform to the south and the Cyprus margin to the north, ca.100 km south of Cyprus (33°-34°N, 32°-33° E)	The flat-topped seamount measures approximately 120 km in diameter at the base, and rises 1500 m above the adjacent bathyal plain, with a summit 756 m deep. Studies reveal a rich and diverse ecosystem of corals and other invertebrates. Possibly an isolated refuge for relict populations of species that have disappeared from the adjacent continental slope. No fishing activity is reported in the area; probably the most pristine environment in the Mediterranean.
Mascarene Plateau, South West Indian Ocean 2 nominations	Supports deep and shallow water fauna, including coral reefs; high fishing intensities including trawling.
Saya de Malha Banks (part of the Mascarene Plateau), between Seychelles, Madagascar, Mauritius and Chagos	The are contains the largest coral reef and seagrass habitat in the world in international waters; stepping stone linking connectivity between whole-ocean shallow water communities and fisheries; crucial to gene flow and migratory straddling stocks across the entire Indian Ocean; major whale calving grounds.

Indian Ocean – Chagos, Lakshadweep, Maldives - a single but large ribbon protected area encircling the entire area	Chagos is almost totally unpolluted and unaffected by direct human impacts except fishing and hence is perhaps one of the world's few remaining 'pristine' environments. The reserve would surround and provide an offshore conservation buffer for the three island groups, whose coral reefs in particular are of exceptional biodiversity and international significance.
Northwest Pacific/Japan: Oyashio-Kuroshio confluence	Area of convergence between the warm Kuroshio Current and the cold Oyashio Current; highly productive region rich in fish and aquatic megafauna, including whales, dolphins, tuna and albatross; productive fishing ground for sardines, squid, bonito, and mackerel.
Southwestern Pacific – box 32^{o}S to 24^{o}S and 172^{o} to 180^{o} East. The area is bordered by theEEZs of Norfolk Island, Fiji, Tonga Australia and New Zealand.	This area contains deep-sea mounts and is a known and well-targeted commercial fishing ground for the high seas fishing fleets mainly focusing on pelagic species. The area also has significant concentrations of deep sea coral habitats. It is threatened by deep-water bottom trawling, tuna fishing and potentially sea bed mining operations.
Norfolk Ridge seamounts, southwest Pacific	Highly endemic deep seamount fauna; many relict species; vulnerable to deepwater trawling.
Equatorial western central Pacific convergence zone between 10^{o} north and south of equator 3 nominations	Convergence zone between northern and southern equatorial currents; high plankton productivity attracts large concentrations of migratory megafauna.
South China Sea/Spratly Islands 6 nominations	Large area of shallow water coral reefs rich in species; probably acts as a regional source of replenishment for depleted populations; disputed between several countries; proposed as international marine protected area.
Lord Howe Rise, between Australia and New Zealand - 2 nominations	Highly endemic deep seamount fauna; vulnerable to deepwater trawling.
Eastern Pacific - box 10^{o}N-25^{o}N and 170^{o}W-150^{o}W	This large sub-equatorial area lies to the south west of the Hawaii EEZ and has high predator diversities and abundance.
Clarion-Clipperton Fracture Zone, Eastern central Pacific 2 nominations	Area with high concentrations of manganese nodules; nodules support hard substrate fauna on sediment covered abyssal plain; likely to be impacted by future mining operations.
Eastern Pacific off Mexico 2 nominations	Two migration corridors for Leatherback turtles between nesting beaches and feeding areas in the south eastern Pacific.
Eastern Tropical Pacific (Panama Bight) bight region – enclosed by Costa Rica, Panama, Colombia, and Ecuador to the east and to the west by Galapagos and Cocos Islands. 2 nominations	Under cold and warm current influences; includes highly productive waters where the Humboldt Current flows east from South American coast; highly productive waters support extraordinary concentrations of marine life, including endangered aquatic megafauna such as Leatherback Turtles. Intensively fished using longlines and purse-seines.
Eastern Pacific - Explorer seamount region to the west of British Columbia	Includes several seamounts and ridges straddling Canada's Pacific EEZ and international waters; supports high diversity of deep sea fish and invertebrates; threatened by bottom trawling.
Eastern Pacific - box within 5^{o}S-33^{o}S and 145^{o}W-90^{o}W	This large sub-equatorial area is adjacent to the EEZs of Chile and Peru and the Humboldt current system and has high predator diversities and abundance.
South Pacific from 0^{o} to 40^{o} South, between 120^{o} East and 130^{o}W.	Critical habitat for a wide variety of whale species; proposed as the South Pacific Whale Sanctuary: http://www.doc.govt.nz/Whats-New/Issues/Archive/A-South-Pacific-Whale-Sanctuary-(Agenda-Paper).pdf
Southern Ocean Polar Front in South Atlantic and Indian Oceans	Transition zone between warm and cold water masses. Critical feeding and migration routes for albatrosses and other aquatic megafauna.

Balleny Islands, Southern Ocean; zone of approximately 150 nautical miles around the islands.	Nesting area for Adelie, Chinstrap and Macaroni penguins; important for marine megafauna including whales and seals.
New Zealand Sub-Antarctic Islands: Campbell and Bounty Plateaus combined; the Auckland Islands/Motu Maha, Campbell Island/Motu Ihupuku, the Antipodes and the Bounty Islands	Collectively the islands, the 800 seamounts and the comparatively shallow surrounding seas represent a strong physical barrier in oceanographic terms. The marine environment is thus one of a slow-moving water mass rich in nutrients. Important for New Zealand Sea Lions, several species of endemic seabird. The area has a rich but poorly described underwater biota, including fragile seamount communities.
Southern Ocean to the south of Tasmania encompassing the Tasman Basin and South Tasman Rise	The northern border of the protected area should meet the Australian EEZ (South of Tasmania), the eastern border should meet the New Zealand EEZ, to the West of the Auckland Islands and Macquarie Ridge. The area is rich in seamounts with a high diversity of the deep sea fauna is well documented. The area is fished by bottom trawlers from several countries including Australia and New Zealand.
Antarctic and Polar Seas 7nominations	Highly productive; habitat for many threatened birds, mammals and deep-sea fish. Require large scale protection.
Antarctica - Ross Sea continental shelf ecosystem; south of the Antarctic Divergence or East Wind Drift. It lies west of 155^{o}W in waters shallower than 3000 m	Distinct from the wider Antarctic marine ecosystem; highly productive and healthy food web includes such charismatic megafauna as whales, seals and penguins; imminent threat to this last remaining sanctuary in the rapid growth of the extraction of toothfish and minke whales; potential threats may arise from bioprospecting, tourism and the introduction of invasive marine species from ship hulls.

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