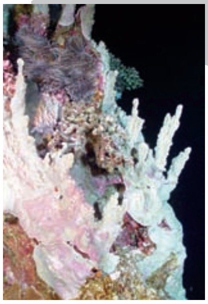
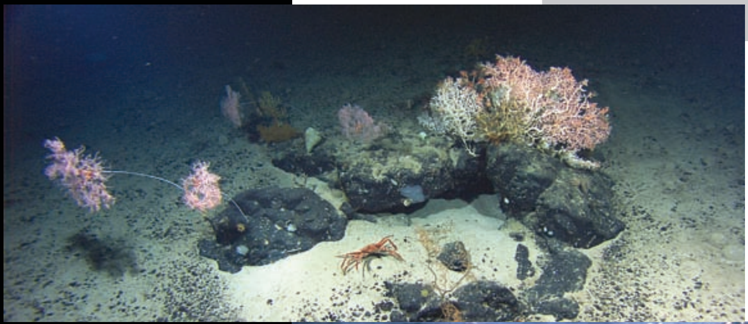
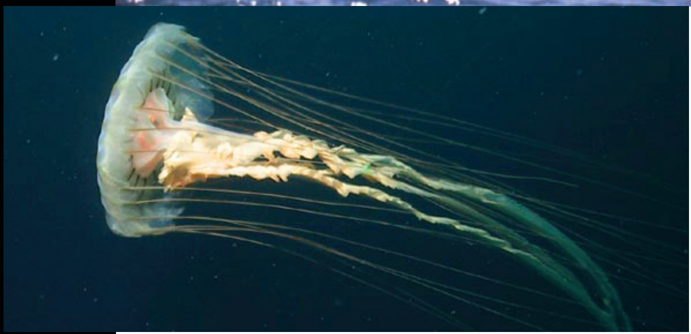
Secretariat
of the Convention on
Biological Diversity

CBD Technical Series No. 20



# PATTERNS OF SPECIES RICHNESS IN THE HIGH SEAS





UNEP

CBD

## CBD Technical Series No. 20

# Patterns of Species Richness in the High Seas[1]

*William Cheung[2], Jackie Alder, Vasiliki Karpouzi, Reg Watson, Vicky Lam, Catriona Day, Kristin Kaschner[3], and Daniel Pauly*

1 Submitted to the Secretariat of the Convention on Biological Diversity, Montreal, Canada.

2 Address for the senior author and others: Fisheries Centre, Aquatic Ecosystems Research Laboratory University of British Columbia, 2202 Main Mall Road, Vancouver, British Columbia, Canada V6T 1Z4

3 Present address: Institut für Seefischerei, Bundesforschungsanstalt für Fischerei, Palmaille 9, 22767 Hamburg, Germany

Published by the Secretariat of the Convention on Biological Diversity. ISBN: 92-9225-034-5


Citation
William Cheung, Jackie Alder, Vasiliki Karpouzi, Reg Watson, Vicky Lam, Catriona Day, Kristin Kaschner, and Daniel Pauly (2005). Patterns of species richness in the high seas. Secretariat of the Convention on Biological Diversity, Montreal, Technical Series no. 20, 31 pages.

For further information, please contact
Secretariat of the Convention on Biological Diversity
World Trade Centre
413 St. Jacques Street, Suite 800
Montreal, Quebec, Canada H2Y 1N9
Phone: 1(514) 288 2220
Fax: 1 (514) 288 6588
E-mail: secretariat@biodiv.org
Website: http://www.biodiv.org

Typesetting: Blackeye Design

cover photos: Courtesy of NOAA at oceanexplorer.noaa.gov
*The top of one of the central domes in Maug caldera; a crab strikes an aggressive pose; A whale's tail shows distinctive fluke patterns used in identification; The scyphomedusae Chrysaroa melanaster.* (Photo: Robert Steelquist)

# CONTENTS

## FOREWORD

The seventh meeting of the CBD Conference of the Parties expressed its concern over the current low level of development of marine and coastal protected areas (MCPAs). Because oceans and seas cover 71% of the earth, the under-representation of marine and coastal ecosystems in the current global protected areas system is particularly alarming. All of us were sobered by the recent statistics indicating that only less than 0.5% of the world's marine environment is protected. At the same time, global and regional assessments tell us that marine biodiversity globally continues to decline rapidly. For example, coral reefs are highly degraded worldwide, approximately 35% of mangroves have been lost in the last two decades, and there are increasing and urgent concerns about the effects of overfishing and destructive fishing practices on biodiversity.

Halting, and perhaps ultimately reversing, this declining trend presents the global community with a formidable challenge. The seventh meeting of the Conference of the Parties agreed that marine and coastal protected areas are one of the essential tools and approaches in the conservation and sustainable use of marine and coastal biodiversity. It also adopted a programme of work on protected areas (decision VII/28), while at the same time updating the programme of work on marine and coastal biological diversity (decision VII/5). Both of these programmes of work support the establishment and maintenance of MCPAs that are effectively managed, ecologically based and contribute to a global network[1] of MCPAs, building on national and regional systems, and including a range of levels of protection. The COP, in both decision VII/5 on marine and coastal biological diversity and decision VII/28 on protected areas, adopted the target of developing such MCPA systems by the year 2012, echoing the commitment made in the Plan of Implementation of the World Summit on Sustainable Development.

If we are to halt the loss of marine and coastal biodiversity globally, we need to rise to the challenge of affording appropriate protection to the 64% of the oceans that are located in areas beyond the limits of national jurisdiction. This area, the global ocean commons, covers 50% of the earth's surface, and is under increasing and acute human threat. Many ecosystems beyond national jurisdiction, such as those associated with cold water coral reefs and seamounts, have extremely high and unique biodiversity. However, these ecosystems are also vulnerable and fragile, and because of this, they are threatened by destructive activities such as deep sea bottom trawling. The protection of ecosystems in marine areas beyond the limits of national jurisdiction can only be achieved through international and regional cooperation. It can be achieved through the use of tools, such as marine protected areas, and through prohibition of destructive practices, such as bottom trawling, in areas with vulnerable ecosystems.

As part of their commitment to the issue of conservation and sustainable use of biodiversity in marine areas beyond the limits of national jurisdiction, the Parties to the CBD have agreed to address options for cooperation for the establishment of marine protected areas. This topic was on the agenda of the first meeting of the Convention's Ad Hoc Open-Ended Working Group on Protected Areas in July 2005, and will also be discussed at the second meeting of this Working Group. The present study, undertaken by the *Sea Around Us* Project of the Fisheries Centre, University of British Columbia, Canada, provided background material for the Ad Hoc Open-Ended Working Group. In particular, it has created the basis for a comprehensive global georeferenced database of biodiversity in marine areas beyond the limits of national jurisdiction. It has also, for the first time, given us a solid understanding of patterns of species richness beyond the limits of national jurisdiction. It is hoped that by publishing this study in

1. A global network provides for the connections between Parties, with the collaboration of others, for the exchange of ideas and experiences, scientific and technical cooperation, capacity building and cooperative action that mutually support national and regional systems of protected areas which collectively contribute to the achievement of the programme of work. This network has no authority or mandate over national or regional systems.

the CBD Technical Series, it will benefit all those countries, organizations and individuals who are working on protecting the fragile and valuable biodiversity of the global commons.

***Hamdallah Zedan***
**Executive Secretary**
**Convention on Biological Diversity**

## ABSTRACT

Maps of the species richness in the high seas are presented, which are based on the distribution of individual species of marine invertebrate and vertebrate groups, complemented with maps of genera and families of invertebrates and fishes. High seas refers to marine areas outside the 200-mile exclusive economic zones (EEZs) and continental shelf areas, or other described national jurisdictions. We considered known latitudinal and longitudinal gradients of the distribution of species richness (declining from the equator, and from a global center of species richness about Indonesia) where appropriate. Maps of the known locations of cold-water corals and seamounts are also presented. There is suggestive evidence that cold-water coral are associated with seamounts. If validated, this would allow predicting the existence of far more cold-water corals sites than so far documented. Both habitat types are threatened by trawling. Lastly, a map of the distribution of threatened non-fish vertebrates is provided. Together, these maps indicate marine biodiversity in the high seas to be richly patterned, with some of these patterns helping to identify areas in need of protection such as seamounts, and the high seas of the Southwest Pacific.

## INTRODUCTION

Biodiversity — the variability among living organisms from all sources, including diversity within species, between species and of ecosystems (Convention on Biological Diversity 1992) — renders humans a multitude of services. In the oceanic spheres, these include providing the basis for fisheries (for food or recreation), drug development or non-extractive use, such as providing scenery for scuba divers (Pauly *et al.* 2005).

Yet, this same biodiversity is coming under threat in the open ocean (Dulvy *et al.* 2003). This is mainly caused by fisheries (Pauly *et al.* 2005), and the task is to design management regimes that minimize diversity loss (Alder and Wood 2004). To this end, detailed knowledge must be available for the ecosystems and individual species occurrences at various places (e.g. for the creation of MCPA), along with broad-based knowledge about global patterns of diversity. It is the latter that we offer here, based on the analysis of the distribution ranges of many marine species of animals, particularly marine vertebrates.

# METHODOLOGY

## GENERAL APPROACH

### 1) Distribution of ecosystems

In this report, the term high seas refers to marine areas outside of the 200-mile exclusive economic zones (EEZs) or similar declared national boundaries and any national jurisdictions (Figure 1). In the high seas, there are a number of defined ecosystems (e.g. pelagial, seamounts, thermal vents) that are used in the description of the richness of habitats and species in marine environments. However, our knowledge of most of these ecosystems is limited, particularly for seamounts (Figure 2) and cold-water corals (Figure 3) although recent research has increased our understanding of these ecosystems. A global dataset of large seamounts (Figure 2), based on bathymetric data (Kitchingman and Lai 2004), was used in this analysis. The map of the approximate location of known cold-water corals used data obtained from the UNEP-WCMP cold-water coral database (Freiwald *et al.* 2004). A dataset of the locations of known cold-water coral (N≈1300) was available (Figure 3). We then investigated the association of cold-water coral areas outside of EEZs with large seamounts by computing the closest direct distance between known cold-water coral areas and large seamounts (with a buffer of 250 km, Anon. 2005).

### 2) Species Distribution

Distributions of individual species were obtained from published maps, notably in FAO catalogues (e.g. Márquez 1990; Roper *et al.* 1984) or from depth and latitudinal range data and other information, and integrated into a GIS system to obtain a range polygon. These polygons were subsequently used in the analysis assuming uniform distributions (i.e., equal probability of occurrence throughout the range). Species that occurred only in EEZ areas (i.e., coastal species) were deleted from the mapping analysis.

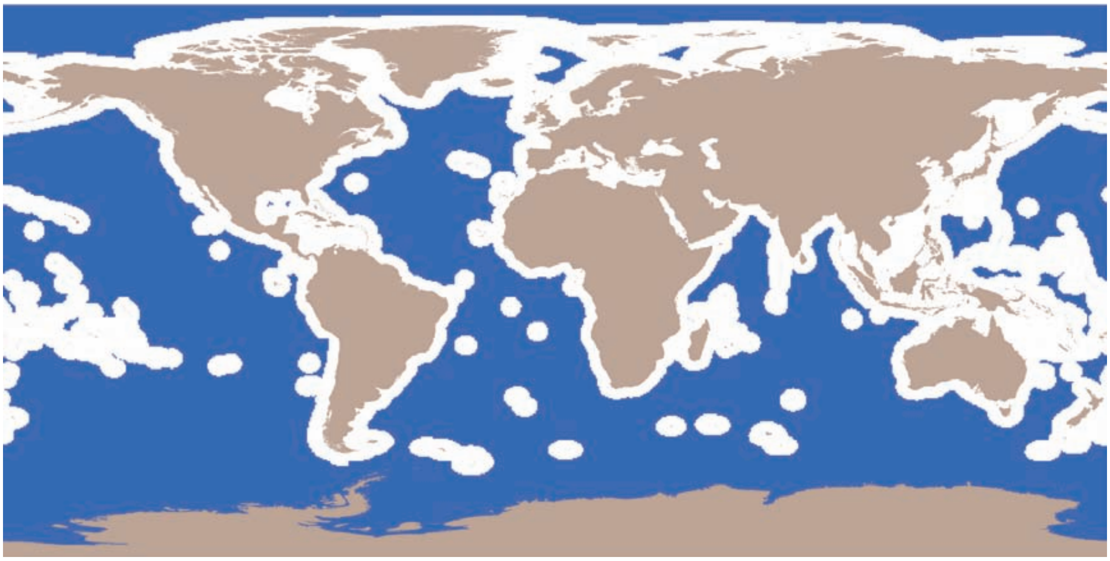


**FIGURE 1:** The high seas as defined in this analysis (i.e., dark blue marine areas outside of national EEZs). This covers approximately 202 million km$^2$, as opposed to 363 million km$^2$ for the World Ocean.

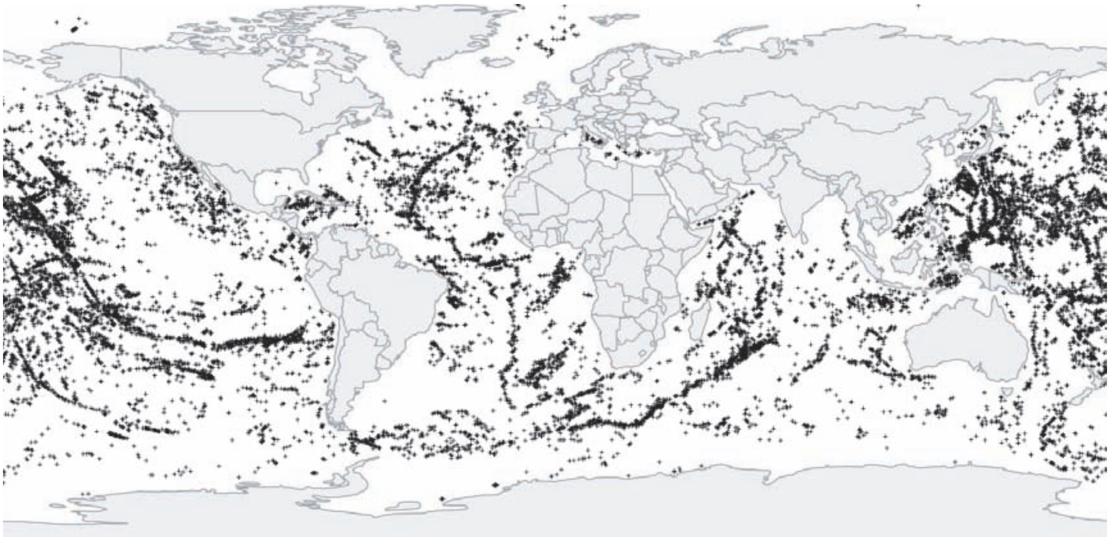


**FIGURE 2:** Distribution of large seamounts estimated by Kitchingman and Lai (2004). This map displays approximately 14,000, particularly well-defined (conical), seamounts. Including a wider range of seamount shapes and sizes could increase their number to 100,000.

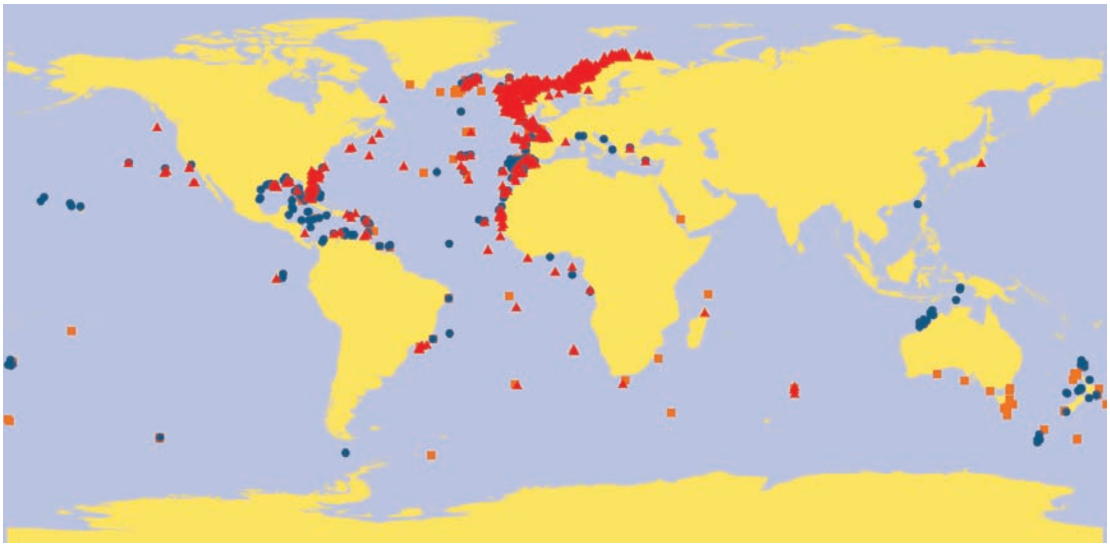


**FIGURE 3:** Distribution of known cold-water coral areas base on species distributions, *Lophelia pertusa* (red triangles), *Madrepora oculata* (blue circles) and *Solenosmilia varialilis* (orange squares) (Freiwald *et al.* 2004)

### 3) General and Families Distribution.

The distribution was obtained as described in (2), by combining the attributes of fish species in a group, as evaluated using FishBase (Froese and Pauly 2000) for fishes and using a variety of sources for invertebrates. Once a polygon was obtained (for a genus or family of fish or invertebrates), it was:

a) made to represent all the species in that group minus the species that were already represented as such; and

b) modified by applying two gradients representing an increase in the number of species in the tropics relative to the higher latitudes (i.e., triangular distributions centered on the equator), and another representing highest abundance in the longitude range centered on Indonesia (95$^{o}$ to 141$^{o}$ E), which declines east and west. This rate of decline was adjusted such that the species richness in the extreme eastern and western Indo-Pacific was equal to the species richness in the Atlantic Ocean (Figure 4). For groups that occur in both the Atlantic and the Indo-Pacific Oceans, the species richness of the Atlantic was adjusted to be 2.5 times lower than the peak of the species richness in the Indo-Pacific (Figure 4), this factor being estimated from the number in the Atlantic versus Indo-Pacific in several groups of fish in FishBase (Froese and Pauly 2000), and found compatible with observations for invertebrates in Ekman (1967). As in (2), groups that were found only in EEZ areas were deleted.

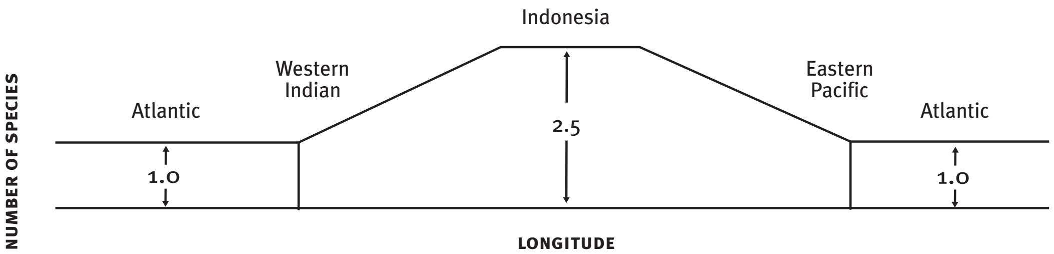



**FIGURE 4:** Longitudinal species richness gradient assumed for higher taxa lacking specific distributions. Adapted from species distributions in FishBase (Froese and Pauly 2000) and Ekman (1967). The ratio 1:2.5 was used for adjusting species numbers in invertebrate and fish genera and families occurring in both the Indo-Pacific and the Atlantic

## GROUP SPECIFIC DISTRIBUTION

### Marine Invertebrates

Out of all groups, marine invertebrates contained the least species-specific information (Table 1). Also, compared with others, the above procedure for generating latitudinal and longitudinal gradients (Figure 4) had the most influence on this group. Invertebrate distributions that were used included 305 species of crustacean, 115 species of mollusks (excluding cephalopods) and 438 species of other invertebrates (e.g., echinoderms). Cephalopods constituted an exception: we had distributional ranges for 169 species (from Roper *et al.* 1984) out of a total of 786 known species (<www.cephbase.org>), among which 119 species occur in the high sea. The distributions of invertebrates were further constrained to species and groups that are found in the high seas (i.e., outside of national EEZ areas or similar declared national boundaries) resulting in crustaceans having the highest species counts among the invertebrates in the high seas (Table 2).

Worldwide distribution data of cold-water corals, with occurrences in the high seas, are not available. Therefore, we superimposed point data which reflects the active sampling conducted in North America and Europe (Figure 3).

**TABLE 1:** Number of species, genera or family of marine animal groups occurring in the high sea explicitly represented and for which distribution maps (polygons) were available. Residual species is species in the group minus the species that were already represented in lower level taxonomic groups.

| | INVERTEBRATES | FISH | REPTILES | SEABIRDS | MAMMALS |
|---|---|---|---|---|---|
| **Representation** | **Polygons/Spp.** | **Polygons/Spp.** | **Polygons/Spp.** | **Polygons/Spp.** | **Polygons/Spp.** |
| Species-specific distribution | 276 / 276 | 463 / 463 | 8 / 8 | 115 / 115 | 100 / 100 |
| Residual spp. at genus level | 34 / 41 | 104 / 631 | – | – | – |
| Total number of spp. represented | 557[a] | 1,942 | 8 | 115 | 100 |
| Extant number in the sea | Approx. 200,000[b] | Approx. 15,000[c] | 88 | 351 | 115 |

[a] Breakdown by group in Table 2.
[b] Metazoans only, both coastal and high seas;
[c] Marine fish only, both coastal and high seas;

**TABLE 2:** Number of commercial invertebrate species in different taxonomic groups represented in the distribution maps (high seas only).

| INVERTEBRATE GROUPS | NUMBER OF COMMERCIAL SPECIES REPRESENTED |
|---|---|
| Crustaceans | 305 |
| Molluscs (excluding cephalopods) | 115 |
| Cephalopods | 119 |
| Others | 18 |

## Fish

Distribution ranges were available for 463 high seas species (Table 1), all commercially important and jointly contributing 9.4% of the marine fish catch in 2000. This included, notably, all large pelagic fish (tuna, billfish, etc.). Also, we had 104 polygons representing genera, with 631 species, and 75 polygons representing families, with 848 species (Table 1).

Ranking on the degree of association with seamounts was performed for each fish taxon with results ranging from 0 (no association) to 1 (obligatory association), based mainly on information in FishBase (Froese and Pauly 2000; <www.fishbase.org>), which incorporated the data in Froese and Sampang (2004). Taxa with ranking of 0.3 or higher are assumed here to be associated with seamounts, and were used to map the distribution of species richness on seamounts (see also Table 3).

**TABLE 3:** Status and Trends: High Sea and Deep-Sea Habitats (modified from Baker et al. 2001)

| DEEP-SEA HABITAT | STATUS | TREND | POTENTIAL THREATS |
|---|---|---|---|
| **SEAMOUNTS** *(Figures 2 and 8a)* | Less than 200 seamounts have been studied; high endemism on studied seamounts; some seamounts are heavily exploited for fisheries resources (Watson and Morata 2004), trawling damages benthic habitats. Few seamounts protected by MPAs (Alder and Wood 2004). | High seas fishing on seamounts continues especially in the Southern Ocean; impacts are not monitored; it is anticipated that heavily exploited stocks will be threatened with over exploitation - therefore fish biodiversity threatened; attention to managing and protecting seamounts is increasing (e.g. Bowie Seamount (Canada), and fishing restrictions on EU vessels in the Azores) | Mining of ferromanganese oxide and polymetallic sulphides, climate change. |
| **COLD-WATER CORALS** *(Figures 3 and 8b)* | Limited knowledge; they may be more widespread than currently known (Figure 8b); high diversity, except for fish and mollusks compared to tropical reefs; easily damaged by trawling, but spatial extent unknown. | Fishing on coral or adjacent to coral reefs with consequential damage still occurs, especially in areas outside of EEZs. As fisheries continue to move further offshore and into deeper waters, the threat to these habitats will continue since these areas are often in the high seas and outside of national jurisdictions. Many countries are identifying coral areas and initiating action to protect them from fishing. | Biotechnology, bioprospecting and climate change; gas and oil platforms can damage corals. |
| **HYDROTHERMAL VENTS** *(see Cone 1997 for review of earlier literature)* | Limited disturbances — currently due to limited research on vents, low number of species, but high endemism and high abundance. Two vent areas (Canada and Azores) are declared MPAs. | Research community is initiating self-policing activities regarding impact of research activities, so it is anticipated in the short-term that impacts from research will decline; in the long-term commercial exploitation is a concern. | High potential for biotechnology, mining, energy and high-end tourism. |
| **OPEN PELAGIAL** *(Figures 5, 6, 10, 13)* | Highly dynamic and diverse ecosystem is heavily exploited globally (Pauly *et al.* 2005) Also increasing levels of pollution and eutrophication impacting on biodiversity (Verity *et al.* 2002). | Overall continuing decline in biodiversity as fishing further offshore and deeper continues; the impact of climate change may exacerbate decline. | Climate change, expansion of aquaculture into the open ocean/ high seas. |
| **DEEP-SEA TRENCHES** | Unique 'hadal' fauna, much of it associated with soft sediments and holothurians; high endemism; diverse and abundant bacterial community; no known disturbances. | Research is increasing in these areas, but, it is anticipated that based on experience of hydrothermal vents, appropriate guidelines will be developed to minimize the impacts of research on these ecosystems. | Research, biotechnology and waste disposal. |
| **COLD SEEP AND POCKMARKS** | Limited knowledge; high endemism; limited disturbances except for Gulf of Mexico (trawling and oil exploitation) or research sites. | As fishing and gas and oil operations continue to go further offshore and deeper, it is anticipated that disturbance may increase. | Biotechnology and mineral exploitation. |
| **SUBMARINE CANYONS** | High diverse flora and fauna with commercial important species such as lobsters; important nursery areas; areas impacted by fishing and oil exploitation. | As fishing and gas and oil operations continue to go further offshore and deeper, it is anticipated that disturbance may increase. | Gas and oil developments. |

### Marine reptiles

All marine reptiles were mapped to species level. Globally they include 7 species of sea turtle, 79 species of sea snakes, 1 saltwater crocodile and 1 marine iguana from Galápagos (Darwin 1841). The distributions of sea turtles are based on published maps from Márquez (1990) and on range information from Heatwole (1987) and Greer (2004) for the sea snakes. However, only the seven species of turtles and one species of sea snake occur outside of EEZs, and are used in this analysis (Table 1).

### Seabirds

All 351 species of seabirds were assigned an area of distribution, defined by a northernmost and southernmost latitude within which each species occurs, and were then divided into four groups according to information about the distance they fly away from their breeding colony to feed. The following groups were created: (a) near shore seabirds — species that forage within 1 km from shore; (b) coastal seabirds — species that fly up to 10 km from shore to find food; and (c) seabirds of the continental shelf — species that forage within 200 km from land.

Group (d) comprised of pelagic seabirds, found primarily on the high seas, and included species that forage in deeper, offshore waters at distances >200 km; this group includes the pelagic, deep-diving penguins, as well as the Procellariiforms (i.e., albatrosses, prions, petrels, and shearwaters). For 12 species of shearwaters, the distributions of three species of tuna (i.e., Yellowfin, *Thunnus albacares*; Southern bluefin, *Thunnus maccoyii*; and Northern bluefin, *Thunnus thynnus*; at <www.seaaroundus.org>) were used to predict and further refine their foraging distribution. This was based on shearwaters' foraging tactics on forming flocks and accompanying surface-schooling tunas to feed in association with them (Au and Pitman; 1988). Only 115 species of birds (from group d) occur on the high seas.

### Marine Mammals

The geographic ranges of 100 marine mammal species were mapped based on the predicted relative suitability of the environment (RES) for each species throughout its range (Kaschner *et al.* in press). The environmental suitability predictions were based on qualitative and, where possible, quantitative observation of the relationship between a species' presence and environmental conditions such as depth and annual sea surface temperature (Kaschner *et al.* in press). Species were assigned to broad habitat preferences categories, and a probability of occurrence was then generated based on the relative suitability of environmental attributes of each cell in a global grid system of 0.5-degree latitude and longitude cells. The geographic range of the species were defined by the known outer-most limits of the occurrence of the species including areas used in annual migrations and dispersal of juveniles but not the extralimital sightings. The RES method predicted relative probabilities of occurrence (see <www.seaaroundus.org>); but these were converted to flat distributions, i.e., we assume here that the species have equal probability of occurrence throughout their range. Of the 115 species, 100 occur on the high seas and were used in the mapping analysis (Table 1).

## ECOSYSTEMS: STATUS, TRENDS AND THREATS

The detailed status of ecosystems of the high seas is poorly understood because there is limited global monitoring of ecosystem-specific features at that scale. While there is an extensive global monitoring system of high seas parameters such as sea temperatures, currents and other physical conditions, monitoring of ecosystem aspects such as quality of benthic habitat, pollution from ships and other anthropogenic changes are limited to primarily fish stocks, marine mammals and some seabird species. The current state of information on high seas habitats is summarized in Table 3.

## SPECIES: STATUS, TRENDS AND THREATS

### Invertebrates

The distribution of exploited marine invertebrates on the high seas is shown in Figure 5. The number of invertebrate species that were distinguished in FAO fisheries statistics was 56 in 1950, 81 in 1970 and 141 in 2000, with the increase primarily due to increasingly detailed catch statistics and new species coming under exploitation. While the number of exploited marine invertebrates globally is high, the number of species caught in the high seas is much lower. High seas catches of marine invertebrates (Table 4) are primarily composed of cephalopods (80%), crustacean (14%) and non-cephalopod molluscs (4%). Other invertebrates contribute only 2% to the total high sea catch of invertebrates. The invertebrates associated with seamounts have been documented by Stocks (2004a). Although her database (Stocks 2004b; http://seamounts.sdsc.edu) is incomplete, this shows that seamounts are characterized by strong endemism. Also, many of the species are sessile, and easily damaged by trawling.

Threats to invertebrate species in shallow waters, due mainly to overexploitation, are high for a number of commercial species, e.g. sea cucumbers (Conand 1998; Uthicke *et al.* 2004), but even deep-sea forms are threatened, again as illustrated by sea cucumbers. Invertebrate species richness on seamounts is highly threatened by fishing, especially trawling (Stocks 2004a). A study of fished and unfished seamounts found that species richness on unfished seamounts was 106 % higher than on fished seamounts, and biomass was more than 7 times higher (Koslow *et al.* 2001). Similarly, cold-water coral species such as *Oculina* and associated rich invertebrate diversity are threatened by fishing especially trawling (Freiwald *et al.* 2004). For example, monitoring of *Oculina* reefs off eastern Florida has recorded extensive damage to the benthic fauna caused by fishing activities (Reed *et al.* in press). What little is known about the distribution of cold-water corals is summarized in Figures 3 and 8b.

Detailed analysis of known cold-water corals (Figure 8b) showed fields of cold-water corals occurring usually at the foothill of seamounts (modal distance of 50–100 km; the diameter of large seamount can reach up to 200 km (Anon. 2005)). This was particularly true for *Madrepora oculata* and *Solenosmilia variablilis*, which had very pronounced modes. In all three species (i.e., *M. oculata*, *S. varialilis,* and *Lophelia pertusa*), two other modes occurred, at 400–450 km and 650–700 km. We attribute this to association with smaller seamounts (not detected by the procedure of Kitchingman and Lai 2004), which are themselves associated with large seamounts they detected (with one large seamount generally associated with several smaller ones). Thus in summary, there is suggestive evidence of an association of high sea cold-water corals with seamounts. This will need to be investigated in future studies.

**TABLE 4:** Total catch and number of species of commercial fishes and invertebrates from the high seas (i.e., excluding EEZ) in each FAO statistical area. The estimated species numbers rely on the assumed latitudinal and longitudinal gradients (see text).

| FAO AREA | AREA (KM²) | HIGH SEA CATCH (THOUSAND T) | NO. OF COMMERCIAL SPP.[a] Inverts | Fish |
|---|---|---|---|---|
| Arctic (18) | 2,042,936 | low, but unknown | 79 | 47 |
| NW Atlantic (21) | 2,630,798 | 155.0 | 134 | 562 |
| NE Pacific (67) | 4,575,286 | 31.5 | 61 | 296 |
| NE Atlantic (27) | 5,247,538 | 413.4 | 97 | 416 |
| W Central Pacific (71) | 6,388,360 | 3,614.6 | 125 | 1010 |
| W Central Atlantic (31) | 7,323,797 | 129.4 | 17 | 236 |
| E Central Atlantic (34) | 9,068,842 | 326.1 | 61 | 507 |
| NW Pacific (61) | 10,252,192 | 3,280.4 | 206 | 998 |
| SW Atlantic (41) | 12,314,766 | 1,226.0 | 124 | 579 |
| SE Atlantic (47) | 14,922,223 | 63.7 | 61 | 508 |
| W Indian (51) | 17,179,872 | 1,361.2 | 216 | 1283 |
| SW Pacific (81) | 20,095,165 | 207.5 | 114 | 841 |
| E Indian (57) | 21,941,343 | 1,772.7 | 62 | 560 |
| SE Pacific (87) | 24,713,142 | 1,140.4 | 125 | 582 |
| E Central Pacific (77) | 30,545,824 | 556.8 | 96 | 497 |
| Antarctic (48, 58, 88) | 34,293,306 | 118.2 | 193 | 188 |
| **TOTAL IN HIGH SEA** | 201,594,047 | 14,396.9 | 557 | 1,942 |
| **TOTAL MARINE** (incl. EEZs) | 362,875,923 | 82,281.6 | 1,166 | 3,584 |

[a] estimated from the number of species identified as such, plus the number of residual species in identified genera and families.

Overall, limited information is available on the distribution of invertebrates, (Figure 5), but the cephalopods are an exception (Figure 6). In this analysis, many distributions are based on the two gradients discussed in earlier section. Various initiatives are underway to remedy this situation (e.g. OBIS, see <www.iobis.org>).

The cephalopods that occur in the high seas are largely squids and cuttlefishes. Four species *Illex argentinus* (31%), *Todarodes pacificus* (12%), *Dosidicus gigas* (8%) and *Ommastrephes bartramii* (1.4%), one genus, *Loligo* (15.5%), and one family, the Sepiidae or cuttlefish (27%), jointly make up 98% of the cephalopod catch. The samples of 119 species, which served to generate Figure 6 indicate that maximum species richness in the high seas occurs in the Atlantic. This is the only case where the peak richness is outside of the Indo-Pacific.

## Fish

The distribution of marine fish in the high seas is illustrated in Figure 7. It should be noted, however, that this figure reflects the latitudinal and longitudinal patterns presented in the methods section. Table 4 also illustrates the species richness of commercially exploited fish in the high seas part of FAO statistical areas.

A number of fish stocks in the high seas are threatened (Worms *et al.* 2003, 2005); these include some species of tuna in the open pelagic systems, notably Atlantic bluefin tuna, as well as demersal stocks such as the Patagonian toothfish found on seamounts in the Southern Ocean (Table 5).

Froese and Sampang (2004) reviewed the biology of seamount fish species, and Morato *et al.* (2004) found that their intrinsic vulnerability is higher than non seamount associated fishes (Cheung *et al.* 2005).

**TABLE 5:** Summary of the status, trends, and threats to biodiversity of fish stocks[1]

| ECOSYSTEM[a] | STATUS | TREND | THREATS |
|---|---|---|---|
| Seamounts & Deep water coral reefs (see Figures 8a and 8b). | Many species such as Patagonian toothfish and Orange roughy are overfished, including in areas outside of EEZs. Areas that were fished more than 20 years ago are not showing signs of recovery. | Continued declines in biodiversity due to overfishing except in MPAs or areas where fishing is restricted; recovery of some stocks may take decades once fishing ceases (see also Watson and Morato 2004). | Overfishing, climate change (Glover and Smith 2003). |
| Open ocean pelagic (see Figure 7), | Concern over specific tuna (e.g. Bigeye in the Pacific, and Bluefin in the Atlantic). | Continued overfishing as aquaculture expands and the demand for fish and fish oil continues to grow. | Overfishing, aquaculture, climate change, pollution, eutrophication (Verity et al. 2002). |

[a] Information on fish stocks associated with thermal vents is not available; they are presently likely not threatened (see Cone 1991).

The distribution of fish associated with seamounts are illustrated in Figures 8a. In the high seas, most cold-water corals are closely associated with the slopes of seamounts (Figure 8b). Hence species richness and abundance of fish on cold-water corals is expected to be similar to those on seamounts, as well as being subjected to similar threats.

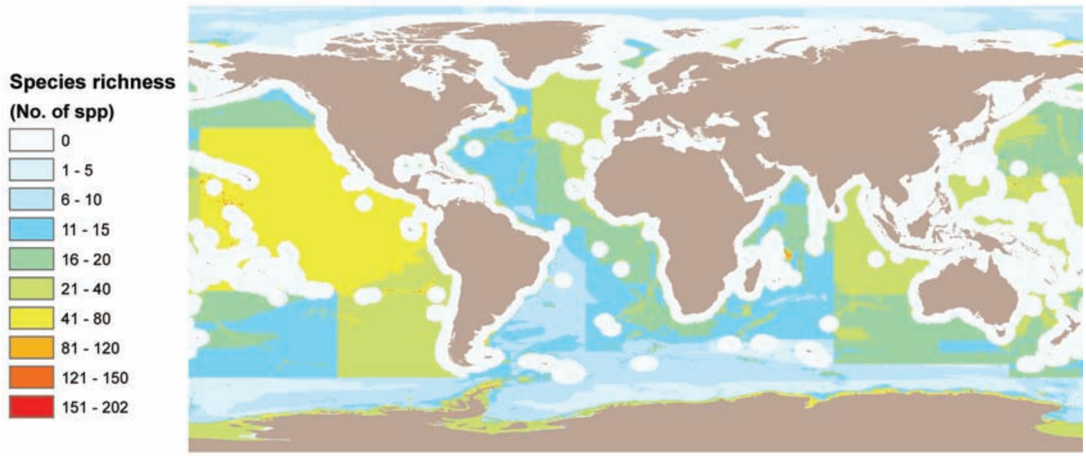



**FIGURE 5:** Map of species richness of exploited marine invertebrates in the high seas. This is based on 330 polygons representing 557 species; plus 276 pertaining to species, notably of cephalopods (119). This map thus largely reflects the assumptions about gradients of species distribution (see text). It is structured in large blocks because for many invertebrate groups, all that was known of their distribution is that they occurred in certain FAO statistical areas, whose borders define the blocks.

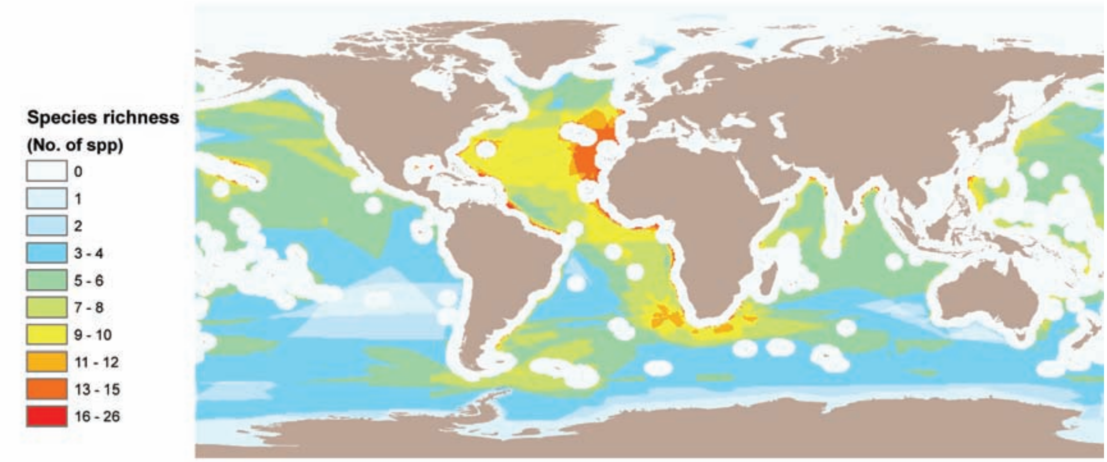



**FIGURE 6:** Map of species richness of commercial cephalopods (largely squids and cuttlefishes) in the high seas, based on 119 distribution maps in Roper *et al.* (1984). This contrasts with the total number (786) of cephalopod species (www.cephbase.org).

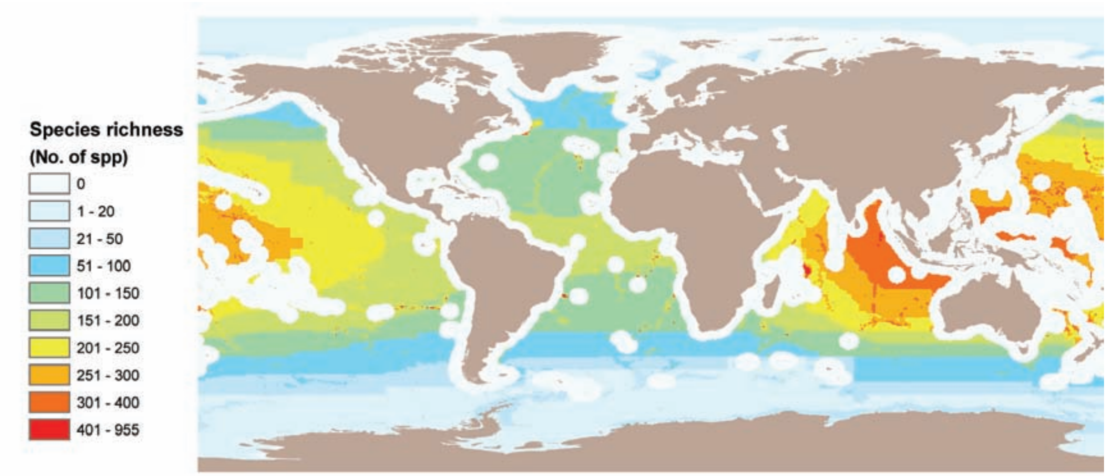



**FIGURE 7:** Map of species richness of exploited marine fishes in the high seas based on 463 species distributions and 189 additional polygons representing 1,942 species. The higher species richness observed in the tropics, and Southeast Asia in particular, is due to the assumptions on latitudinal and longitudinal gradient (Fig. 3) utilized in the analysis, and is likely to reflect patterns observed in the field (see Ekman 1967 and text).

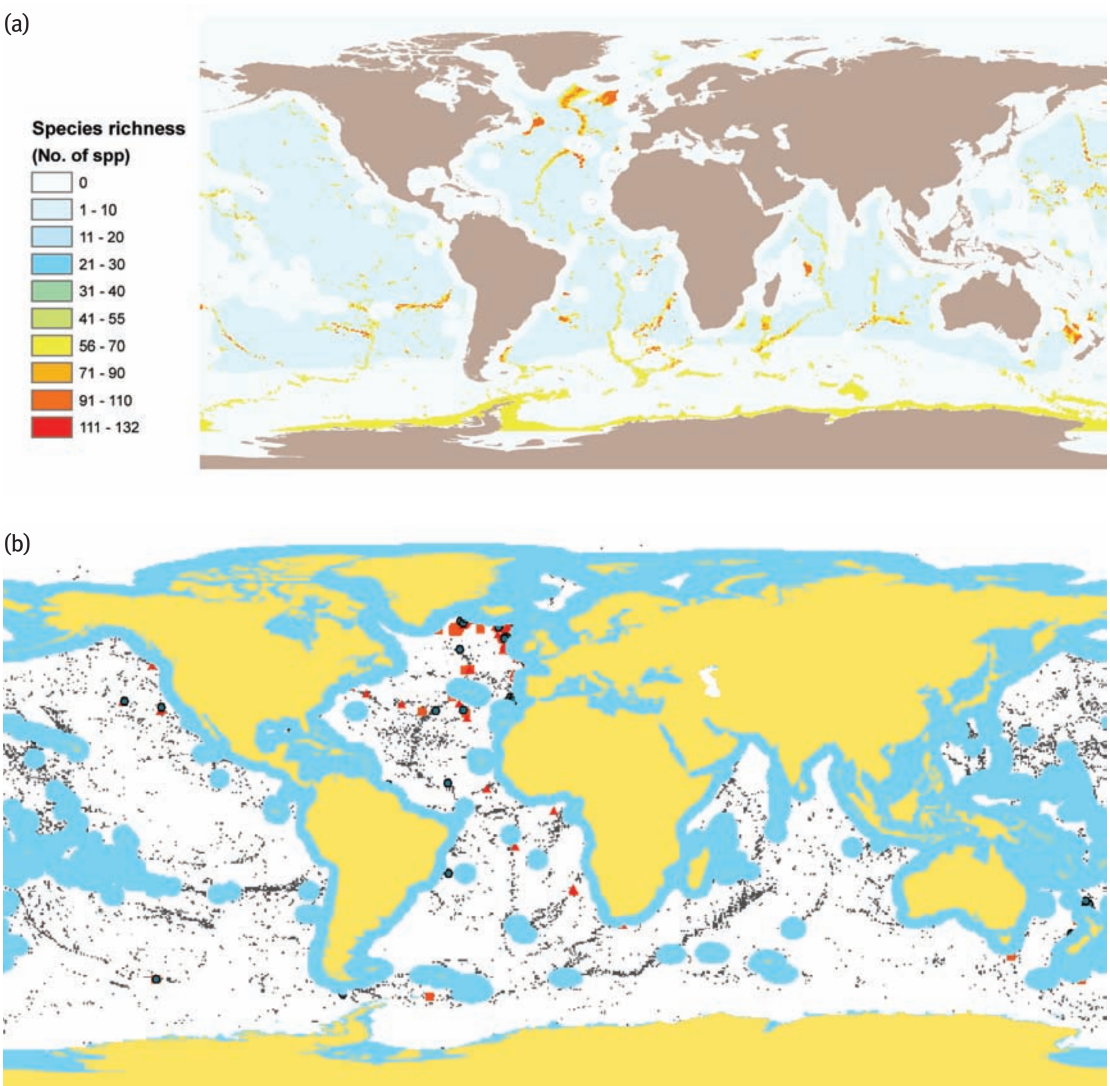



**FIGURE 8:** Seamount and their associated species in the high seas: (a) species richness of exploited fish associated with seamounts. Latitudinal and longitudinal gradients were not applied; (b) Cold-water coral (Figure 3) overlaid on the distribution of seamounts (Figure 2), both outside EEZs. The modal distance between the centroid of seamounts and cold-water coral reefs is 50 km. Modes with higher distances are likely associated with smaller seamounts (see text). This suggests that outside of EEZs, cold-water corals are exposed to the same threats as oceanic seamounts (Figure 8a)

## Marine Reptiles

The map of the species richness of reptiles is dominated by the seven species of turtles, with many species widely dispersed on the high seas (Figure 9). The resolution of the mapping method fails to identify the areas where turtle biodiversity is endangered, i.e., beaches and the pelagic (particularly driftnet and longline) fisheries that catch turtles as bycatch.

## Seabirds

Seabird species richness is also higher in the Pacific than the Atlantic (Figure 10). On the other hand, the majority of seabird species does not occur on the equator, but in the Southern Hemisphere. We also note, in the Southern Hemisphere, the important role of isolated islands that can serve as nesting grounds around which feeding occurs.

Biodiversity of seabirds is declining rapidly compared to other groups of birds when the IUCN Red List (Figure 11) is used. Albatross species are declining at an alarming rate with longline fishing as the greatest threat to these birds (Birdlife International 2004). Petrels are also declining, but not as fast as albatross species. The recent introduction and further development of longline hooks that do not entangle seabirds cautiously points to a slowing trend for many seabirds. Moreover, the food supply of many seabirds is reduced by fishing (e.g. in the case of reduction fisheries which exploit their prey (forage fish)) and by fisheries for tuna and other large pelagics, as these fish tend to drive their prey close to the surface, and thus render accessible, small pelagic fishes that are otherwise not available to bird predation (C. Walters, Fisheries Centre, UBC, pers. comm.).

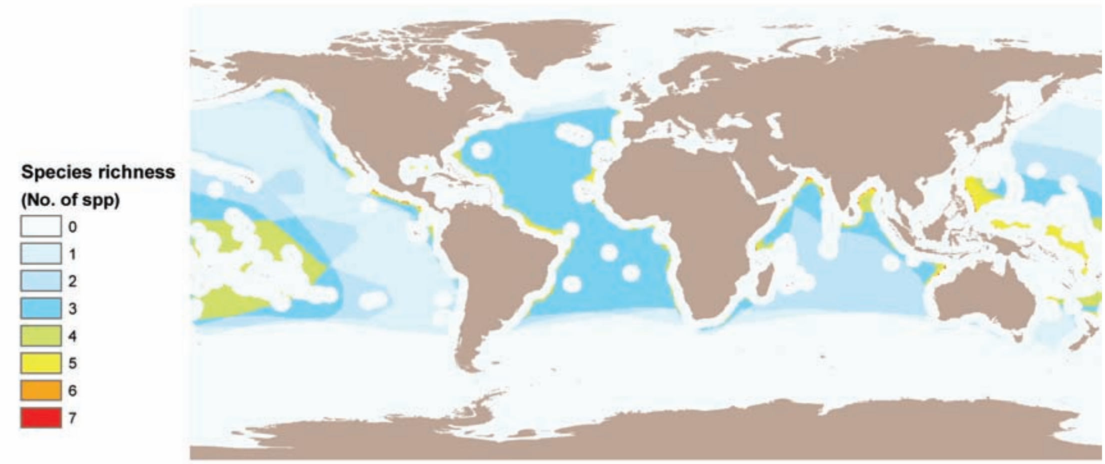



**FIGURE 9:** Map of species richness of turtles and one pelagic sea snake found in the high seas, based on distribution maps of all extant species (8).

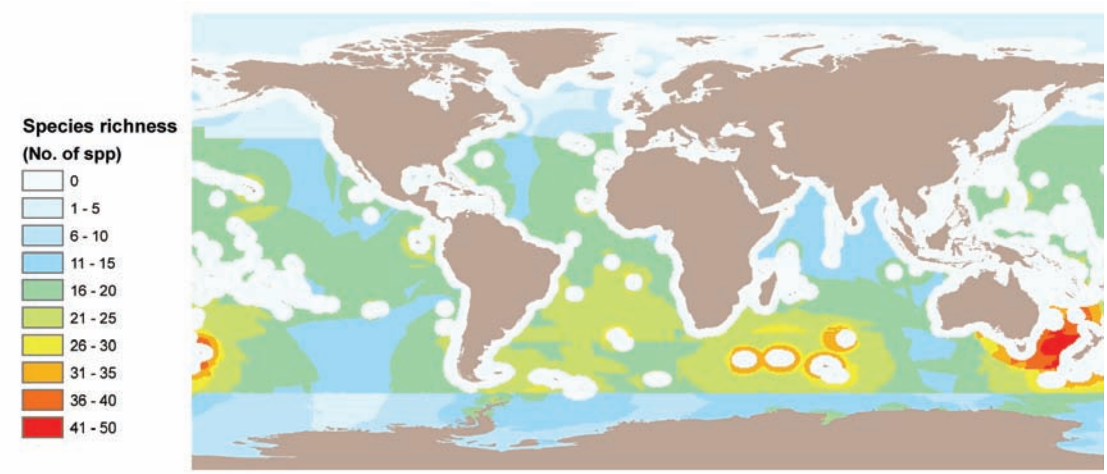



**FIGURE 10:** Map of species richness of pelagic seabirds, based on the distribution maps of the 115 species. The area of high species richness is in eastern Australia, New Zealand and on islands north of the Antarctic Convergence.

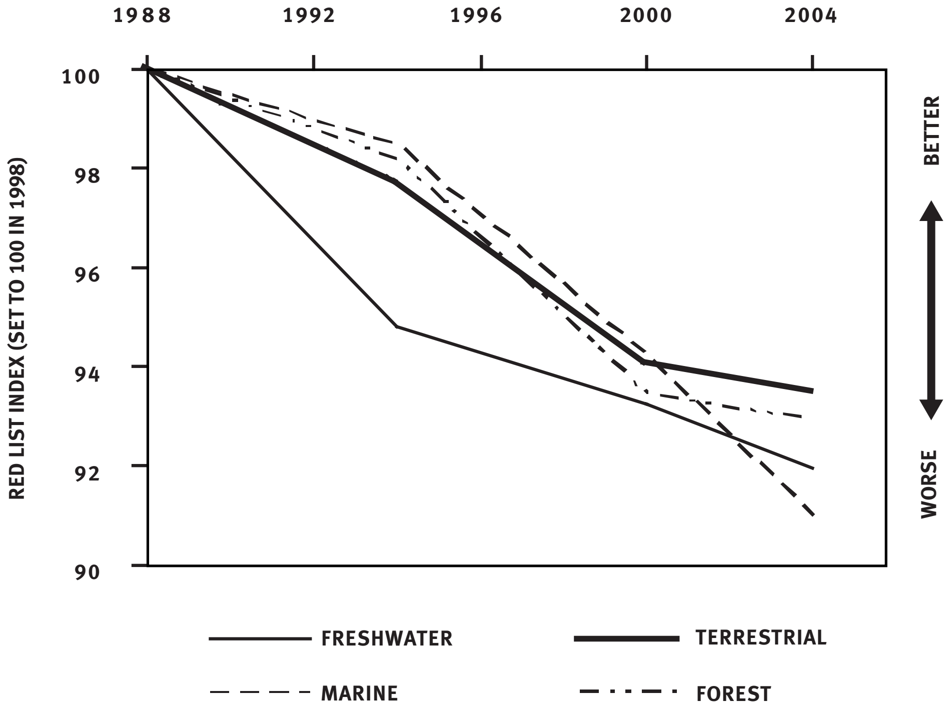



**FIGURE 11:** Relative decline in the Red List Index for birds by habitat (D'Cruz and Finlayson in press)

## Marine Mammals

Marine mammal distributions are characterized by a latitudinal gradient wherein the maximum number of species occurs in the Southeast Pacific (Figure 12). There is low diversity in the North Atlantic, where at least two coastal species, the Atlantic grey whale, and the Caribbean monk seal, are extinct.

## General Patterns

*Fish and Invertebrates*

In this analysis (Figure 13), few species of invertebrates are accounted for individually. The exception is for cephalopods, where we have maps for 119 high seas species. This applies to mainly squids and cuttlefishes (Figure 6), which are abundant in the high seas, and contributes significantly to fisheries catches.

For many of the high seas species mapped in the higher order groups, two gradients of species richness were used; one with the number of species decreasing poleward from the equator, the other with the number of species peaking in Southeast Asia and declining eastward and westward. These gradients were imposed for fish and invertebrate species, where information on species distribution was scarce, and to account for some of the patterns of species richness known to occur. This analysis reveals several 'hot spot' in the high seas areas that are associated with seamounts in the Indian and Pacific Oceans, many of which lie in the inter-tropical belt. In the Atlantic, only a few hot spots are indicated and these are also associated with seamounts.

*Non-fish Vertebrates*

We had access to a large amount of information on the distribution of non-fish vertebrates, i.e., marine reptiles, seabirds and marine mammals (223 species in total occurring in high sea; Figure 14). The species-specific information for these groups helps verify the assumptions embedded in the gradients used above, except that the seabirds pushed the overall distribution southward. In this analysis, the only potential 'hot spot' for non-fish vertebrates that emerges is in the high seas area of the Tasman Sea. We note that the ratio between Atlantic and Indo-Pacific non-fish vertebrate taxa is roughly as described in Figure 4.

*All Marine Taxa*

Figure 15 combines all our distribution maps and pinpoints areas of higher marine species richness. In the high seas, there are large areas of high species richness in the tropical Indo-Pacific compared to the Atlantic. However, within the Atlantic, at least two small areas of high species richness emerge in the Northeast and Northwest Atlantic and from areas that are not associated with seamounts, but overlap with important fishing grounds. In the North Atlantic, small areas associated with ridges and some seamounts are also highlighted. This study also identifies areas of high species richness along the Southern Ocean convergence zone.

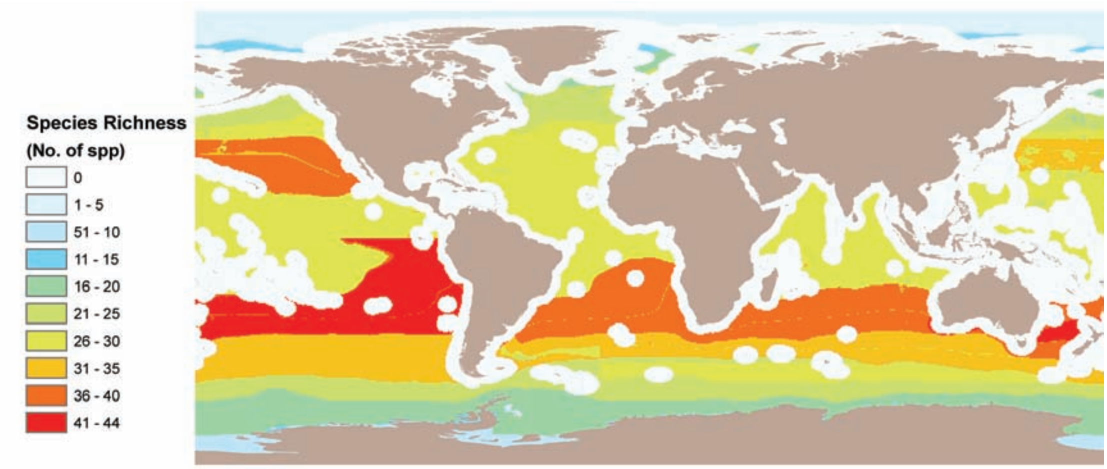



**FIGURE 12:** Map of marine mammal species richness based on distribution maps of all 100 species occurring in the high seas. Distribution of species richness is characterized by latitudinal bands with highest species richness in the southeastern Pacific. Two species of marine mammals (Caribbean monk seal and Atlantic grey whale) in the North Atlantic are extinct.

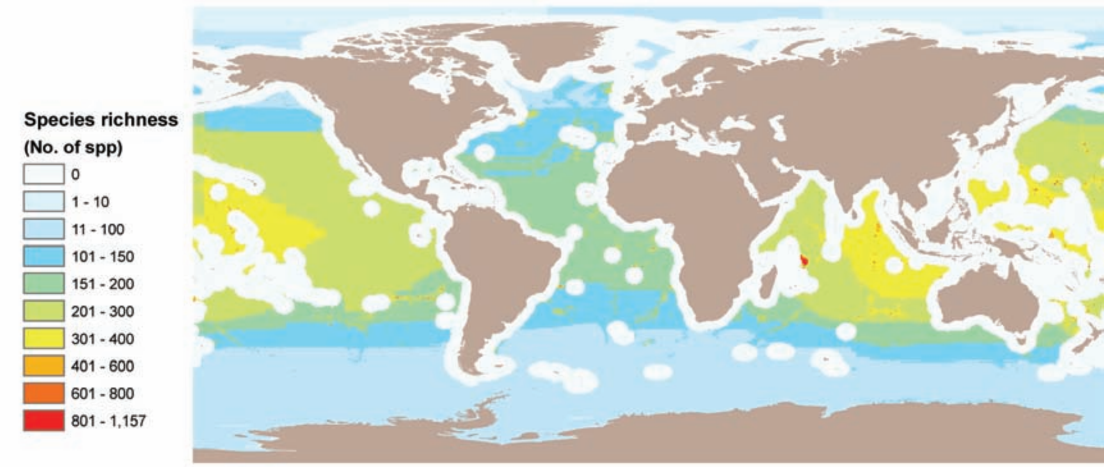



**FIGURE 13:** Map of species richness for exploited marine fishes and invertebrates in the high seas based on 1,072 species distribution maps, and 267 polygons representing an additional 3,678 species. The latitudinal and longitudinal gradients and habitat associations are responsible for the major observed patterns of species richness.

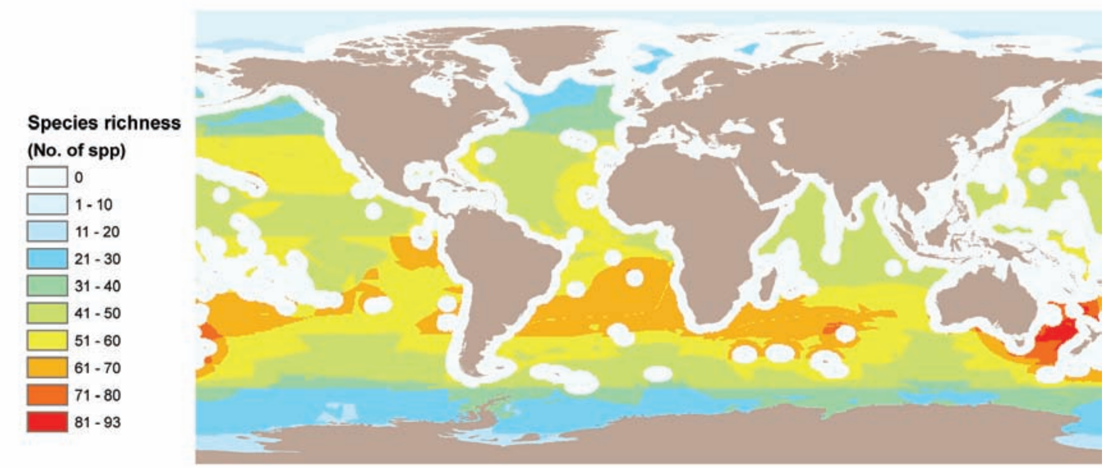



**FIGURE 14:** Map of non-fish marine vertebrates' species. The observed patterns largely reproduce the assumptions on latitudinal and longitudinal gradients for fish and invertebrate species, except for a southward shift of the maximum species richness. Moreover, the ratio of species number in the Indo-Pacific relative to the Atlantic is similar to the assumption depicted in Figure 4.

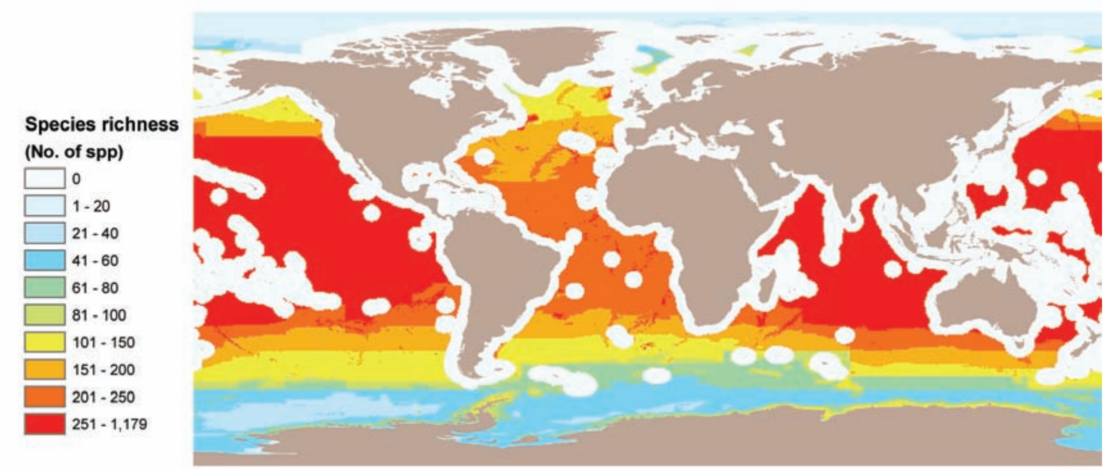



**FIGURE 15:** Map of marine species richness in the high seas (based on the distributions of exploited invertebrates and fishes, and of reptiles, birds, and marine mammal species). The high species richness in the tropics, especially in the Pacific and Indian Oceans, is due to the assumed latitudinal and longitudinal gradients for fishes and invertebrates, modified by the distributions for marine mammals, birds, and reptiles.

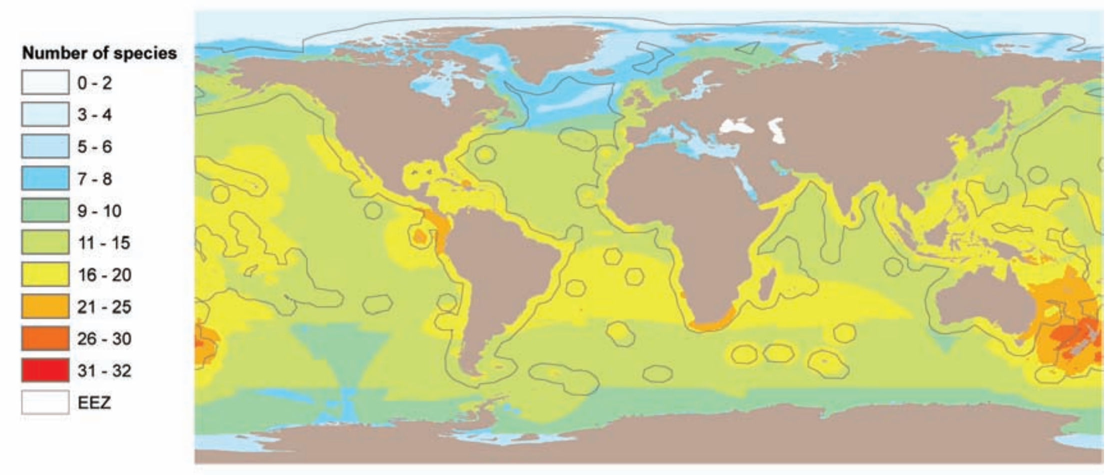



**FIGURE 16:** Map of threatened marine non-fish vertebrates that are listed as vulnerable, endangered, or critically endangered on the IUCN Red List (Baillie *et al.* 2004) based on their species-specific distribution (N=103). The threatened birds largely dominate the observed pattern with 81 species listed versus 16 for marine mammals and reptiles (6).

## TOWARDS SELECTING PRIORITY SITES FOR CONSERVATION

This analysis confirms that areas of highest species richness and thus priority for conservation of marine biodiversity are located in the tropical Indo-Pacific (Figures 15 and 16). Also, this analysis suggests that cold-water corals tend to associate with seamounts, and therefore efforts to protect seamounts have the potential to also protect cold-water corals. Cold-water corals may also be associated with continental slopes, which in some cases occur partially outside country's EEZs or similar national boundaries highlighting the need to consider MPAs that encompass national and international seas. However, more research is needed into this question.

When non-fish vertebrates are considered on their own (Figure 17), the priority areas remain in tropical Indo-Pacific, even when the gradients of latitude and longitude applied to fish and invertebrate species are not considered. In this analysis, these gradients assumed for fish and invertebrates genera and families, but there is strong evidence for their existence, notably our maps for non-fish vertebrates and published distributions of coral reef species (Roberts *et al.* 2002). A few 'hot spots' do emerge in the Northwest and Northeast Atlantic, which overlap with important fishing grounds (Figures 15 and 17). The importance of seamounts as hot spots is also evident in the South Atlantic and Eastern Pacific (Figure 8a). Reptiles, seabirds and marine mammal have distributions based on species-level information and are independent of the gradients imposed, yet areas for conservation are suggested to overlap with areas for exploited fish and invertebrates (Figure 15).

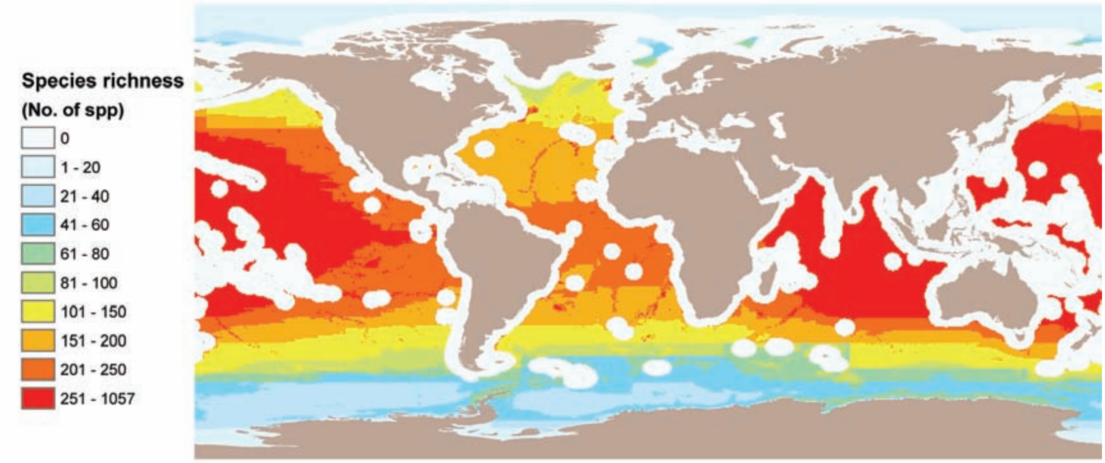



**FIGURE 17:** Map of marine fish and higher vertebrates' species richness in the high seas. The observed patterns largely reproduce the assumptions on latitudinal and longitudinal gradients for fish species, except in the Atlantic, where the lower background richness allows for the effects of seamounts to be visible.

If the latitudinal and longitudinal gradients as represented here in fact exist, then the tropical Indo-Pacific should be the priority area for conserving marine biodiversity, along with seamounts and cold-water coral areas. The need to implement specific conservation efforts in the Indo-Pacific region to conserve biodiversity is further corroborated by our analysis of threatened marine non-fish vertebrates. In this case, the high seas areas of the southwest Pacific (Figure 14) are particularly highlighted as in critical need for protection, the observed pattern being mainly driven by seabirds, representing 88% of listed species (Figure 16).

In order of priority, this analysis highlights the following areas for targeted conservation action:

- the high seas of the Indo-Pacific, specifically centered on SE Asia, Northern Australia and the Tasman Sea (Figures 14, 15 and 16);
- seamounts in the high seas of the North and South Atlantic, and the Southern Ocean convergence zone (Figures 16 and 18), especially since protecting seamounts and surrounding areas will more than likely protect cold-water corals;
- high seas areas adjacent to islands in the Southern Ocean (Figure 12); and
- small shelf areas in the high seas of the Northeast and Northwest Atlantic (Figures 15 and 17).

It should be noted that this analysis, due to lack of time and resources, did not take into consideration threatened marine fish and invertebrates. However, it will be undertaken shortly, and when completed it may suggest alternative or additional areas for priority action.

This investigation identified priority data gaps:

- the distributions of all red-listed species (that do not have species-specific maps), primarily for fish;
- information on seamount and cold-water coral species from a range of depths, and in particular from poorly sampled areas such as the Indian Ocean;
- associations between cold-water corals and seamounts on the latter's so that inferences on cold-water corals can be drawn from seamounts, where information is increasingly available; and
- studies of the features of animals and their behaviours which makes them vulnerable to fishing.

In contrast to the priority coastal areas for marine conservation, high seas areas that are in urgent need of conservation actions, are not only in the tropical Indo-Pacific, but also occur in the temperate areas of the northern and southern hemispheres.

## ACKNOWLEDGEMENTS

This report significantly benefited from contributions made by Colette Wabnitz, particularly with respect to the marine reptile component of this study. The authors gratefully acknowledge the financial support provided by the European Union. Also, we thank the Secretariat of the Convention of Biological Diversity for commissioning this study, in particular, Dr Marjo Vierros.

## REFERENCES


Alder, J. and L. Wood. 2004. Managing and Protecting Seamounts. In: *Seamounts: Biodiversity and Fisheries*. Fisheries Centre Research Report, **12(5)**:67–74.

Anon. 2005. <http://www.log.furg.br/WEBens/arches/~rfreeman/_27GLY409__273_Morphology.html > accessed April 8, 2005.

Au, D.W. and R.L. Pitman. 1988. Seabird relationships with tropical tunas and dolphins. In: *Seabirds and Other Marine Vertebrates. Competition, Predation, and Other Interactions*, J. Burger (ed.), Columbia University Press, New York, 174–212p.

Baillie, J.E.M., C. Hilton-Taylor, and S.N. Stuart, 2004. *2004 IUCN Red List of Threatened Species — A Global Species Assessment*. IUCN, Switzerland.

Baker, C.M., B.J. Bett, D.S.M. Billett, and A.D. Rogers, 2001. An environmental perspective. In: *The status of natural resources on the high seas*, WWF/IUCN (ed.), WWF/IUCN, Gland (Switzerland), 1–67.

Birdlife International. 2004. *State of the world's birds 2004: indicators for our changing world*. Cambridge, UK: BirdLife International

Cheung, W.W.L., T.J. Pitcher, and D. Pauly. 2005. A fuzzy logic expert system to estimate intrinsic extinction vulnerabilities of marine fishes to fishing. *Biological Conservation*, **124**:97–111.

Conand, C. 1998. Overexploitation in the present world sea cucumber fisheries and perspectives in mariculture. In: *Echinoderms*, San Francisco, Mool and Telford (eds). Balkema: Rotterdam, 449-454 p.

Cone, J. 1991. *Fire under the sea: volcanic hot springs on the ocean floor*. William Morrow, New York.

Darwin, C. 1841 [1989]. *Voyage of the Beagle*, J. Browne and M. Neve (eds), Penguin Books: London, 432 p.

D'Cruz, R. and M. Finlayson (eds). in press. *Wetlands & Water: Ecosystem Services and Well Being. The Millennium Ecosystem Assessment and the Ramsar Convention on Wetland*. Island Press: Washington, D. C.

Dulvy, N.K., Y. Sadovy, and J.D. Reynolds. 2003. Extinction vulnerability in marine populations. *Fish and Fisheries*, **4(1)**: 25-64.

Ekman, S. 1967. *Zoogeography of the Sea*. Sidgwick & Jackson: London, 417 p.

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

Froese, R. and D. Pauly. 2000. *FishBase 2000: Concepts, design and data sources*. ICLARM: Los Banõs, Philippines. 344 p. [available on CD-ROM and DVD; updates at www.fishbase.org]

Froese, R. and A. Sampang. 2004. Taxonomy and biology of seamount fishes. In: *Seamounts: Biodiversity and Fisheries*. Fisheries Centre Research Report, **12(5)**:25–31.

Glover, A.G. and C.R. Smith. 2003. The deep-sea floor ecosystem: current status and prospects of anthropogenic change by the year 2025. *Environmental Conservation,* **30(3)**: 219–241.

Greer, A.E. 2004. *Encyclopedia of Australian Reptiles*. Australian Museum Online <http://www.amonline.net.au/herpetology/research/encyclopedia.pdf> Version date: 7 February 2005.

Heatwole, H. 1987. *Sea Snakes*. The University of New South Wales Press: Kensington, Australia, 85p.

Kaschner K, R. Watson, A. W. Trites and D. Pauly, in press. Mapping worldwide distributions of marine mammals using a Relative Environmental Suitability (RES) model. *Marine Ecology Progress Series.*

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

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

Márquez, R. M. 1990. FAO Species Catalogue: Volume 11: *Sea Turtles of the World*. FAO: Rome, 81 p.

Morato, T., W.L. Cheung, and T.J. Pitcher. 2004. Vulnerability of seamount fish to fishing: Fuzzy analysis of life history attributes. In: *Seamounts: Biodiversity and Fisheries*. Fisheries Centre Research Reports, **12**(**5**):51–60.

Pauly, D., J. Alder, A. Bakun, K. Freire, S. Heileman, K. H. Kock, P. Mace, W. Perrin, Y. Sadovy, K. Stergiou, U. R. Sumaila and M. Vierros. 2005. Chapter 18: Marine Fisheries Systems. In: *Conditions and Trends Assessment Volume* of the Millennium Ecosystem Assessment. Island Press: Washington, D. C.

Reed J. K., A.N. Shepard, C. C. Koenig and K. M. Scanlon. 2005. Mapping, habitat characterization, and fish surveys of the deep-water Oculina Coral Reef Marine Protected Area: a review of historical and current research. In: *Cold-water Corals and Ecosystems*, A. Freiwald and J.M. Roberts (eds), Springer Publishing House, Heidelberg, Germany.

Roberts C. M., C. J. McClean, J. E. N. Veron, J. P. Hawkins, G. R. Allen, D. E. McAllister, C. G. Mittermeier, F. W. Schueler, M. Spalding, F. Wells, C. Vynne, and T. B. Werner. 2002. Marine biodiversity hotspots and conservation priorities for tropical reefs. *Science*, **295**:1280–1284.

Roper, C. F. E., M. J. Sweeney and C. E. Nauen. 1984. Cephalopods of the world. An annotated and illustrated catalogue of species of interest to fisheries. *FAO Fisheries Synopsis*. **125**(**3**):277 p.

Stocks, K. 2004a. Seamount Invertebrates: Composition and vulnerability to fishing. In: *Seamounts: Biodiversity and Fisheries*. Fisheries Centre Research Report, **12**(**5**):13–16.

Stocks, K. 2004b. Seamountsonline: an online resource for data on the biodiversity of seamounts. In: *Seamounts: Biodiversity and Fisheries*. Fisheries Centre Research Report, **12**(**5**):17–24 .

Uthicke, S., D. Welch and J.A.H. Benzie. 2004. Slow growth and lack of recovery in overfished Holothurians on the Great Barrier Reef: evidence from DNA fingerprints and repeated large-scale surveys. *Conservation Biology*, **18**:1395–1404.

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

Watson, R. and T. Morato. 2004. Exploitation patterns in seamount fisheries: a preliminary analysis. In: *Seamounts: Biodiversity and Fisheries*. Fisheries Centre Research Report, **12**(**5**):61–74 .

Worm, B., H.K. Lotze, R.A. Myers, 2003. Predator diversity hotspots in the blue ocean. *Proceeding of the National Academy of Sciences of the United States of America*, **100**: 9884-9888.

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