

Deep-Sea Biodiversity: A Quick Guide

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The deep sea is the largest ecosystem on Earth but it is also the least understood. The seas cover 71% of the Earth's surface and 65% of this is open-ocean. 88% of the open oceans are deeper than 1km and 76% have depths of 3-6km (Herring, 2002). Ocean trenches are the deepest parts of the oceans (the hadal zone) the Marianas Trench is up to 10,912m deep. Such a vast habitat represents a huge challenge for marine research and for management of human impacts on marine life.

For the purposes of this short paper, I consider the deep-sea as all areas of the ocean deeper than the continental shelf. This is generally below 200m depth, although in some areas, such as Antarctica, the shelf is much deeper (600m). In the pelagic realm (open ocean), this depth approximately corresponds to the epipelagic zone, where photosynthetically available light penetrates the surface of the ocean. Below this is the twilight or bathypelagic realm. Here, some light is still detectable, although not enough for photosynthesis, and animals are specially adapted to live in low light conditions. Below this, the water column is referred to as the abysso-pelagic realm with the interface between the water column and surface of the seabed known as the benthopelagic or suprabenthic zone. The seabed beyond the continental shelf is also classified into several zones based on depth and geophysical characteristics. The edge of the shelf is known as the shelf-break and this is the transition zone to the continental slope that goes from 200m to about 4000m depth. In places, the continental slope is cross-divided by canyons, which connect the continental shelf to the deep sea. At 3,000 - 4,000m there is a gradual decrease in the gradient of the slope (sometimes called the continental rise) until the seabed becomes the relatively flat, sediment covered abyssal plains. These cover a vast area of the ocean floor and are interrupted by topographic irregularities such as abyssal hills and seamounts and the mid-ocean ridges. In some cases the abyssal plains are bounded by deep-ocean trenches that occur where oceanic tectonic plates are subducted underneath continental plates.

Until the late 19th century the deep sea was considered as azoic and it was only with the Challenger expedition (1872-1876) that it was realised that animals live to depths of at least 5,500m. Life in the deepest reaches of the oceans was confirmed by subsequent expeditions including the Danish Galathea expedition of 1950-1952 which recovered animals from depths greater than 10,000m. Since the 1960s, scientists have studied the life of the deep oceans using a variety of semi-quantitative (trawls and dredges) and quantitative (box cores and mega-cores) sampling methods and more recently this has been supplemented by direct observations of the seabed using submersibles and remotely operated vehicles. These efforts still amount to sampling only a tiny fraction of the deep sea but have revealed a startling diversity of marine life.

The most species-rich habitats of the deep sea are the surface and upper layers of the sediments that cover most of the deep-sea bed. The sediments are inhabited by species of animals belonging to a range of phyla, varying in size from single-celled protists to large sea cucumbers and urchins. The most diverse groups are the small animals

living in the sediments including the tiny nematode worms, the segmented polychaete worms, molluscs, including bivalves and gastropods and peracarid crustaceans (Gage & Tyler, 1991).

In 1992, Grassle & Maciolek analysed samples of animals from the seabed along a transect on the continental slope of the eastern USA. They extracted over 90,000 specimens of animals belonging to nearly 800 species, many of which occurred rarely in the samples and a few of which comprised >2% of the specimens. Extrapolations from this dataset suggested that, considering the area of deep-sea bed in the world's oceans, there maybe as many as 10 million species in the deep sea. Some scientists considered that this was an underestimate of diversity as the Grassle & Maciolek study had included larger animals but not the very small animals found in the meiofauna (animals <0.5mm but >0.063mm).

In the last 2 years scientists have begun to think about the diversity of species in the deep-sea in a different way (Lambshead & Boucher, 2003; Rex et al., 2005). In particular, it has been recognised that in large habitats, such as the sediments of the continental slope and abyssal plains, samples obtained by biologists actually represent the regional fauna. Given the size of the habitats involved, the sampling effort to get an estimate of regional biodiversity is much larger than that usually encompassed by deep-sea studies. This means that generally, the more samples taken, the more species will be found. Relatively few species may actually be present in significant numbers at any one place in the deep sea but these maybe the important ones representing ecologically important and reproductive populations. This occurs because of "source-sink dynamics", where the larvae and juveniles of marine animals disperse over large areas of the deep sea, but many settle in areas not particularly suitable for them and whilst they can survive as adults they do not reproduce ("sink populations"). Species will tend to be more abundant in areas where conditions are suitable for them and it is in these places where "source" reproductive populations exist. Regional species pools also affect sampling in pelagic planktonic and nektonic communities. If a transect running from the coast out into the ocean is sampled at a given latitude then the oceanic samples will be more diverse than the coastal because the former represent a sample of the diversity of a large regional pool of species. At a regional or global scale, however, the diversity of coastal plankton species is higher as nearshore environments are more fragmented and physical conditions change over a given distance more than in the large ocean gyres.

The implications of source-sink dynamics are that the extremely large estimates of species richness in the deep sea (100 million) are likely to be wrong. However, the deep oceans are still a very large habitat and the numbers of species present are still likely to be large. The way species are distributed is critical in terms of management of high-seas biodiversity. If, for example, all species are present everywhere, then we would expect that even damaging a large area of the deep seabed would not risk the extinction of species. However, if species are distributed at a regional or sub-regional scale, then significant impacts within a region will run the risk of eliminating populations or even species.

Depth has a strong influence on the abundance, species richness and species composition of communities living on or in the seabed (e.g. Rex et al., 2005). Abundance and biomass of communities decreases exponentially with depth but

species richness peaks at mid-slope depths (1,500 – 3,000m depending on locality and groups of animals studied) and then decreases towards the abyss. Data on species richness in the deeper parts of the slope is still very limited by lack of sampling so this pattern is not certain at present. Another pattern that is clear from deep-sea studies is that species exhibit zonation in their distribution with depth (Carney, 2005). Moving from the shelf break to the abyssal plains the species present on and in the sediments of the seabed change (turnover). A zone of high species turnover occurs from the shelf break to depths of 500m and then another at approximately 1,000m and finally there is a transition to an abyssal fauna from 2,000 to 3,000m.

The distribution of species across parts of the ocean at the same depth (isobaths) is not well understood. This is because of the limitations of present sampling, especially at abyssal depths, and problems in identifying species (taxonomy). Abyssal species tend to show restricted geographic distributions to one ocean or region as the abyssal plains are divided by the continents and by the mid-ocean ridges (Vinogradova, 1997). In addition, latitude has an influence on distribution of species suggesting that historical factors, surface productivity patterns and other parameters correlated with latitude also influence species diversity. Latitudinal gradients in species diversity have been detected for some groups of deep-sea animals (Rex et al., 1993).

Asides from the sediments of the abyssal plains and continental slope, there are a number of other habitats in the deep oceans including: seamounts, hydrothermal vents, hydrocarbon seeps, other reducing habitats (whale falls, extreme oxygen minima), cold-water coral reefs, canyons and the ocean trenches.

There are up to 100,000 seamounts in the world's oceans with an elevation greater than 1,000m (Wessel, 2001). However, smaller features are significant in terms of their influence on species distribution and abundance. As a result, a new definition of seamounts has been accepted recently by biologists:

“Protruding irregularities or bottom features that rise greater than 100m from the sea floor”

(New Zealand Ministry of Fisheries draft Seamount Management Strategy; Rowden et al., 2005)

The seamounts online database indicates that about 200 seamounts have been biologically sampled, although a recent study (Rogers et al., in submission) indicates that 271 have been sampled for corals. Research has also not been even across the globe, with areas such as the entire Indian Ocean, and large parts of the northeastern, western, equatorial and southern central Pacific, South Atlantic and Southern Oceans being largely devoid of sampling.

Studies have suggested that the biodiversity of seamounts can be high and that there is a high level of endemism associated with them (De Forges et al., 2000). In the southwestern Pacific, for example, up to a third of species sampled from seamounts have been new to science and even adjacent seamounts appear to have quite different communities of species. In some cases, the high diversity of species is associated with fragile cold-water corals reefs. To date, the most diverse group of organisms found on seamounts are corals belonging to the Scleractinia (stony corals); Octocorallia

(gorgonians); Antipatharia (black corals); Stylasterida (hydrocorals) and Zoantharia (zoanthids) (Rogers et al., in submission). Analysis of the distribution of corals on seamounts showed that the distribution of the main groups is significantly affected by depth. It also revealed that several areas in the world have a high diversity of corals on seamounts, including the southwestern Pacific, the northeastern Pacific and the North Atlantic. However, sampling strongly influences this dataset and high diversity in the North Atlantic is probably a result of comparatively large study effort in this area. It is notable that the distribution of corals on seamounts did not reflect the overall global distribution of many coral species. Corals frequently were not sampled on seamounts in parts of the world where they occur in other habitats. This reflects the low overall sampling effort, especially in some localities, but also suggests that the distribution of organisms on seamounts is strongly influenced by the physical characteristics at a particular locality and that seamounts may operate like submarine islands.

This has strong implications for the interpretation of data from previous studies on seamounts. The species diversity of islands depends on their area, distance to sources for colonising species, rates of species immigration and extinction and other factors. Thus, large differences in the species composition of seamount communities may be found even on adjacent seamounts because of differences in the survival of colonising species resulting from differences in physical conditions and random factors associated with recruitment. This also suggests that seamount communities should resemble to some extent depauperate versions of source populations. There is evidence for this in at least some North Atlantic seamounts (Piepenberg & Müller, 2004). As with islands, the geographic isolation of seamounts can lead to reproductive isolation of populations and subsequent speciation. This suggests that endemism is likely on seamounts and will probably be a function of geographic distance to source populations (the continental slope).

Seamounts harbour abundant populations of seabed animals and fish compared to surrounding deep-sea habitats. This is thought to result from processes such as trapping of plankton (trophic focusing) rather than increased primary productivity resulting from localised upwelling (e.g. Rogers, 1994; Genin, 2004). As a result of increased food abundance, seamounts are a focus of activity for large ocean predators. Some species of fish spawn over seamounts, including orange roughy and the Japanese eel.

Hydrothermal vents and hydrocarbon seeps have very specialised faunas, characterised by low biodiversity but very high endemism. The animal communities in these habitats are driven by chemosynthesis, the bacterial oxidation of hydrogen sulphide or methane. These habitats cover very small areas of the seabed and are located along mid-ocean ridges or back-arc basins (hydrothermal vents) or along continental margins (seeps). Specialised animal communities only occur in the deep sea around these habitats and are not typical of shallow-water vents and seeps. These habitats have now been found all over the world and it is likely that many more will be discovered. Some similarities exist between the fauna of seeps and that associated with the breakdown of whale carcasses.

The largest reducing habitats in the world are extreme oxygen minimum zones. These occur in parts of the world where surface productivity is high and water circulation

low. Bacterial respiration strips oxygen from the water column and sediments. Extreme oxygen minimum zones are very poor in species diversity and have a very specialised fauna of animals adapted for life in hypoxic environments. However, there can be a marked peak in abundance and diversity of species immediately beneath extreme oxygen minimum zones as a result of enhanced supply of organic material.

Cold-water coral reefs occur on the shelf break and continental slope around the world but are also found in fjords and on seamounts and banks (Rogers, 1999). As with tropical, shallow water reefs, a rich fauna of animals is associated with cold-water corals reefs. These animals are found on the living coral, on and in the dead coral framework and in the sediments associated with the coral reef. Over 1,300 species have been found associated with reefs formed by the coral *Lophelia pertusa* off the coasts of Europe (Roberts & Gage, 2003). On the seamounts, south of Tasmania, reefs formed by the coral *Solenosmilia variabilis* are also associated with a rich associated fauna up to one third of which are new species (De Forges et al., 2000). Cold-water coral reefs develop in areas where this is a combination of specific physical and biological characteristics, including the presence of hard substrates, the occurrence of specific water masses, and strong currents, bringing a rich food supply (Rogers, 1999; Freiwald et al., 2004). Reefs may take thousands of years to develop (>8000 years in the North Atlantic) and individual corals grow at a rate of 0.5 – 2.5 cm per year.

Other corals, especially gorgonians may form beds or meadows which may also harbour a variety of other species and which form foraging sites for large predators (e.g. Hawaiian monk seals; Parrish et al., 2002). These corals may live for several hundred years.

Canyons are subject to vigorous currents and are often the site of increased biological activity. This manifests as very abundant populations of a limited number of species and the occurrence of large marine predators such as whales. Trenches are dominated by a low diversity of species, which tend to be endemic to a single trench or group of trenches (Vinogradova, 1997). These may occur at a higher density than similar animals from the surrounding deep sea.

Vulnerability of deep-sea ecosystems

The depletion of fisheries on the continental shelf has led to an increasing move to exploit offshore fisheries resources since the 1960s. Deep-sea fishing now takes place to 2000m depth and targets fish populations on the shelf break, continental slope, offshore banks and seamounts. Several types of fishing are deployed on the high seas including trawling, static nets and long lining. Deep-sea fish live in food-limited environments with low natural rates of mortality, slow growth rates and low rates of recruitment to populations. Fish, such as the orange roughy or grenadiers live for in excess of 100 years and in some cases will not mature until they are 20-30 years old (Rogers, 1994). Such conservative life histories render populations of deep-sea fish extremely vulnerable to depletion by fishing. Fish populations that concentrate over small areas, such as seamounts, to spawn are particularly vulnerable to intense fishing pressure. As a result, many populations of deep-sea fish, such as orange roughy, have been depleted over very short timescales (<5 years). Recently an analysis of North Atlantic populations of 5 species, *Antimora rostrata*, *Coryphaenoides rupestris*,

Bathyraja spinicauda, *Notocanthus chemnitzii* and *Macrourus berglax*, all caught as target species or bycatch, has demonstrated that they are critically endangered under IUCN criteria (Devine et al., 2006). This problem is not restricted to deep-sea fish but has also been demonstrated for large ocean predators that also often have conservative life histories (Myers & Worm, 2003).

As well as impact on target and non-target species of fish, marine reptiles, birds and mammals, some types of fishing are highly destructive to the marine environment. Bottom trawl gear, designed to cope with rough terrain, has been widely deployed to catch fish on the continental slope and on banks and seamounts. Heavy trawl gear mechanically ploughs the seabed smashing the animals that are attached to the seabed or which are not sufficiently mobile to move away. Large-scale destruction of deep-sea coral reefs and coral and sponge beds has been recorded from many parts of the world (Freiwald et al., 2004). On seamounts, the entire framework of a cold-water coral reef along with the associated fauna can be removed as a result of extremely intense fishing pressure (up to 17,400 km of trawling per km² of seamount area; O'Driscoll & Clark, 2005). Corals are extremely slow-growing and have low rates of recruitment, which maybe sporadic (Rogers, 1999). Trawling may also alter the habitat in which they live to the extent that it is no longer suitable for colonisation by larvae. Even where corals are not completely destroyed by trawling they maybe reduced to a size where they can no longer reproduce (Waller & Tyler, 2005). Recovery from such fishing impacts may take hundreds or even thousands of years, if recovery is possible at all.

The other major threat to the deep-sea fauna is climate change. It is known that past climate change events have had a dramatic impact on the distribution of animals in the oceans, including the deep sea, and may have played a major role in shaping patterns of biodiversity today (Rogers, 2000). Changes in temperature, oxygenation and patterns of productivity all have the potential to dramatically impact the distribution of deep-sea animals. More recently, it has been recognised that as a result of ocean acidification large parts of the oceans will become under-saturated in aragonite and calcite. This is likely to have a significant impact on cold-water corals and other animals with aragonite and calcitic skeletons (Orr et al., 2005). Corals and associated species will be affected indirectly through dissolution of dead coral skeletons, on which many corals settle, and which form the framework of reefs. Corals may also be directly affected as a result of increased difficulties in uptake of aragonite and skeletal erosion. Scleractinia, appear to be less diverse in the North Pacific than in the Atlantic or southwestern Pacific, possibly because the aragonite saturation horizon is shallower in the North Pacific.

Other activities that currently or are likely to impact the deep oceans include the extraction of oil, gas, methane hydrates and mining of polymetallic sulphides (around vents) or manganese nodules (abyssal deep-sea). The oceans are already contaminated with a range of human wastes, especially including clinker, coal and plastics discarded or lost from ships but also munitions and even nuclear waste.

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