

The Offshore Directory

*Review of a selection of habitats,
communities and species of the
north-east Atlantic.*

A report for WWF by Susan Gubbay with
contributions from Maria Baker, Brian Bett
and Gerd Konnecker

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Preface

Environmental protection of the world's oceans is the subject of a number international agreements including several which are concerned with the control of marine pollution. Two examples are the *1972 Convention for the Prevention of Marine Pollution by Dumping from Ships and Aircraft* (the Oslo Convention) and the *1974 Convention for the Prevention of Marine Pollution from Land-Based Sources* (the Paris Convention). In 1992 these two conventions were merged into the *Convention for the Protection of the North-east Atlantic* and a joint body, the Oslo & Paris Commission (OSPAR), was established to oversee its implementation. In 1998, a new annex was added to the convention relating to the protection and conservation of the ecosystems and biological diversity. To take this forward two workshops have been held under the auspices of OSPAR to develop criteria to identify habitats and species for protection, conservation and, where practical, restoration and/or surveillance or monitoring. There have also been four related workshops to identify potential locations where OSPAR might promote the establishment of marine protected areas (MPAs).

WWF, the global environment network, has had a long-standing interest in the conservation of marine habitats and species, including the establishment of MPAs, and has promoted the latter as a key management tool for marine nature conservation. The developing OSPAR programme is therefore supported by WWF as it presents an opportunity to apply habitat and species conservation measures, including MPAs, beyond territorial waters. Through its observer status on the commission, WWF has submitted reports and papers on offshore MPAs and played an active part in the workshops on this subject.

This report is a further contribution from WWF to the debate on offshore habitat and species conservation and MPAs. It describes physiographic and hydrographic features, biological communities and some of the deep-water species in the OSPAR area which lie outside the territorial waters of the contracting parties. They have been selected to show the variety of this environment. In each case the conservation issues and desirable conservation actions are described, with an emphasis on identifying locations of marine nature conservation interest so that these could be considered as possible sites in any future offshore MPA programme.

The majority of this report was researched and written by Susan Gubbay in 1998 and 1999. For this October 2002 publication, new chapters have been contributed by Maria Baker, Brian Betts and Gerd Konnecker. There have also been progressive legal developments for offshore conservation since the Offshore Directory was initiated in 1998. Most notable, are that the Norwegian government has designated the Sula Reef as the first protected *Lophelia pertusa* reef in the north-east Atlantic (March 1999) and the UK High Court judgement (November 1999) that the EU Habitats Directive (92/43/EEC) applies offshore ("to the UK Continental Shelf and superjacent waters up to a limit of 200 nautical miles.."). Links between the work under OSPAR and the EU Habitats Directive are covered in another WWF publication, *Implementation of the EU Habitats Offshore: Natura 2000 sites for reefs and submerged sandbanks* (June 2001). At the time of this report's publication, management plans for the first deep sea MPAs in the north-east Atlantic are being developed – for the Lucky Strike and Menez Gwen hydrothermal vents in Azorean waters.

There is also very bad news. The Darwin Mounds comprises a unique collection of sandy and cold-water coral mounds in the north-east Atlantic situated about 185km north-west of Cape Wrath, the north-west tip of mainland Scotland. They were officially discovered in 1998 and have already suffered damaged. Evidence points to destruction of the coral on the mounds by the trawl doors of fishing vessels registered outside of the UK. It is essential, for the protection of the mounds, that they are designated as an MPA with urgency by the UK government and that the European Union takes action to prevent fishing on the mounds.

Although it is clear that there are substantial gaps in our knowledge and understanding of the offshore marine environment, it is hoped that the compendium of information in this directory will be a useful reference to those working towards marine habitat and species conservation and the identification, establishment and management of MPAs in the OSPAR maritime area.

Sarah Jones and Stephan Lutter (WWF North-east Atlantic Programme)

1 Introduction

Vast expanses of sea and sea-bed, more than 80 per cent of the world's oceans, lie outside the territorial waters of coastal nations. These are some of the least explored areas on Earth. Because of logistics and practical considerations, marine research and investigation has tended to be focused on the continental shelf, particularly on areas immediately adjacent to land: these are some of the most productive, diverse and economically valuable areas of sea, but which are under considerable pressure from human use. Study of the offshore environment is more challenging and, as a result, less is known about its wildlife and habitats. Nevertheless, fascination with the deep sea means that it has been the subject of study for more than a century.

In the mid-19th century the discoveries by Norwegian naturalist Michael Sars, and the expeditions organised under the auspices of the Royal Society of London led by Charles Wyville-Thomson, were instrumental in opening up deep sea biology as a field of study. Their work showed that life existed in the deep sea and created the momentum that led to the pioneering three-and-a-half year round-the-world voyage of *H.M.S. Challenger* in 1872. Expeditions by French, Danish, Norwegian, German, Swedish and American scientists are some of the many that followed and which overturned the view that the deep sea was a barren environment, devoid of life beyond certain depths. Sea-bed features such as the Wyville-Thomson Ridge, Porcupine Sea Bight, and Challenger Deep, bear the names of these early explorers and their survey vessels as a reminder of achievements in laying the foundations of modern oceanography. The last of the old-style oceanographic circumnavigating voyages were the Swedish *Albatross* and the Spanish *Galathea* expeditions which, in the latter case trawled animals from the bottom of ocean trenches at depths of more than 10,000m. In the mid to late 20th century, Russian biologists were at the forefront of deep sea research and, more recently, the advent of deep sea manned submersibles such as the *Trieste*, *Alvin*, and *Nautilie* enabled direct observations of remarkable deep sea communities to be made for the first time.

There is still a considerable amount to learn about the offshore environment. Research and exploration continues in many fields including oceanography, hydrography, geology and marine biology. International programmes have been set up to study circulation patterns in the ocean, not only from the sea surface but also from space, and collaboration between scientists from around the world is moving forward our understanding of the oceans. The exploration and exploitation of marine resources has been another driving force. World fish catches in 1996 were around 95 million tonnes and considerable quantities of the world's hydrocarbon production comes from the oceans. In both fields, there is pressure to find more resources and this inevitably means moving further offshore. Deep sea fish have not only become part of the world fish catch but certain stocks are already so depleted that they can no longer be exploited economically. Oil and gas production is taking place in inhospitable areas that were uneconomic to exploit only 20 years ago, such as the Arctic and the north-east Atlantic oceans.

With growing pressure on offshore resources and the impact of human activity becoming more apparent in this environment, some aspects of offshore marine research are being driven by concerns over the effects of human activity on the oceans. On a global scale, the effects of climate change are a major issue. There are also studies of localised, albeit widespread, effects

such as the impact of fishing gear on the sea-bed habitats and biological communities, the transport and introduction of non-native species in the marine environment, and the effects of pollutants on the structure and function of marine communities and species. These and many other concerns are leading to calls for more to be done to safeguard the biodiversity of the oceans.

1.1 OCEAN MANAGEMENT

Control of ocean space, and access to the resources of the oceans, have always been of great strategic importance and, consequently, the subject of disputes between nations since early seafaring days. The conflicts have mostly revolved around issues of territory, defence and trade. In the 15th century, the Portuguese opened up sea routes for trade with West Africa and India. Columbus, with the support of Spain, crossed the Atlantic hoping to find a westward route to Asia to gain a trade advantage over the Portuguese and in the process discovered America.

Issues of territory, defence and trade remain at the forefront of ocean management but as population numbers have risen, and competition for ocean resources has become more acute, so has the need for a globally-agreed regime for operating on the world's oceans. Such a regime was first formally discussed in 1958 during the United Nations conference on the law of the sea. Following many years of negotiation, the culmination was the historic and wide-ranging agreement of the *1982 United Nations Law of the Sea Convention*, which came into force in 1994.

The Law of the Sea Convention (UNCLOS) sets out the legal regime covering the rights and responsibilities of states with respect to the world's oceans. Topics covered include jurisdictional boundaries (territorial seas, the exclusive economic zone, continental shelf and high seas), rights to exploit living and non-living marine resources, marine scientific research and environmental protection.

On the high seas there are no restrictions on access, and no country has exclusive rights to fish stocks, minerals or any other marine resources. The only controls are those that have been reached through international agreement and this has led to the ratification of a number of international conventions and treaties on marine issues. While UNCLOS is the most far-reaching, there are others that cover specific ocean uses or apply to particular geographic areas. The *1995 Agreement on Straddling Fish Stocks and Highly Migratory Fish Stocks* and the *1998 Convention on the Protection of the North-east Atlantic* are two examples. Declarations from international meetings have also shaped the management of our use of the oceans as illustrated by the International Conferences on the Protection of the North Sea. Four conferences have been held including the first meeting in 1984. They are attended by ministers from countries surrounding the North Sea and, through the conference declarations, provide political impetus to make progress on environmental protection of the North Sea.

1.2 THE OSPAR CONVENTION

The Convention for the Protection of the north-east Atlantic (OSPAR Convention) is a significant regional agreement which came into force in 1998 following the merging of the *1972 Convention for the Prevention of Marine Pollution by Dumping from Ships and Aircraft* (the Oslo Convention) and the *1974 Convention for the Prevention of Marine Pollution from Land-Based Sources* (the Paris Convention). A joint body, the Oslo & Paris Commission (OSPAR) oversees implementation of the convention.

The convention applies to what is described as the “maritime area” which extends westwards from mainland Europe to sections of the mid-Atlantic Ridge, eastwards to the continental North Sea coast, and from the North Pole to the Straits of Gibraltar. It does not include the Baltic or Mediterranean (box 1, figure 1).

Contracting parties undertake measures to prevent and eliminate pollution as well as monitoring and assessing the quality of the marine environment in the OSPAR maritime area. Assessment is a major area of work at the present time with regional quality status reports being prepared for each of the five OSPAR regions (figure 1). These will enable a quality assessment for the entire maritime area to be made. The aim was to complete these reports by 2000 and use them to guide the future work and priorities of OSPAR.

Of particular relevance to this directory is annex V of the convention (*Protection and Conservation of the Ecosystems and Biological Diversity of the Maritime Area*) which provides a framework for contracting parties to develop their own conservation measures. Article 2 includes a requirement for parties to: “take the necessary measures to protect and conserve the ecosystems and the biological diversity of the maritime area, and to restore, where practicable, marine areas which have been adversely affected”.

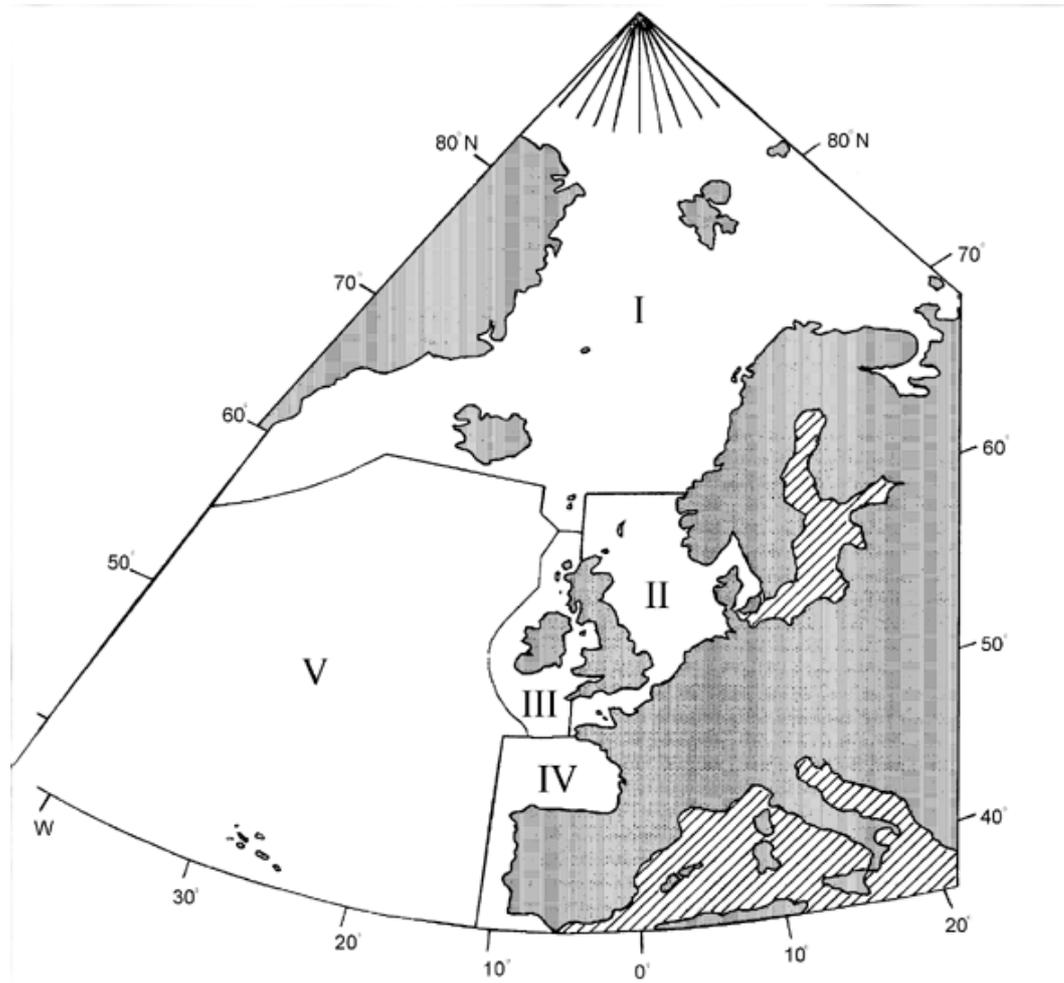
Annex V and an accompanying strategy for its implementation were adopted in 1998. It centres around an assessment of the species and habitats that need to be protected and of those human activities that are likely to have an adverse effect on them. These will be identified through the development of criteria for the selection of species, habitats and ecological processes, and application of these criteria to compile lists of species and habitats including those that are threatened or declining. Two workshops have been held to develop these criteria and they are now at the stage of awaiting approval from OSPAR.

BOX 1 : The OSPAR maritime area and Regions

For the purposes of the convention "maritime area" means the internal waters and the territorial seas of the contracting parties, the sea beyond and adjacent to the territorial sea under the jurisdiction of the coastal state to the extent recognised by international law, and the high seas, including the bed of all those waters and its sub-soil situated within the following limits: those parts of the Atlantic and Arctic oceans and their dependent seas which lie north of 36° north latitude and between 42° west longitude and 51° east longitude, but excluding: the Baltic Sea and the Belts lying to the south and east of lines drawn from Hasenore Head to Griben Point, from Korshage to Spodsbjerg and from Gilbjerg Head to Kullen, the Mediterranean Sea and its dependent seas as far as the point of intersection of the parallel of 36° north latitude and the meridian of 5°36' west longitude; that part of the Atlantic Ocean north of 59° north latitude and between 44° west longitude and 42° west longitude.

REGION	DESCRIPTION	AREA	COASTLINES
Region I	Arctic waters	Eastwards from the North Pole, along 51°E along the coast to 62°N. South border follows this latitude but includes Faeroe Western border follows 42°W to North Pole.	Russia, Faeroes Norway Iceland Greenland
Region II	Greater North Sea	Western limit at 5°W and northern limit between Scotland and Norway at 62°N, 5°W	Norway, Sweden Denmark, France Belgium, Netherlands, UK
Region III	Celtic seas	5°W & west coast of GB between 60°N & 48°N, western boundary is 200m isobath to the west of longitude 6°W, also between latitudes 60°N & 48°N.	UK, Ireland
Region IV	Bay of Biscay & Iberian coast	South of 48°N to southern limit of the convention area, to the east of 11°W.	France, Spain Portugal
Region V	Wider Atlantic	62°N, south to 36°N, eastward to 11°W	Rockall Azores

Figure 1: The OSPAR maritime area and Regions



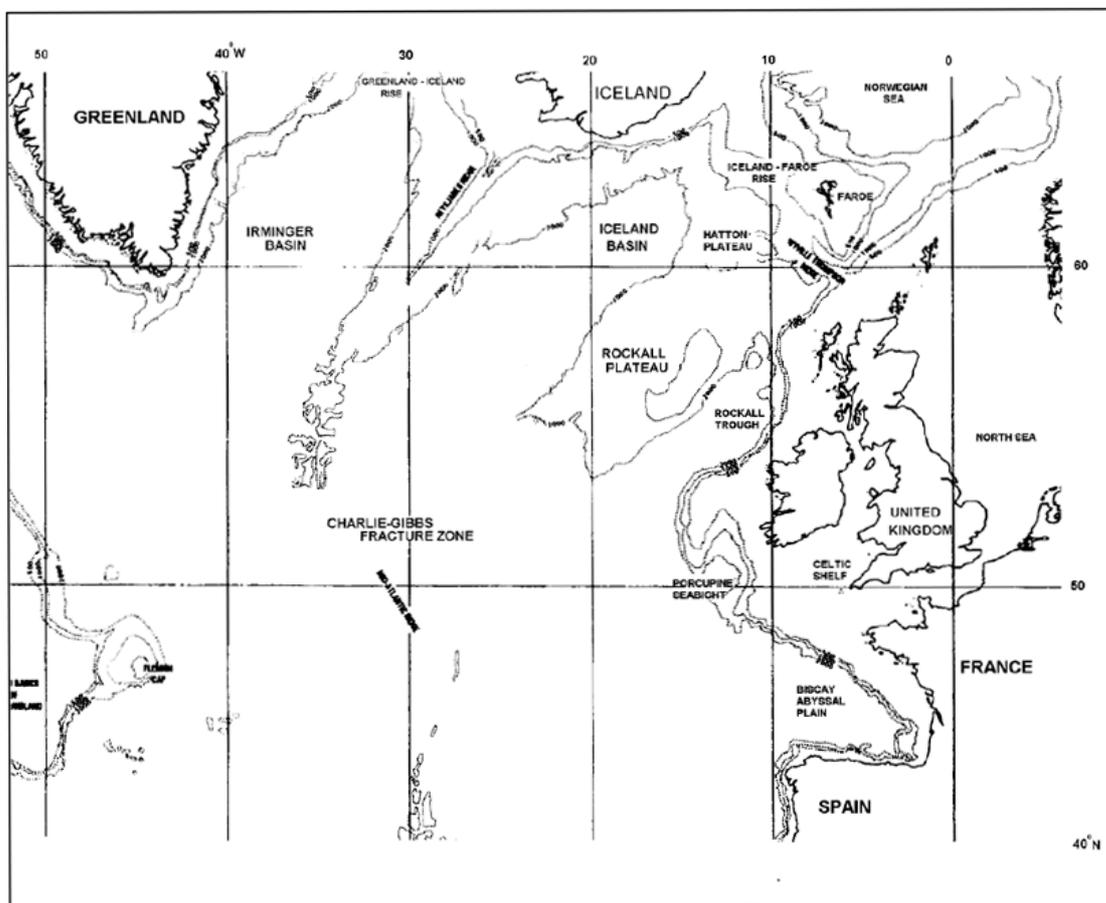
This report describes physiographic and hydrographic features, biological communities and some of the deep water species in the OSPAR maritime area which lie outside the territorial waters of the contracting parties. They have been selected to show the variety of this environment. In each case the conservation issues and desirable conservation actions are described including, where available, information on locations of marine nature conservation interest. Although it is clear that there are substantial gaps in our knowledge and understanding of the offshore environment, it is hoped that this compendium of information will be a useful reference to those working towards the conservation of offshore habitats and species and the identification, establishment and management of MPAs in the OSPAR maritime area.

1.3 THE OSPAR

The OSPAR maritime area covers a large geographical area, extending from the North Pole to the Straits of Gibraltar and from the coasts of mainland Europe eastwards to the mid-Atlantic Ridge. Large topographical features such as the Arctic mid-ocean ridge, the mid-Atlantic Ridge, and the Greenland-Iceland/Iceland-Faeroe rise dominate sections of the sea-bed. There are also

extensive relatively flat and featureless areas, such as in the Porcupine Abyssal Plain and Iberian Abyssal Plain, and deep channels such as the Norwegian Deep and Rockall Trough. The continental shelf, that fringes the various coastlines, is relatively narrow in most places. The exceptions are around the British Isles and north-western France where it forms the shallow seabed of the North Sea, Irish Sea, Celtic Shelf and the northern Bay of Biscay (figure 2). The habitat diversity created by features such as these is apparent on many scales; as underwater mountain chains, steep slopes, rocky sea-bed or micro-variations in sediment types. The coastal fringes generally exhibit much greater habitat variety however these areas, which lie within the territorial waters of the OSPAR contracting parties, are not the subject of this report. A classification of offshore habitats in the OSPAR maritime area is currently under development and has been the subject of two workshops held in 1999 and 2000.

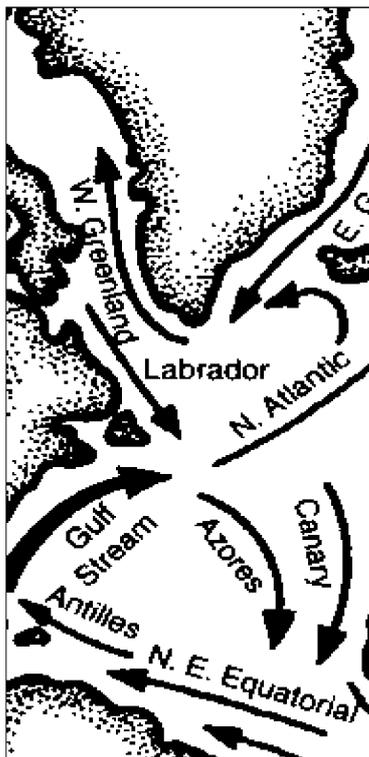
Figure 2: Major sea-bed features in the north-east Atlantic



The circulation of seawater is largely driven by differences in the density of the water but it is also influenced by bottom topography and surface winds. A number of distinct water masses have been identified in the region. To the south and south-east of Greenland, for example, the cold temperature and relatively high salinity of the seawater causes it to sink. This then flows southwards through the narrow channel between Greenland and Spitzbergen creating what is

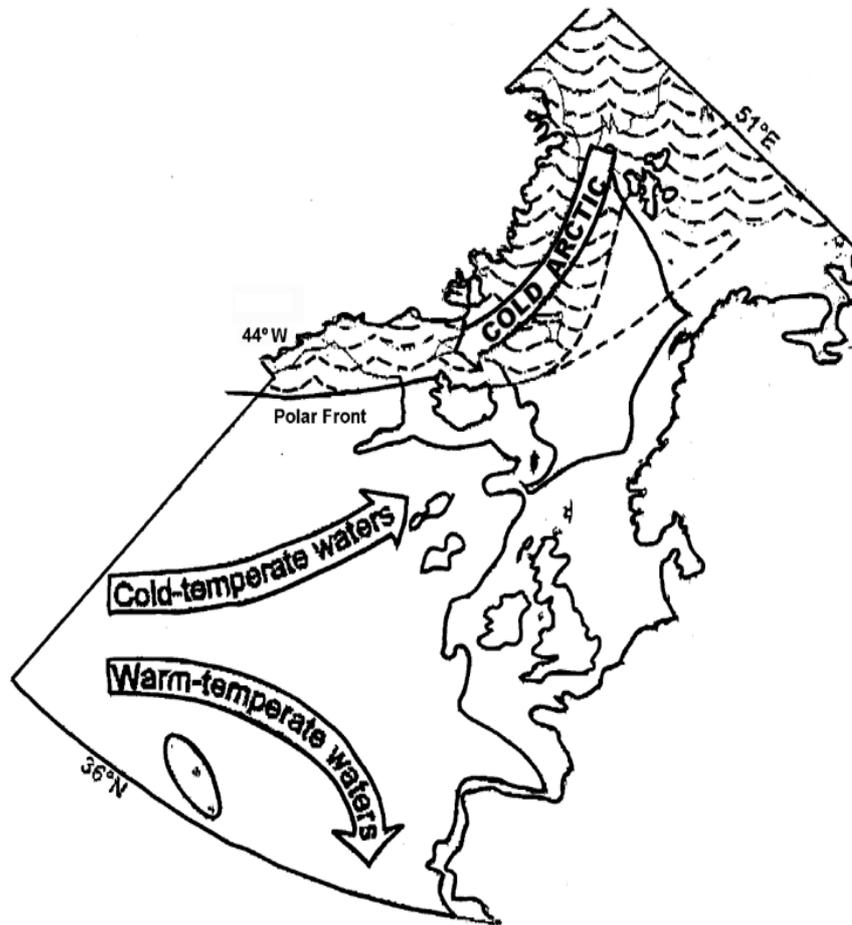
known as the North Atlantic Deep Water which, extends over much of the abyssal plain. The North Atlantic current on the other hand carries warm water from low latitudes on the eastern side of the Atlantic to the western coasts of Europe. Off the coast of Portugal the effects of wind on seawater circulation can be observed. The consistent northerly winds which blow during the summer months move surface water offshore to such an extent that deep cool water is drawn to the surface creating a seasonal upwelling (figure 3). Other hydrographic features include gyres, eddies, and frontal boundaries which persist for varying periods of time and can be on a scale of a few centimetres to many kilometres across.

Figure 3: Major surface currents in the north-east Atlantic



The characteristics of the different water masses enable a wide variety of marine species to exist in the area. This is reflected in the fact that the OSPAR maritime area extends across several biogeographic zones. A number of biogeographical classifications have been developed for the region with the differences reflecting the group of plants and animals being used as the basis for the classification. One classification which has tried to combine these is that developed by Hayden *et al.*, (1984) which describes two ocean realms, one coastal realm, two marginal seas and archipelagos, and three faunal provinces. A classification proposed by Dinter (1999) also combines different aspects of biogeography but separates the pelagic, shelf and upper slope and abyssal realms. The pelagic realm is divided into an east Atlantic temperate realm, which contains warm-temperate waters and cold-temperate waters, and an Arctic realm with cold-arctic waters (figure 4). The shelf and upper continental slope realms are divided further into provinces and the Abyssal sub-divided into Arctic and Atlantic sub-regions.

Figure 4: Biogeographical units of the OSPAR maritime area – Pelagic zone (from Dinter, 1999)

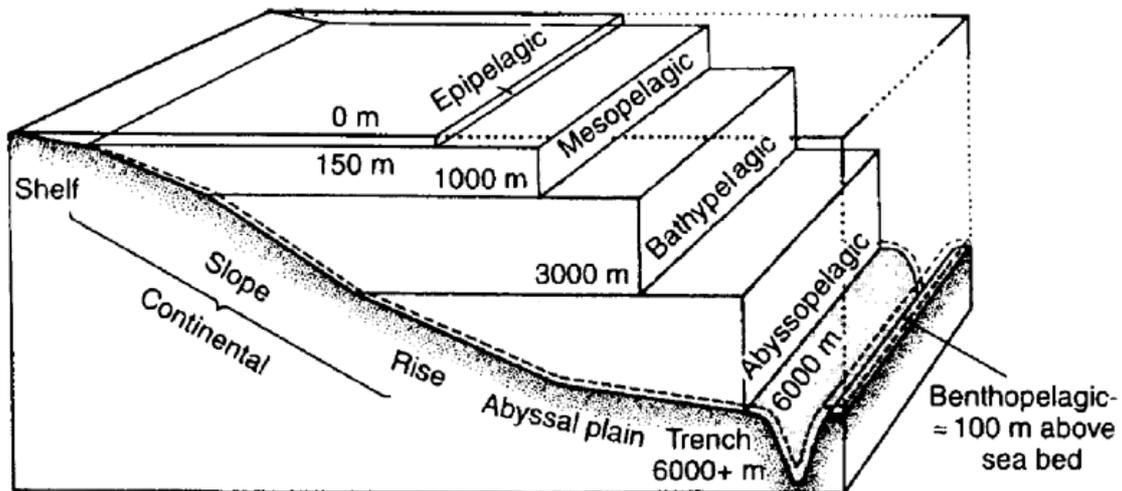


In the high Arctic, where there is permanent pack ice, where water temperatures are low and summers brief, the productivity and biomass is relatively low. Ice algae develop on the under-surface of the ice during the summer providing food for grazing animals while on the sea-bed components of the benthic communities include shellfish, sponges, bryozoans and polychaetes. The main top predators are seals, polar bears, beluga and bowhead whale. The sub-Arctic, just to the south, provides a striking contrast. Polar and north temperate waters mix in this area making the Bering Sea tremendously productive. The region supports some of the world's most important fisheries (herring, cod, capelin) as well as substantial populations of marine mammals (whales and seals) and seabirds. The zooplankton play a key role providing food for the major fish stocks, such as herring, blue whiting and mackerel which migrate into the area to feed in the spring and summer. The boreal region, with its temperate conditions lies to the south. Shallow rocky areas are colonised by extensive forests of kelp and soft corals while sediment communities may be dominated by mussel beds, seagrass, and the calcified red seaweed, maerl as well as supporting a rich infauna. The extensive mudflats and saltmarshes which border coastal areas are important landfalls for migrating wildfowl and waders along the north Atlantic flyway. Offshore islands also support major colonies of breeding seabirds. The Lusitanian

province, further south, has faunal affinities with the Mediterranean with extensive beds of the seagrass *Posidonia*.

In the open ocean the most marked changes in fauna are linked to depth resulting in a vertical zonation. The water column has been classified into a number of zones (figure 5) and these are used by different species in a variety of ways. Some migrate considerable distances through the water column on a daily basis while others are thought to spend their entire life within a limited part of the water column. Because the water masses in the deep sea originate at the surface, they are generally well oxygenated even at the sea-bed and this enables life to exist on and in deep sea-bed sediments. Here, too, it is possible to see patterns in species distribution with some species occupying a wide depth range and other restricted to a narrow band. The sharpest change in faunal composition occurs at the edge of the shelf.

Figure 5: Ecological zonation in the deep sea from Merritt & Haedrich, 1997).



The isolated volcanic islands of the Azores are a “hotspot” in the Atlantic as they are influenced by a complicated current regime with different elements dominating at different times of year (Santos *et al.*, 1995). The large-scale oceanic circulation is dominated by the Azores current that flows from west to east but the marine fauna and flora have more affinities with those of the eastern Atlantic. The islands have been described as being at a crossroads where shallow marine fauna and flora of different origins meet. Eddies from western Africa as well as the Atlantic coasts of Europe transport eggs and fish larvae, shallow seamounts may serve as stepping-stones for dispersal of some species, and rafting and fouling contribute to colonisation by other species. The islands are also on the migration path for some species such as the sperm whale and whale shark.

1.4 SELECTION OF HABITATS, COMMUNITIES AND SPECIES

In the lead up to publication in 2000, regional quality status reports were prepared by contracting parties and the OSPAR Commission. They brought together detailed information on many aspects of the maritime area including the geography, hydrography, marine biology and human activities, for a quality assessment. This directory seeks to supplement the assessment work by focusing on nature conservation in order to inform the debate on implementation of annex V of the convention and especially the identification of habitats and species for nature conservation action. The following sections, therefore, describe some of the distinctive habitats and communities in the area as well as those that are known to be of particular interest from a nature conservation perspective. A mix of wide-ranging, specialist, and vulnerable species are also described as well as those for which the OSPAR area is known to be of particular importance. The habitats and species that have been chosen are necessarily influenced by the knowledge base but an attempt has been made to include recent discoveries as well as those that have been the subject of study for many years. The ultimate objective is to show something of the richness, variety and uniqueness of the biodiversity in the OSPAR maritime area.

2 Offshore habitats, communities and species

2.1 SEAMOUNTS

Seamounts are undersea mountains which are typically cone shaped, rising steeply from the seabed but which do not emerge above sea level. In some studies the definition is limited to circular or elliptical features of volcanic origin (Epp & Smoot, 1989) while in other cases height is the defining factor. Only those features that are more than 1,000m high with a limited extent across the summit, for example, have been defined as seamounts by the US Board of Geographic Names (quoted in Rogers, 1994). Seamounts can be very large features not only in terms of their height but also in area as some may be several kilometres across the base. Those which have flat summits, due to wave erosion when they were above sea level, are known as guyots.

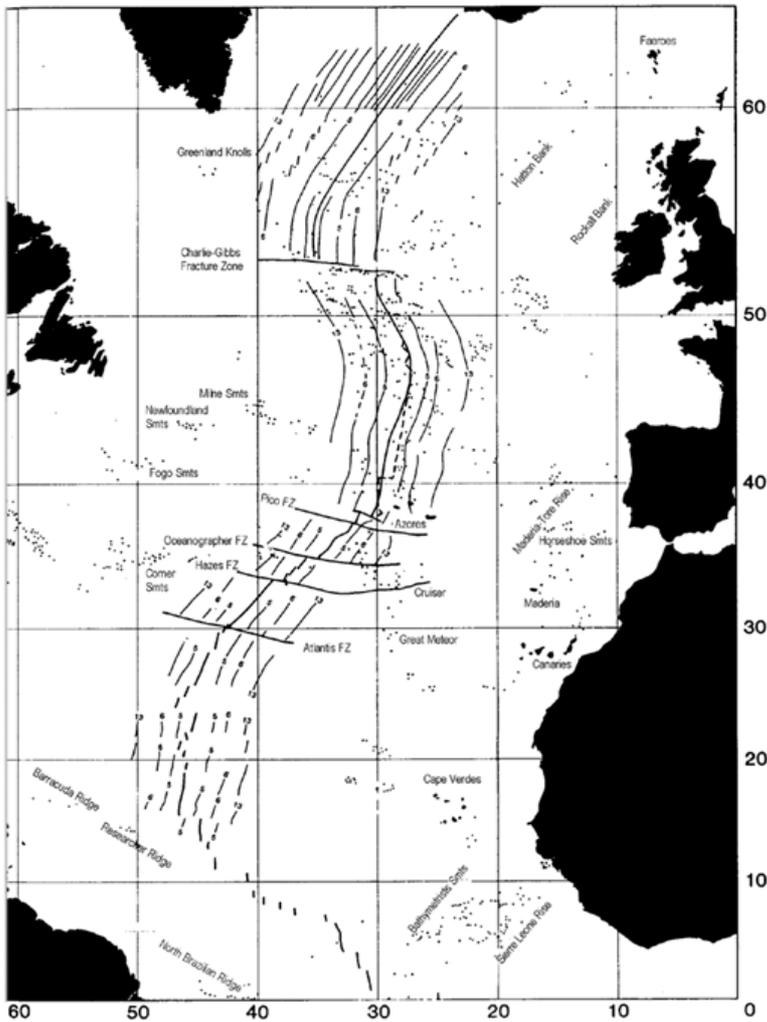
Seamounts often occur in chains or clusters that are probably linked to seafloor hotspots and the associated volcanic activity. Geological studies indicate that they have been generated along the mid-Atlantic Ridge for the past 35 million years although some, such as the seamounts around Rockall Bank and between the south-west corner of Rockall and the Charlie-Gibbs fracture zone, may have formed before then (Epp & Smoot, 1989).

Seamounts are a distinct and different environment to much of the deep sea. Their steep slopes, which are often current-swept, and the predominance of hard exposed rock surfaces provide a marked contrast to the characteristically flat and sediment-covered abyssal plain. Their profile and elevation from the surrounding seafloor also effects the circulation of water in the area for example by deflecting currents as well as leading to the formation of trapped waves, jets and eddies (Rogers, 1994). Some of these eddies are known to become trapped over seamounts to form closed circulations (Taylor columns) which have been observed to persist for several weeks.

2.1.1. Occurrence in the OSPAR maritime area

There are a large number of seamounts in the OSPAR maritime area. An analysis of narrow beam bathymetric data collected by the US Naval Oceanographic Office between 1967 and 1989 identified more than 810 seamounts in the North Atlantic, a number which, even then, was considered to be an underestimate because of incomplete data coverage and the omission of small features from the analysis (Epp & Smoot, 1989). The majority lie along the mid-Atlantic Ridge between Iceland and the Hayes fracture zone hence their abundance in the OSPAR maritime area. There are also groups of seamounts some distance from the mid-Atlantic Ridge to the south-west of the Rockall Bank, west of Portugal on the Maderia-Tore Rise, and the Milne seamounts to the east of the mid-Atlantic Ridge (figure 6). The greatest concentration of seamounts occurs between the Charlie-Gibbs fracture zone and the latitude of the Azores.

Figure 6: Location of seamounts in the North Atlantic (from Epp & Smoot, 1989)



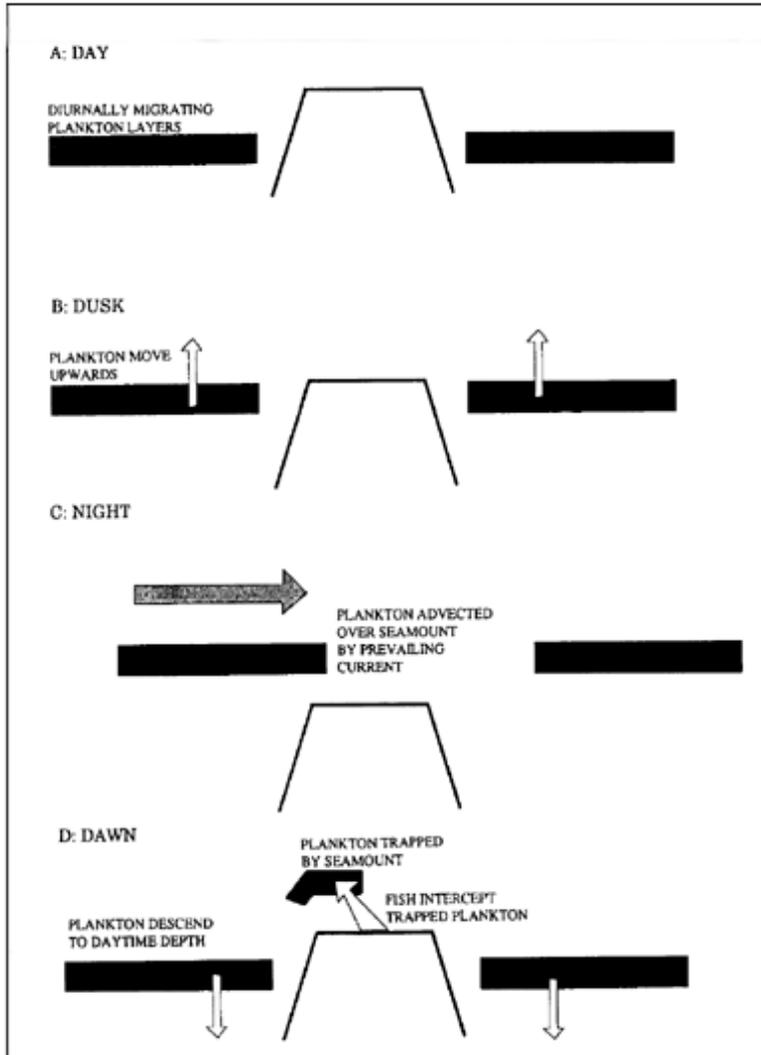
2.1.2 Seamount communities

A review of the biology of seamounts was published in the early 1990s, bringing together what was known about the species and communities found in these areas, the factors that influence the structure of seamount communities, and the effects of commercial exploitation on the associated species (Rogers, 1994). Much of the information presented here is based on that review.

The enhanced currents that sweep around the seamounts and the exposed rock surfaces provide ideal conditions for suspension feeders and it is these that often dominate the benthos. Corals can be particularly abundant on seamounts with gorgonian, scleratinian and antipatharian corals all recorded on these features particularly in areas where the current is greatest, such as on vertical walls and on the crests of seamounts with wide peaks. Other suspension feeders that may be found in abundance are sponges, hydroids and ascidians. Crinoids, holothurians, shrimps and echinoderms may also be present and, in very clear conditions macroalgae and encrusting coralline algae on shallower seamounts.

Areas of soft sediment may also occur on seamounts and in these locations xenophyophores are often the most abundant epifaunal organism (see section 2.11) with polychaetes the most common infauna of sites surveyed. Some seamounts are associated with hydrothermal venting and therefore support the specialised communities found under such conditions (see section 2.7).

Figure 7: Diurnally migrating layers of plankton (from Rogers, 1994)



The pelagic communities above seamounts have also been investigated revealing both qualitative and quantitative differences when compared to the pelagic fauna and flora in the surrounding water. One effect is that biomass of planktonic organisms over seamounts is often higher than surrounding areas, possibly as a result of upwelling around the seamount. In other cases the opposite has been observed and it has been suggested that this may be due to intensive grazing by predators or the downward migration and scattering of components such as migrating euphausiids during the day. Acoustic observations and trawls have revealed the

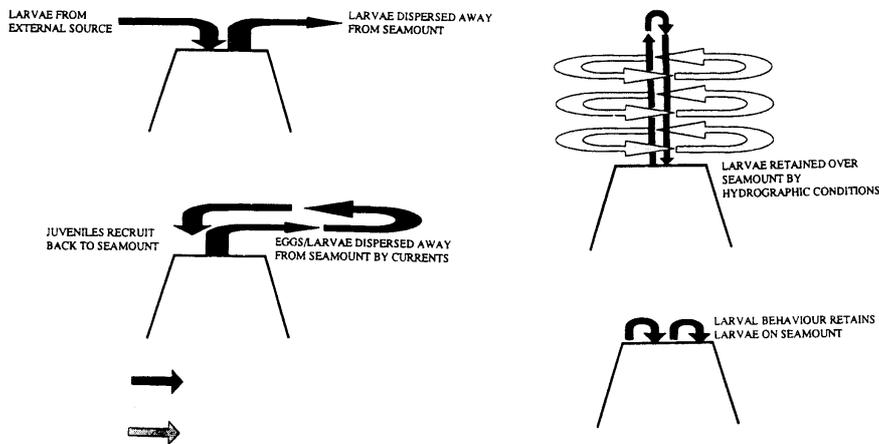
movement of nekton over the seamounts which are located at depth during the day (500-600m in the case of *Diaphus suborbitalis* which was studied on the Equator seamount in the Indian Ocean) to between 80-150m at night. This species was revealed to be feeding on diurnally migrating oceanic plankton and was, in turn, an important component of the diet of large fish species including sharks, rays, tuna and swordfish which were much more abundant around the seamount than in the surrounding oceanic waters (Parin & Prut'ko, 1985 in Rogers, 1994).

The concentration of commercially valuable fish species around seamounts is well documented. Aggregations of fish such as the orange roughy are supported in the otherwise food-poor deep sea by the enhanced flow of prey organisms past the seamounts. (Koslow & Gowlett-Holmes, 1998). It has also been suggested that zooplankton undergoing normal diurnal vertical migration are swept onto seamounts or banks by prevailing currents and trapped over the seamount as light levels increase as they are unable to complete their downward migrations (figure 7). One of the studies which has provided evidence of this was in the southern California Bight where redfish (*Sebastes* spp) were seen to be intercepting layers of downwardly vertically migrating plankton around the bank. The concentration of fish species is also likely to be influenced by other factors such as their behavioural ecology, reproduction and life histories but these aspects have still to be studied in any detail (Rogers, 1994).

There is an ongoing debate about whether seamounts support significant numbers of endemic species because of their relative isolation, the different hydrographic conditions compared to the surrounding sea-bed and the life history characteristics of the species which have colonised these areas such as the method of recruitment (Rogers, 1994). The dominant larvae at most seamounts are widespread oceanic species and they are frequently dispersed away from their parent seamount population (Boehlert & Mundy, 1993). In some species, recruitment to seamount populations appears to come from long-lived dispersive larvae that originate from other geographically removed populations (figure 8). It has therefore been suggested that the biota tended to be dominated by species inhabiting the nearest shelf areas and that seamounts might be acting as stepping stones for transoceanic dispersal of species (Wilson & Kaufmann, 1987).

Wilson & Kaufmann (1987) estimated that 15 per cent of the benthic invertebrates on seamounts worldwide were endemic to a particular seamount or local seamount group but only 598 species were reported from seamounts at that time. More than twice as many invertebrate species are now known to occur in such areas. There is morphological and genetic evidence that populations of some organisms on seamounts are distinct from surrounding populations located on other seamounts, the abyssal plain and continental shelf but this is an aspect which will no doubt continue to be subject to review as more is learnt about seamount species.

Figure 8: Models for recruitment to species on seamounts (from Rogers, 1994)



2.1.3 Conservation issues

The biological resources of seamounts have been the target of intensive exploitation over the years as they support commercially valuable fish, shellfish and corals. This has created serious problems as resources have been fished before there is a reasonable understanding of the biology of the species being targeted, and no formal stock assessment or quotas. The result has been over-exploitation and major crashes in the different stocks. Examples include the crash in populations of the rock lobster, *Jasus tristani* on the Vema seamount due to a combination of overfishing and unpredictable larval recruitment; fishing of the pelagic armourhead *Pseudopentaceros wheeleri* over the southern Emperor seamounts and seamounts in the northern Hawaiian Ridge to commercial extinction within 10 years of their discovery; and the orange roughy *Hoplostethus atlanticus* fishery on seamounts off the coasts of New Zealand and Australia where new discoveries of stocks are typically fished down to 15-30 per cent of their initial biomass within 5-10 years (Koslow *et al.*, in press).

The effects of the fishing pressure is exacerbated by the life history characteristics of some of these species. Orange roughy, for example, form large spawning aggregations near banks, pinnacles and canyons during the winter. When this is considered together with their longevity, low natural rates of mortality, slow growth and variable recruitment of fish species on seamounts, it is clear that they are very vulnerable to exploitation particularly when there is an intense and localised fishing strategy.

Corals are another group of species that have been targeted for exploitation since their discovery on seamounts in the mid-60s and depletion of traditional reserves in the Mediterranean. Red, pink, gold, black and bamboo corals have all been collected from these sites on a substantial scale. In 1983, for example, approximately 70 per cent of the world catch of red coral (about 140,000kg) came from the Emperor-Hawaiian seamounts (Grigg, 1986 in Rogers, 1994).

The effects of these commercial operations go beyond depletion of the target species. Work on seamounts off southern Tasmania has revealed extensive damage to the benthos as a result of trawling activity (Koslow & Gowlett-Holmes, 1998). Comparisons between heavily fished seamounts and those that were lightly fished showed that the habitat of heavily fished sites was predominantly bare rock with an increasing proportion of coral rubble or coral sand towards the base of the seamount. Fishers reported a large coral bycatch in the early years of the fishery and data suggest that virtually all coral aggregate living or dead has been removed leaving behind bare rock and pulverised coral rubble. Photographic evidence of the impact of fishing included trawl tracks from otter boards on the bare rock (Koslow & Gowlett-Holmes, 1998). The risk of severe depletion and even extinction of elements of the benthic seamount fauna is increased by the combination of their restricted habitat requirements and highly localised distributions that lead to high levels of local endemism.

Because most seamounts lie in international waters there has been little action to try and limit the damaging effects of the various fisheries. There are, however, examples of action when sites lie within exclusive economic zones. In 1995 interim protection was introduced for a group of seamounts south of Tasmania (Koslow & Gowlett-Holmes, 1998). The fishing industry agreed not to trawl in a previously untrawled area covering 370km² for three years to allow scientific investigations to take place so that the management options could be assessed. In light of the findings a permanent MPA was established around the seamounts in 1998 not for just the benthic community or the seamount community (which includes seamount associated benthopelagic fish) but the seamount-associated ecosystem which extends throughout the water column. A highly protected zone in which fishing and mineral exploration (including oil) is prohibited extends from 500m to 100m below the sea-bed. The water column above this, up to the surface, has been designated a management resource zone with the aim of ensuring long term protection and maintenance of biological diversity while allowing the tuna longline industry access to the surface waters. The Bowie seamount in the north-east Pacific is another example where an MPA has been established. In this case it is a pilot scheme established by the Fisheries & Oceans Canada in 1998 under Canada's Oceans Act.

2.1.4 Conservation actions

There is very little information about the biological communities of seamounts in the north-east Atlantic. Sites which are known include Anton Dohrn, a flat topped seamount (guyot) which extends from the sea-bed at 2,000m to around 700m in the central part of the Rockall Trough (figure 9), the Josephine and Gettysburg seamounts south of the Tagus Abyssal Plain, and the Milne seamounts on the south-western margins of the OSPAR maritime area. Some examples of seamounts will need to be included in any representative system of MPAs, however site selection is delayed by the fact that there are no biological research programmes focused on these features at the present time and hence little opportunity to assess their status, relative conservation importance or contribution to biodiversity in the OSPAR maritime area.

Figure 9: Bathymetry of the Anton Dohrn seamount (from Jones *et al.*, 1994)

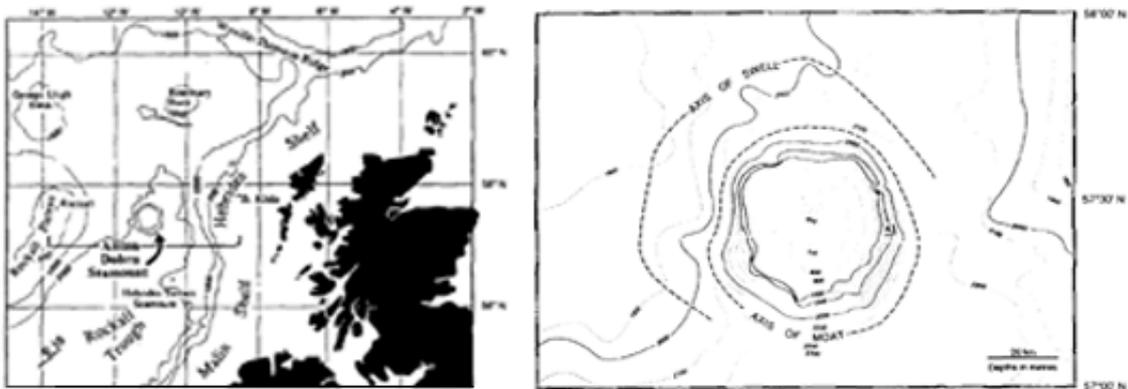
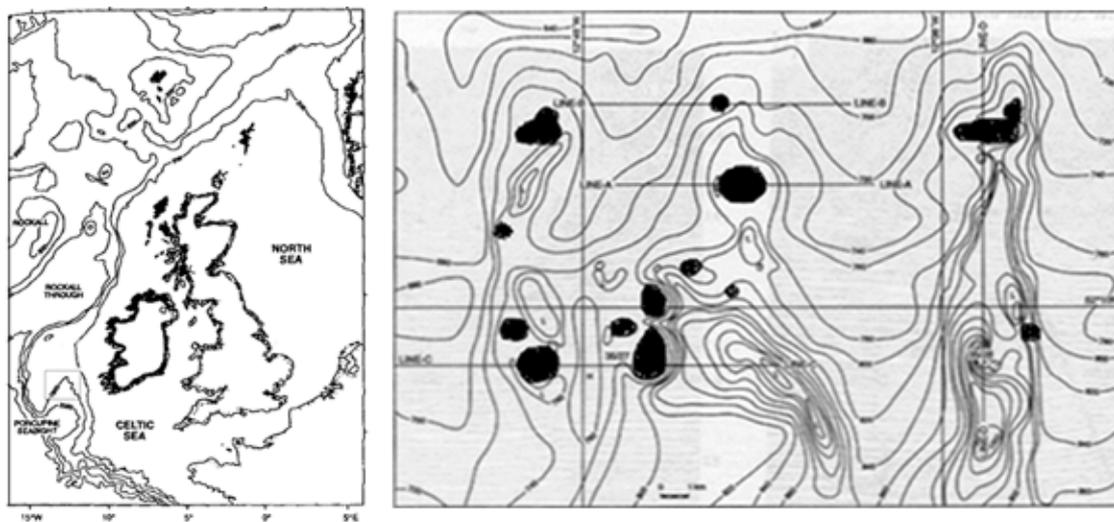


Figure 10: Detailed bathymetry of some carbonate mounds in the Porcupine Basin (from Hovland *et al.*, 1994)



Given the conservation importance of seamount habitats which have been investigated, the pressures on these features and the associated communities and species in other parts of the world, and the lack of information on the resource extraction and impacts on seamount communities in the north-east Atlantic, the identification of sites to focus research and conservation action should be undertaken as soon as possible. Site protection, combined with other measures directed at the specific activities which are a threat to the marine communities or species associated with seamounts such as restrictions or prohibitions on fishing or mineral extraction, can then be directed at these sites.

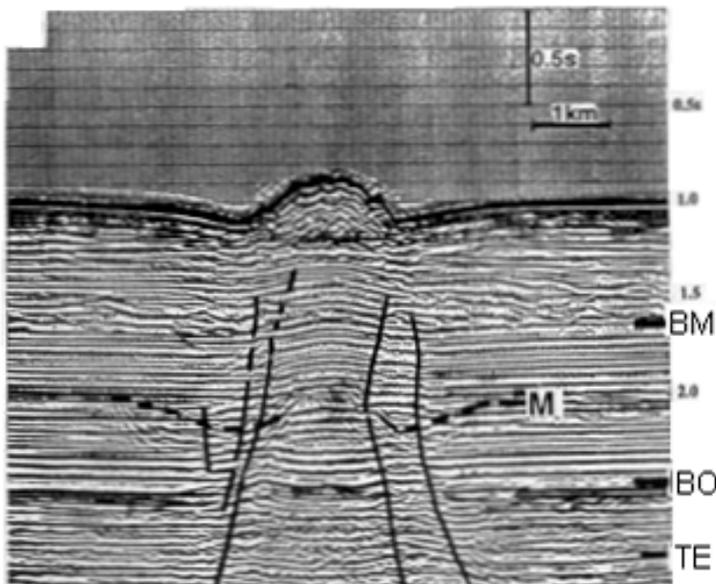
2.2 CARBONATE MOUNDS

In recent years large clusters of giant carbonate mud mounds, some more than 300m high, have been discovered off the continental margins of Europe. They are accumulations that generally occur in localised clusters and which vary in size and shape, being conical, ridged and ring shaped and, in some cases, having very steep sides. Large and small dome-shaped knolls which lie on the surface of the sea-bed have been described as well as complex knolls and pinnacle knolls (Hovland *et al.*, 1994) (figure 10). The examples in the Porcupine Basin are up to 2km long and 350m high (Kenyon *et al.*, 1998). Seismic profiles have also revealed buried mounds in the Porcupine Basin (the Magellan Reefs) some 50-100m high, but covered by tens of metres of sediment (Henriet *et al.*, 1998).

There is uncertainty and debate over the way in which carbonate mounds are formed and it may be that a variety of mechanisms are operating. In some areas the seepage of light hydrocarbons and nutrient-rich pore waters through the sea-bed might be the mechanism. The mounds studied by Hovland *et al.* (1994) from the Porcupine Basin, for example, were close to sub-surface faults so their formation could therefore be linked to sub-surface tectonic structure and deep hydrocarbon generation (figure 11). In another area, detailed studies of several sea-bed mounds at the foot of the south-eastern Rockall Trough margin show that they are most likely to be volcanic rocks, outcropping at the seafloor, and that the growth of cold water corals taking advantage of increased currents off the bottom may have contributed to their formation (Kenyon *et al.*, 1998). The Magellan Reefs, on the other hand do not show any obvious correlation with deeper faults but may instead have been caused by funnelling of methane to the surface through hundreds of seeps to the sea-bed (Henriet *et al.*, 1998).

Recent surveys of the surface mounds in the northern Rockall Trough revealed tail-like features all with a common orientation (Masson *et al.*, 1998). These are thought to be the result of interactions with the prevailing bottom water current that may distribute material originating from the mounds and or influence sedimentation downstream of the mound.

Figure 11: Sismic profile of carbonate mounds and sub-surface fault traces
(from Hovland *et al.*, 1994)



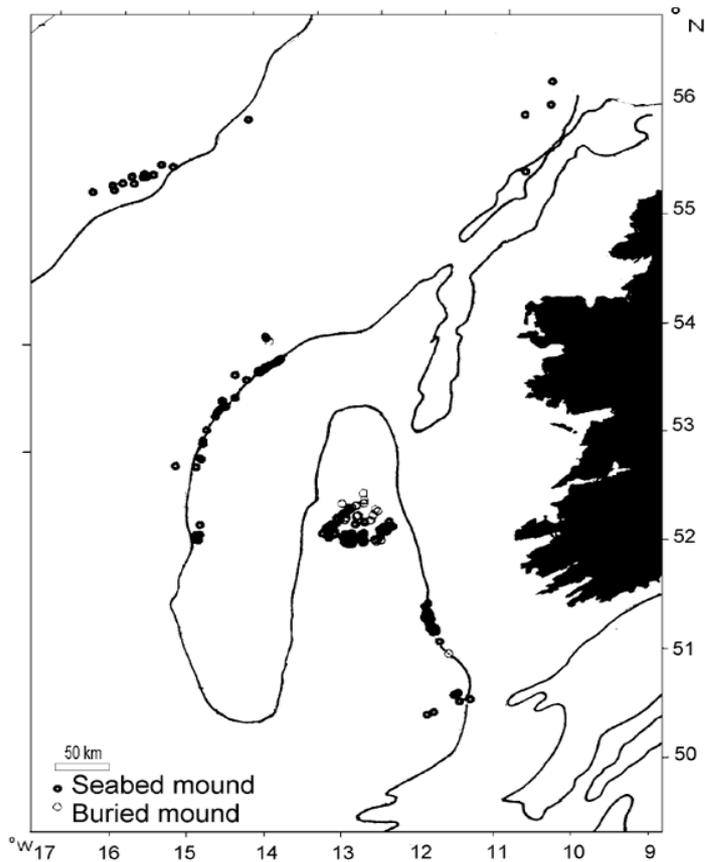
Lines indicated inferred fault plans and suspected hydrocarbon migration routes to the surface.

BM=Base Miocene; BO= Base Oligocene;
TE=Top Eocene; M=first multiple reflector

2.2.1 Occurrence in the OSPAR maritime area

Carbonate mounds are widely distributed on the eastern margin of the north Atlantic from the Iberian Peninsula to offshore Norway in water depths of 50m to perhaps 2,000m (Masson *et al.*, 1998). The findings of deep sea surveys undertaken in the last few years suggest that the European slopes of the Rockall and Porcupine basins may be the most prolific area for the formation of carbonate mounds in the world (Anon, 1999). Recent discoveries include a giant cluster of reefs including hundreds of buried mounds off south-west Ireland (Kenyon *et al.*, 1998) (figure 12) and a new field of seafloor mounds in 1000m of water in the northern Rockall Trough (Masson *et al.*, 1998)

Figure 12: Carbonate mounds off the coast of Ireland (from Anon, 1999)



2.2.2 Carbonate mound communities

Sampling of the biological communities associated with carbonate mounds have revealed that they are often dominated by suspension feeders and can support rich deep-water coral communities. Living corals have colonised some of these mounds and debris from the deep-water colonial coral (*Lophelia* sp.) has been recovered from cores as well as the surface of mounds (Kenyon *et al.*, 1998).

Surveys of the Porcupine and Rockall banks have indicated that the summits and upper slopes of most of the carbonate mounds and knolls identified on sidescan sonar were covered by a carpet of coral debris. Living coral was also present with the most abundant species being the colonial corals *Lophelia pertusa* and *Madrepora oculata* which formed colonies up to 30cm high. The solitary coral *Desmophyllum cristagalli* and the octocoral *Stylaster* sp. were also occasionally present and nearby areas of cobbles and small boulders provided a surface for settlement of individual coral colonies (Wilson & Vina Herbon, 1998).

Sampling of the fauna from Porcupine Basin carbonate mounds revealed that although most of the animals were suspension feeders there were also deposit feeding, carnivorous or omnivorous species. (Sumida & Kennedy, 1998). The branching structure of dead coral underlying the living colonies provided a surface for settlement which was also elevated from the sea-bed and was extensively colonised by sponges, bryozoans, hydroids, soft corals, ascidians, calcareous tube

worms, zoanthids, crinoids and bivalves. Many large eunicid worms and sipunculids were also found burrowing inside the coral material, perhaps using the coral for shelter. The suspension feeding ophiuroid *Ophiactis balli* was also abundant, sheltering in the dead coral material and the suspension feeding bivalve *Astarte* sp. abundant in the sediment underlying the thickets at some sites.

The area around carbonate mounds can also support an abundance of species. In the case of the Porcupine Basin there was extensive evidence of the working of the sediment apparently by echiuran worms, cerianthid anemones and caridean shrimps (Wilson & Vina Herbon, 1998). Whereas the tail-like features downstream of carbonate mounds in the northern Rockall Trough showed high densities of the xenophyophore *Syringammina fragilissima* compared to numbers in the background sediments. There was also a slight increase in the density of metazoan invertebrates on the tails and mounds relative to the background (Masson *et al.*, 1998) (box 2). The reason for this clustering is unclear at the present time.

A number of factors may have influenced the development of these rich communities. Elevation from the surrounding sea-bed, a suitable surface for attachment, and shelter among the branching structure of the corals can all play a part. It has also been suggested that, in areas where hydrocarbon seepage might be a mechanism for mound formation, there is localised eutrophication, providing nutrients for bacteria which, in turn, act as a food source for colonial, cold water ahermatypic corals (Hovland *et al.*, 1994).

Box 2: Biological characteristics of three types of seafloor mound surveyed in the northern Rockall Trough (from Masson *et al.*, 1998)

Feature	Background	Tail	Mound
Acoustic parameters			
Sidescan backscatter	Low	Moderate	High
Bathymetric profile	Level	Level	Elevated
10 kHz return strength	Normal	Normal	Reduced
Faunal density (/100m²)			
Xenophyophores	2.1	32.8	29.5
Invertebrates	1.6	2.3	4.3
Fish	4.5	5.2	5.4
Other observations			
invertebrate detritivore /sestonivore ratio	14	5.5	1.0
Xenophyophore predator density (/100m ²)	0.3	0.9	0.8
Observations of coral	None	Single, apparently, isolated colony attached to glacial erratic boulder fields.	7 occurrences of coral with associated debris Number of coral colonies ranges 1 to 70

2.2.3 Conservation issues

Carbonate mounds and their associated marine communities have been the subject of study during a number of deep sea expeditions in recent years and they continue to be a focus for research. Much clearly remains to be learnt about these features and the biological communities they support however, the presence of coral colonies and coral debris on these structures has already raised conservation issues.

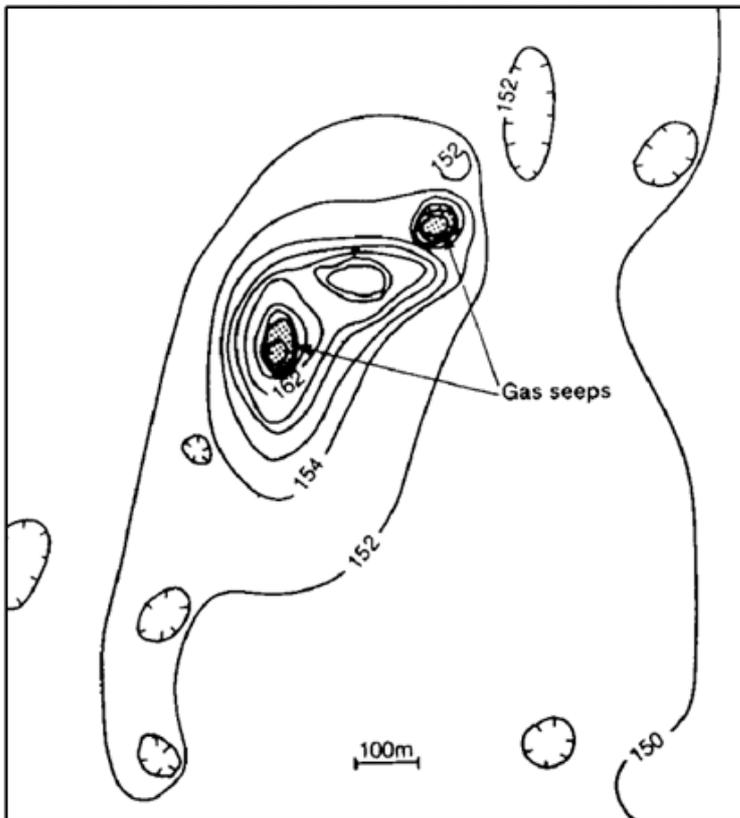
Some surveys have reported extensive carpets of dead corals and only small colonies of living coral on carbonate mounds, suggesting that conditions were suitable for the growth and development of the coral banks at some stage but that this is no longer the case (Kenyon *et al.*, 1998). Possible reasons put forward to explain this are natural changes in the current regime, sea temperature and food supply to the area. Another possibility is that the paucity of living coral is linked to fishing activity which is very intensive in some of the areas where mounds occur and that repeated trawling does not allow time for the continual growth of coral colonies.

Coral colonies will clearly be vulnerable to sea-bed disturbance and therefore management of such activities in the vicinity of carbonate mounds may need to be considered. There is also a need to distinguish between impacts caused by human activity and natural fluctuations over long periods of time.

2.2.4 Conservation actions

The mapping of carbonate mounds is an ongoing task and, as a consequence, the full extent and distribution of these features in the OSPAR maritime area is still to be determined. Major clusters are already known to occur in the Porcupine Basin and the Rockall Trough however, and it is these sites which are the focus of current study and for which most is known. These locations are, therefore, the logical places to start determining the conservation importance of carbonate mounds and their associated marine communities to see if there are any regional differences in the marine life they support, to assess their contribution to the biodiversity of the deep sea in the OSPAR maritime area and identify potential MPAs.

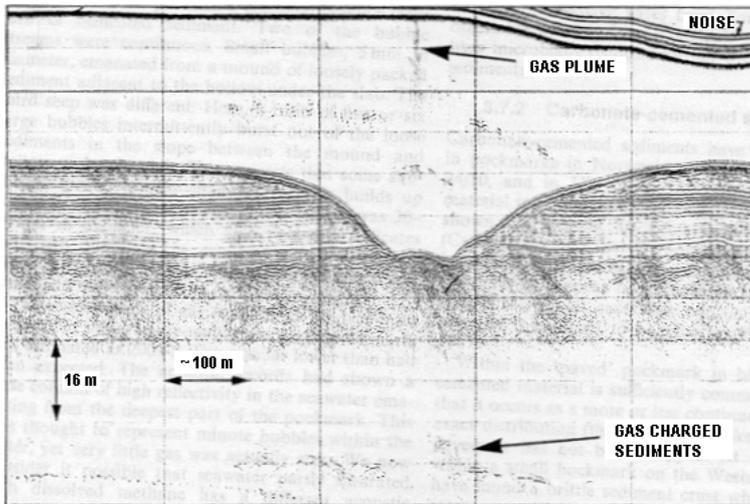
Figure 13: Bathymetry of an active pockmark in UK block 15/25 (from Hovland & Judd, 1988)



2.3 Pockmarks

Pockmarks are crater-like features on the sea-bed, occurring in areas of soft sediment and which can measure several hundred meters across and tens of metres deep (figures 13 & 14). They were first seen in the North Sea in 1970 and are believed to be formed by the rapid expulsion of gas and liquid through the sea-bed, which displaces the fine-grained sediment to form craters (Hovland & Judd, 1988). Slabs and crusts of methane-derived carbonate cement have been found in pockmarks providing additional evidence that they are formed by gas seepages and that they are still active. They are thought to maintain their form by subsequent intermittent expulsion of methane and seepage of CO₂ from sediment pore-water (Hovland & Thomsen, 1989). Seismic profiles have also revealed the presence of buried pockmarks in the North Sea (Long, 1992).

Figure 14: Shallow seismic profile across active pockmark in UK block 15/25 (from Hovland & Judd, 1988)



The source of the gases that lead to the creation of pockmarks in the North Sea appears to be the petroleum in the Kimmeridge Clay which is the principal source rock of the northern North Sea. The grain size, permeability, and shear strength of the sea-bed surface sediment, as well as the rate of gas emission are all factors which determine whether or not pockmarks will form (Hovland & Judd, 1988). Where the sediment is fine grained and soft it can be eroded by the escaping gas but in other cases, for example if the sediment is composed of stiff clays, erosion does not take place and therefore pockmarks are not visible even though gas may be actively seeping from the sea-bed.

Analysis of the seepage gases reveal that they are generally pure methane whereas the interstitial gases contain not only methane but also ethane, propane, butane, pentane and hexane. The heavier hydrocarbons therefore appear to be adsorbed on the mineral grains of the clay sediments while the methane passes through (Hovland & Judd, 1988).

The shape and size of pockmarks depends on the sediment type and the gas and pore-water seepage rate. Seven different types have been described (box 3) all of which, apart from strings of pockmarks, have been recorded in both the Norwegian Trench and the Witch Ground Basin in the North Sea.

They are generally about 50m wide and 3-4m deep in silty clays but can be much larger. The example shown in figures X & Y was roughly oval in shape, 450m wide, 700m long and 17m deep (Hovland & Judd, 1988).

Box 3: Pockmark morphology (from Hovland & Judd, 1988)

Pockmark type	Description
<i>Standard circular & elliptical pockmarks</i>	Probably most common. Orientation can be aligned to topography or water currents.
<i>Composite pockmarks</i>	Where a number merge with each other.
<i>Asymmetric pockmarks</i>	Have a distinct and often quite lengthy 'tail'.
<i>Pockmark strings</i>	Only in the Norwegian Trench. Individuals are commonly symmetrical shallow and 10-15m in diameter. Strings or chains may extend for 100-150m in a straight line.
<i>Elongated pockmarks & troughs</i>	Resemble gullies or troughs. One known example is more than 1km long and about 200m wide and corresponding with a furrow that may be an iceberg plough mark.
<i>Unit pockmarks</i>	Very small (<5m) sea-bed depressions found in isolation, groups and in association with larger pockmarks.
<i>Fresh pockmarks</i>	Unusually large features which are surrounded by unit pockmarks.

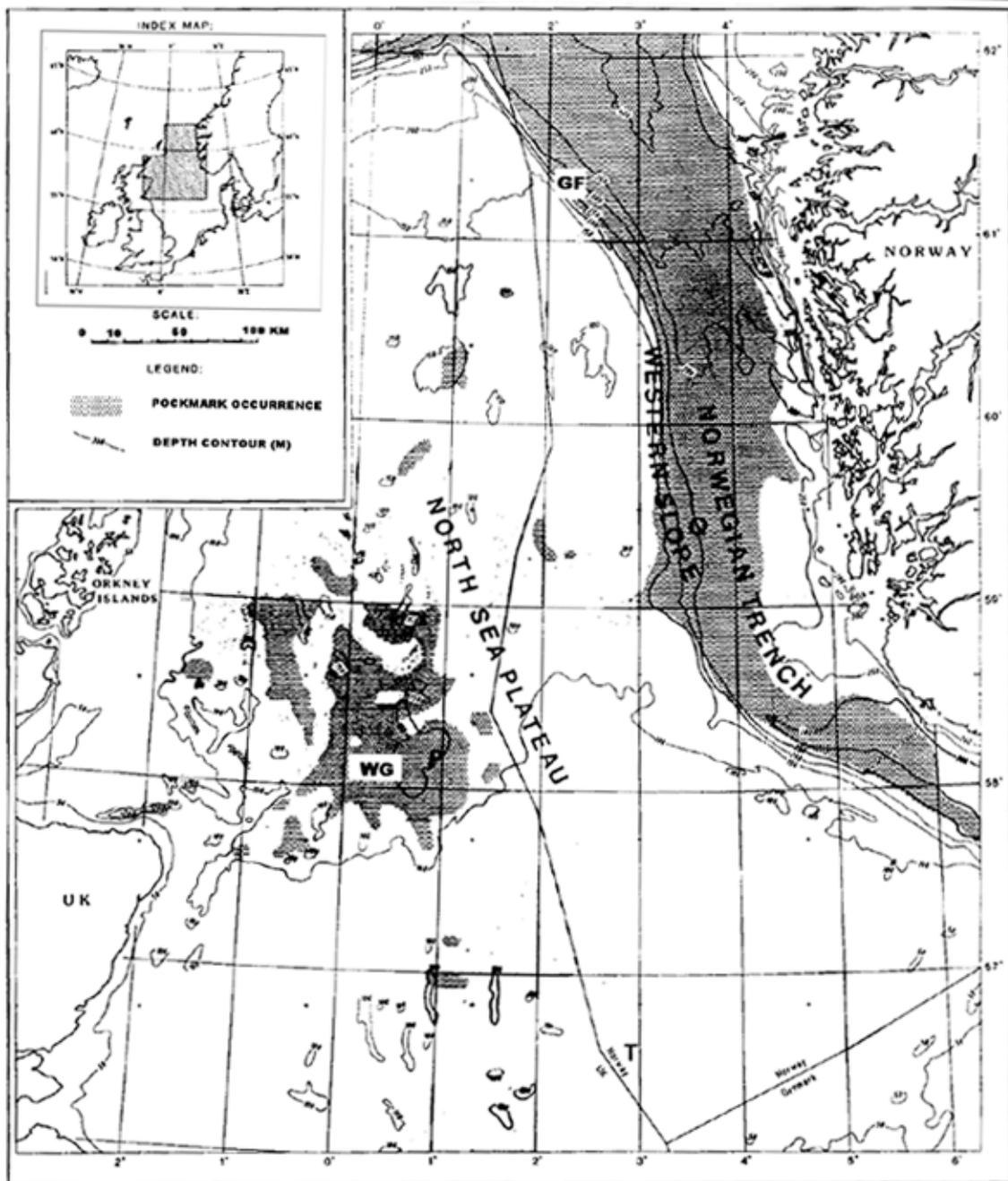
2.3.1 Occurrence in the OSPAR maritime area

Pockmarks occur on the sea-bed throughout the world's oceans. They are particularly common in the North Sea but appear to be limited to the northern region (none have been located south of the 56 parallel) which is assumed to be a function of the sea-bed sediment types rather than the absence of gas seepages (Hovland & Judd, 1988).

The soft clays and muds of the North Sea provide an ideal medium for the formation of pockmarks where gas is or has been escaping and they are only preserved because of the stability of the sea-bed. The three main areas where they have been mapped are in the Norwegian Trench, the Witch Ground Basin and on the North Sea plateau (figure 15). Only a small percentage of the pockmarks in the North Sea are believed to be continuously active (Hovland, 1984).

Figure 15: Occurrence of pockmarks in the northern North Sea (from Hovland & Judd, 1988).

GF – Gullfaks Field WG – Witch Ground Basin T – Tommeliten

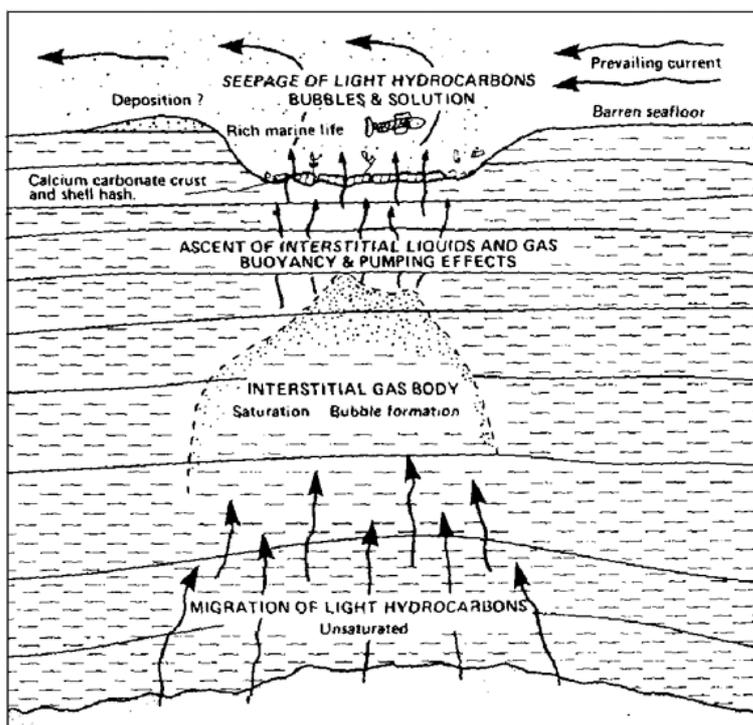


2.3.2 Marine communities associated with pockmarks

One of the observations made during surveys of pockmarks is the greater diversity and abundance of marine life in the vicinity of these features. There has been some debate about why this occurs and whether production in these communities is enhanced by a bacteria-based food web, based on the methane seeping from the sea-bed in a similar way to other chemosynthetically based communities that have been found in the deep sea (see section 2.7).

The fauna of pockmarks is especially abundant in bivalves, shrimps, bryozoans, starfish, hydroids, sea anemones and sea pens (Hovland & Judd, 1988; Hovland & Thomsen, 1989). Fish accumulate in these areas as well and may be attracted by the abundance of food and shelter (figure 16).

Figure 16: Diagram of assumed biological significance of pockmarks (from Hovland & Judd, 1988)



The most abundant and varied visible pockmark fauna are found inside carbonate-paved pockmarks and inside the small 'eyed' pockmarks at Tommeliten. Thirty eight different species, including some that were unidentified, were found in and on a small carbonate-cement rock sample, for example (box 4). Other observations include a higher abundance of large fish (notably Torsk *Brosme brosme*, wolf fish *Anarhichas lupus* and Norway haddock *Sebastes viviparus*), shrimp, krill and squat lobster inside pockmarks than outside. The apparently higher particulate matter including plankton and detritus, and the presence of bacterial mats has also been reported and may be particularly significant if they are acquiring energy from the methane to support a chemotrophic food chain (Hovland & Judd, 1988). Dense accumulations of dead and living bivalves have also been found inside pockmarks in some sites (for example, Tommeliten). They occur in banks a few metres to several tens of metres across and it has been suggested that they concentrate in these areas as the organic matter suspended by the seeps may be a good source of food or perhaps because the gills contain methane-oxidizing bacteria.

Box 4: Species associated with North Sea pockmarks (from Hovland & Judd, 1988).

Species identified inside some North Sea pockmarks

Bivalves *Arctica islandica*; *Pseudamussium septemradiata*
Shrimps *Pandalus borealis*; *Spirontocaris lilljeborgii*
Squat lobsters *Nephrops norvegicus*; *Calocaris macandreae*
Fish Ling (*Molva molva*); Torsk (*Brosme brosme*); Norway haddock or Red fish (*Sebastes marinus*);
Catfish or Wolf-fish (*Anarrhichas lupus*); Cod (*Gadus morhua*)

Species found on and inside carbonate-cemented sediment from a pock-mark in Norwegian block 25/7

Annelids: *Eunice sp.*; *Chaetopterus variopedatus*; *Serpula vermicularis*; *Spirobis sp.*
Ascidians: *Ascidia virginea*; *Ascidia sp.*; *Styela sp.*
Barnacles: *Verruca stroemia*.
Bivalves: *Modiolus phaseolinus*; *Hiatelia arctica*; *Monia patelliformis*;
Pseudamussium septemradiata; *Chlamys sp.*; *Ardira islandica*; *Thyasira flexuosa*.
Brachiopods: *Terebratulina caputserpentis*.
Brittle stars: *Ophiopholis aculeata*; *Ophiothrix fragilis*; *Ophiactis abYssicOla*; *Ophiura albida*.
Bryozoa: *Sertelia beaniana*; *Berenicea patina*.
Chitons: *Lepidopleurus asellus*.
Echinoids: *Strongylocentrotus drobachiensis*.
Gastropods: *Trivia arctica*.
Hydroids: *Hydroides norvegicus*.
Isopods: *Janira maculosa*.
Sponges: *Placostegus tridentatus*; *Microserpula sp.*

An investigation of a large pockmark (600 x 300m with a maximum depth of 18.5m below the surrounding sea-bed of 150m) noted that the fauna was characterised by two species not previously reported from the Fladen Ground. These were a bivalve *Thyasira sarsi* (which is known to contain endosymbiotic sulphur-oxidising bacteria) and a mouthless and gutless nematode *Astromonema sp.* which was the dominant meiofauna species in the pockmark sediments and which also contains endosymbiotic bacteria (Dando *et al.*, 1991). The view from this study however, was that the methane carbon from the methane seep was not contributing to the carbon of the surrounding infauna on a significant scale but that the greater density of visible fauna may be due partly to the hard substrate (carbonate cement slabs and shells) providing a habitat for anthozoans and bryozoans and partly to resuspension of the bottom sediments by escaping gas. This could provide additional food for filter feeders and small fish would be more abundant due to the shelter provided by rocks and shell debris. The bivalves, euphausiids and other organisms which are concentrated in these areas also seem to be species known from the surrounding background community rather than specialists as in deep sea vent sites.

2.3.3 Conservation issues

The original studies of pockmarks in the North Sea were undertaken in order to assess whether they raised any safety issues for North Sea oil exploration and production which was gathering pace at that time. The discovery of concentrated and abundant marine life in these areas was not an issue at first but it has since become of interest for a number of reasons. There has, for example, been discussion of whether chemotrophic bacteria support the food chains in these

areas and therefore whether there may be species which have specialised to take advantage of this source of food in the same way that deep sea hydrocarbon seeps support a specialised fauna. While this has not proved to be the case it is nevertheless apparent that the distribution and abundance of the benthos and some mobile species are affected by pockmarks. The presence of the hard substrate provided by the carbonate cement in an environment that is dominated by soft sediment is probably a factor, but there is also a higher diversity of species which colonise soft sediments or which are mobile in these areas compared to the surrounding sea-bed in the northern North Sea. Another factor may be less impact from the heavy demersal fishing pressure on the North Sea but this is speculation at the present time.

2.3.4 Conservation actions

The issue of whether any conservation action should be focused on the marine communities found in North Sea pockmarks has not been given any consideration to date. A number of reasons may account for this including the fact that no specialised fauna have been found in these areas and the fact that they are very common in some parts of the North Sea. The associations and density of marine life in these areas does, nevertheless, make them different from surrounding areas and a distinct habitat in the North Sea. Conservation programmes that seek to include representative examples of marine habitats and communities in networks of protected areas should therefore include such sites. Other considerations should be to continue to investigate aspects relating to the formation, longevity and ecology of pockmarks and whether the deeper pockmarks provide any refuge from fishing gears which impact the sea-bed.

The Norwegian Trench - Pockmarks exist along most of the Norwegian Trench including some parts of the Skagerrak. They are present throughout most of the area covered by the youngest sediments although generally most common along the western slope. Many of the examples are aligned parallel to the slope. The smallest examples have been found in the Tommeliten area whereas those in the Norwegian Trench are up to 15m deep and 100m wide formed in soft, silty clay.

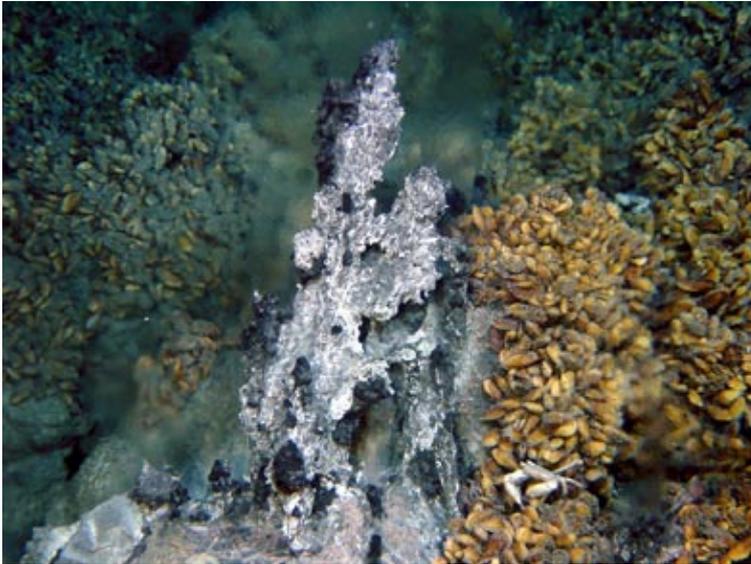
Witch Ground Basin - Pockmarks are common in the Witch Ground Basin, a depression in the plateau area of the central North Sea. They are typically 50-100m across and 2-3m deep although active pockmarks may be up to 400m wide and 17m deep. Many of the pockmarks in this area have a lengthy tail. Pockmarks have been recorded at densities of up to 40 per km² in this area.

North Sea plateau - The pockmarks in the North Sea plateau have been found in hollows and channels with reports of up to 20 per km² in one hollow.

2.4 Hydrothermal Vents

Deep sea hydrothermal vents and the marine life associated with them were discovered in 1977 during a manned submersible expedition off the Galapagos Islands. Since then the chemical, geological and biological characteristics of these areas have attracted a great deal of attention as they are dramatically different from other deep sea habitats. The most striking contrast is that water temperature in the deep sea is generally between 4°C and -1°C, but at hydrothermal vents superheated water emerges from the sea-bed in concentrated jets which can reach temperatures of nearly 400°C.

Plate 1a: Vent Species



Extremely dense musselbeds (*Bathymodiolus azoricus*) and deep-water scavenging crabs (*Chaceon affinis*) right next to the hot water source (copyright ATOS/Ifremer).

The hydrothermal activity around vents is caused by seawater penetrating the upper layers of the Earth's crust through channels formed in cooling lava flows. The water reacts chemically with hot basalt in the Earth's crust and then rises back to the sea-bed to emerge as superheated water containing compounds such as sulphides, metals, carbon dioxide and methane (Tunnicliffe *et al.*, 1998). The water may bubble out from cracks and crevices on the sea-bed as hot springs (5-60°C) or emerge in concentrated jets of very hot water (270-380°C). In the latter case, as the water cools, the dissolved minerals precipitate out in black clouds to form large chimneys which are known 'black smokers'. At slightly cooler temperatures the sulphides are mostly precipitated within the rocks and sediment so the venting fluids appear cloudier and are known as 'white smokers' (Gage & Tyler, 1991). The tall chimneys formed around the vents and the surrounding sediments are almost pure metallic sulphides and are a unique geological feature of hydrothermal vents (Tunnicliffe *et al.*, 1998).

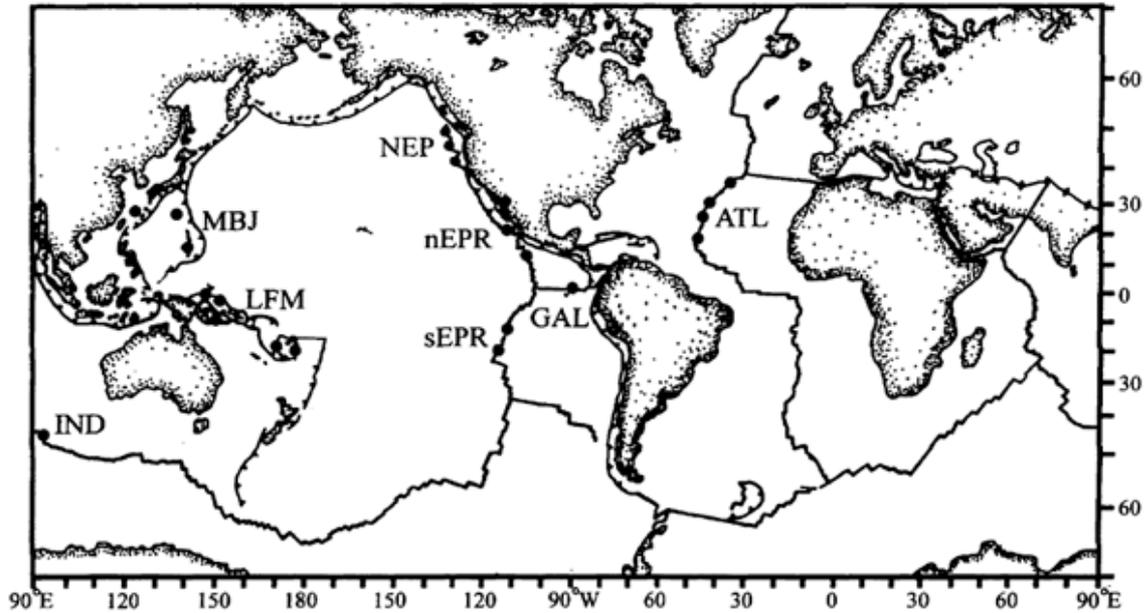
Hydrothermal vents are most commonly found where ridges of the Earth's plates are actively spreading. On fast spreading ridges, such as the east Pacific rise at 13°N, vent sites appear to have a short lifetime (generally no longer than about 100 yrs) and the zone of hydrothermal activity shifts along the ridge. On slow spreading ridges such as the mid-Atlantic Ridge, the hydrothermal activity is spatially more focused and stable over the long term, even if the lifetime of an individual vent site is similar to that on fast spreading ridges (Comtet & Desbruyeres, 1998).

2.4.1 Occurrence in the OSPAR maritime area

Since hydrothermal vents were first discovered, researchers have found similar habitats in nearly all the areas of deep sea tectonic activity which have been investigated. Vents have been reported from the Pacific, Indian and Atlantic oceans and not only associated with spreading

centres but also subduction zones, fracture zones and back-arc basins (spreading centres associated with subduction processes in deep trenches) (Gage & Tyler, 1991) (figure 17).

Figure 17: Distribution of major vent sites around the world (from Tunnicliffe *et al.*, 1998)



IND - south-east Indian Ridge, LFM - Lau, Figi, Manus Woodlark & Lihir sites, MBJ - Marianas, Bonin & Okinawa, NEP - Explorer, Juan de Fuca & Gorda Ridges, nEPR - 9°-21° N East Pacific Rise, GAL - Galapagos Rift, sEPR 17°-25°S, ATL - mid-Atlantic Ridge

Active hydrothermalism occupies only a small portion of the spreading ridges; thus the available habitat occurs at irregular intervals. The interval between vents depends on the nature of both volcanism and tectonism of that ridge. Searches for vents are concentrated within the axial valley of a ridge but off-axis venting may be more prevalent than currently appreciated as water does circulate on a large scale through the flanks of ridges (Hekinian & Fouquet, 1985).

Vents and their associated communities are transient and variable not only on short time scales of days and seconds but also over decades. Variability in the hydrothermal discharge causes changes in the animal communities associated with vents. As a consequence, the vent fauna must adapt to unstable environmental conditions and nutrient supply by rapidly colonising new vents (Comtet & Desbruyeres, 1998). Evidence for the longer term variability can be seen in accumulations of dead giant bivalve shells which, as they are known to only persist for about 15 years before being dissolved, must indicate quite recent change in conditions. Geophysical and geochemical evidence suggests short bursts of hydrothermal activity lasting decades or less. The habitat is neither permanent nor contiguous; dispersal and migration are the major links between neighbouring vents (Tunnicliffe *et al.*, 1998).

2.4.2 Vent communities

Hydrothermal vents support some of the most unusual animal communities on the planet. The species which survive in these surroundings must be able derive energy under conditions where photosynthesis is not possible, to tolerate great extremes and variability in the temperature and the chemical composition of the surrounding water, and cope with potentially toxic concentrations of various heavy metals. Animals which have adapted to this environment include the giant vent clam *Calyptogena magnifica*, the mussel *Bathymodiolus thermophilus*, the tube worm *Riftia pachyptila*, crabs such as *Cyanograea praedator* and *Bythograea thermydron*, and two species of shrimp from a new family (Bresiliidae) *Rimicaris exoculata* and *R.chacei*.

Plate 1b: Vent species

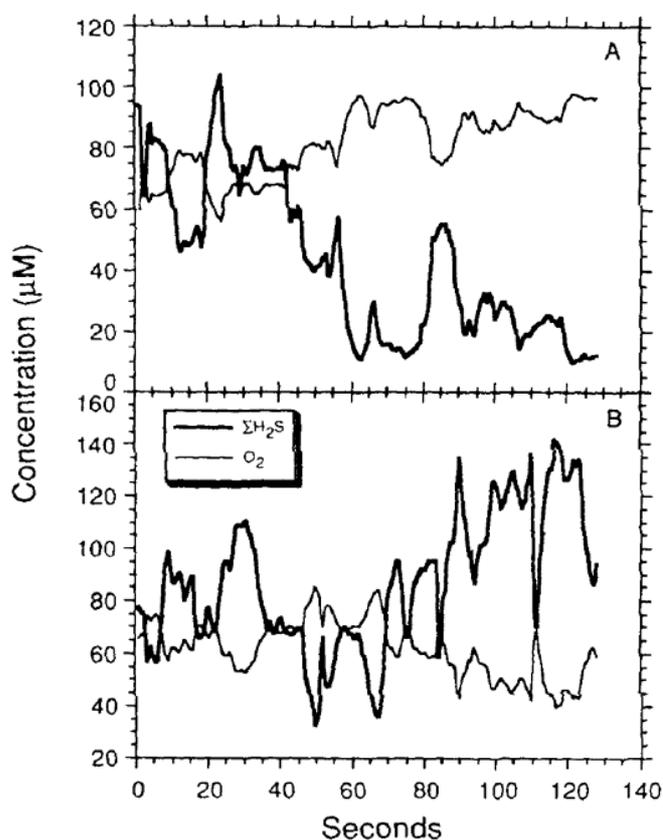


Photo by kind permission of Daniel Desbruyeres, IFREMER. (Lucky Strike hydrothermal vent showing densely populated mussel bed (*Bathymodiolus azoricus*) with associated shrimps (*Charocaris fortunata*)).

Most vent species occur where the temperature does not exceed 30°C and hydrogen sulphide content is less than 400µM although they can be found in areas where the water temperature is as high as 50°C (Childress & Fisher, 1992). The variable flow through the sides and top of the chimneys therefore supports a complex mosaic of animal patches in the vicinity of the vents but not in the vents themselves. The main reason for this is that primary production around the vents is dependent on chemoautotrophic bacteria that derive energy from sulphur-containing inorganic compounds. The bacteria, which are found in the gills and tissues of some vent species such as the clams and vestimentiferan worms, as well as being free-living on the basalt rock surfaces or the shells and tubes of nearby animals, use compounds from both the venting waters and the surrounding seawater to derive energy. The most favourable areas for colonisation by these primary producers is therefore near enough to the venting waters to take up sulphide before it is oxidised or too diluted, but far enough away to take up an oxidant from the surrounding seawater (Childress & Fisher, 1992).

In much of the deep sea, animals live with very narrow, stable temperature ranges. Vent animals, on the other hand, must be able to tolerate high concentrations of toxic metals and sulphides, low concentrations of O₂ and respond quickly to rapid fluctuations as well as a wide range of temperatures. Studies of the temperature and chemical composition of the water around vents have revealed that the vent and ambient waters are not well mixed in the areas where the animals live. This means that species colonising these areas are exposed to discrete parcels of water, of the more extreme properties over periods of seconds as well as on longer time scales, such as through daily variations in vent flows (figure 18). Because of these extremes it has been said that the thermal environment of vents has more in common with the high intertidal zone than the deep sea (Childress & Fisher, 1992).

Figure 18: Short-term fluctuations in H₂S and O₂ (from Childress & Fisher, 1992)



The specialised adaptations which allow organisms to exploit vent habitats include major reorganisation of internal tissues and physiologies to house microbial symbionts, biochemical adaptations to cope with sulphide poisoning, behavioural and molecular responses to high temperature, presence of metal-binding proteins and development of specialised sensory organs to locate hot chimneys (Tunnicliffe *et al.*, 1998). The result has been specialised faunas which are rarely found in other environments. They are also not a very diverse group of species but because they can exploit an abundant energy source around vents they are often present in very

high densities (Childress & Fisher, 1992). The most numerous and conspicuous organisms are those which have developed symbiotic relationships with chemoautotrophic bacteria and it is these species which dominate the primary production in the vent community.

Vent waters throughout the world have great similarity from the point of view of organisms: the major controls on composition are seawater and host rock (basalt) chemistry neither of which shows gross differences around the globe. Biologically important factors such as heat and dissolved concentrations of sulphides, iron and manganese show far more change in the few years after an eruptive event on a single ridge segment than among sites around the world (Butterfield *et al.* 1997). Despite this, it is apparent from studies to date that the fauna on Atlantic vents are less varied and different from those in the Pacific.

Vestimentiferan tube worms and bivalve molluscs which are common at Pacific sites are absent in Atlantic vents. Instead, the dominant animals are bresiliid shrimps with *Rimicaris exoculata*, a species whose adult stage appears to depend on exosymbiosis with sulphur bacteria, being particularly abundant. These shrimps ingest sulphide particles from 350°C black smoker chimneys from which they appear to graze associated free-living micro-organisms (Gebruk *et al.*, 1997). At the Luck Strike vent field the fauna is dominated by dense beds of a new species of mussel of the genus *Bathymodiolus*, as well as supporting a totally novel amphipod fauna including a new genus, and the echinoderm *Echinus alexandri* (Van Dover *et al.*, 1996). The presence of several new taxa and species emphasises that study of vent faunas is still at a relatively early stage. Undoubtedly further new species will be identified as exploration continues. At the same time, more needs to be learnt about major issues such as the role of invertebrate/bacteria symbioses in the trophic structure of the communities, the influence of depth on the community structure; reproduction and life history, and modes of dispersal of larvae and colonisation (Gebruk *et al.*, 1997). A long-term multidisciplinary research programme known as MOMAR (Monitoring on the mid-Atlantic Ridge near the Azores) has been set up for study of the biological and physico-chemical activity at the four known vent sites south of the Azores (Menez Gwen, Lucky Strike, Saldanha and the Rainbow vents).

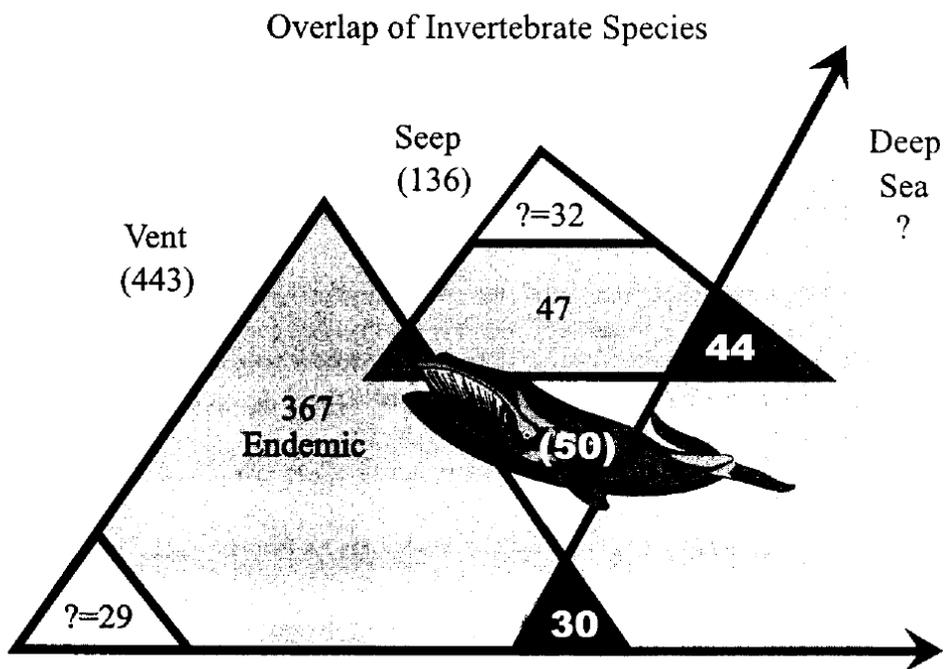
Studies comparing vent faunas and those of other sulphide-rich environments show some similarities in their mode of nutrition but relatively little overlap in the species. Only a small percentage of more than 440 species recorded from hydrothermal vents have been found around hydrocarbon seeps or on decaying bones on the ocean floor (figure 19). Consequently these habitats are not currently considered to be dispersal stepping stones for vent fauna (Tunnicliffe *et al.*, 1998)

2.4.3 Conservation Issues

The unusual nature of the marine communities that occur around hydrothermal vents makes them particularly important areas in terms of the biodiversity of the deep sea as well as being a focus for deep sea research. There are regular expeditions to the well-known sites to make observations and measurements, deploy instruments and collect specimens of the marine life, seawater and rocks. As many of these sites only cover a small geographic area and include relatively fragile structures, they can be under considerable exploration pressure. At some sites this has already reached a point where man-induced changes in the distribution and occurrence of vent fluid flows, and of associated vent communities, have been documented (Mullineaux *et al.*, 1998). On the other hand scientists are now able to keep some species alive in aquaria for

several months enabling longer-term studies to take place under laboratory conditions and providing study opportunities to more scientists without repeated disturbance to the biological communities *in situ* (Santos, *pers com*). A research programme is being established in the Azores to take this work to the next stage.

Figure 19: Overlap of invertebrate species among sulphide-rich habitats and the deep sea
(from Tunnicliffe *et al.*, 1998)



The need for better co-ordination and co-operation between the different groups interested in hydrothermal vents has been recognised as has the fact that some research techniques are incompatible (monitoring undisturbed systems versus manipulation of the system, for example). As a consequence, a case has been made for establishing research reserves at hydrothermal vents (Mullineaux *et al.*, 1998). A web-based information site on deep sea reserves at hydrothermal vents has been set up on the InterRidge website as a forum where researchers can propose vent reserves and where others in the oceanographic community can respond to them. The Canadian government has proposed the Endeavour vent field on the Juan de Fuca Ridge in the Pacific as a pilot marine protected area while in the OSPAR area, co-operative sampling effort has been proposed to minimise disturbance of the Eiffel Tower and 'PP24' chimneys in the Lucky Strike vent field.

Apart from research expeditions, it can be expected that hydrothermal vents will also be subject to pressures from other activities. Tourist trips to hydrothermal vents were advertised for the first time in 1999 and there are proposals for the extraction of minerals and metals from vent habitats in the South Pacific. Where such activity is proposed for locations in the high seas

voluntary agreement on procedures, limits and approaches is the first necessary step and one which is being pursued by the research community working on hydrothermal vents.

2.4.4 Conservation actions

The need for care in the exploration and research of hydrothermal vent communities has been recognised by those studying these unusual deep sea habitats. Research protocols, co-ordinated studies and protected areas are among the ideas being taken forward by scientists working on these communities. The three vent fields in the OSPAR maritime area which are most well known at the present time are Menez Gwen, Lucky Strike and the Rainbow vents (figure 20) and these are therefore the most likely focus for such actions at the present time.

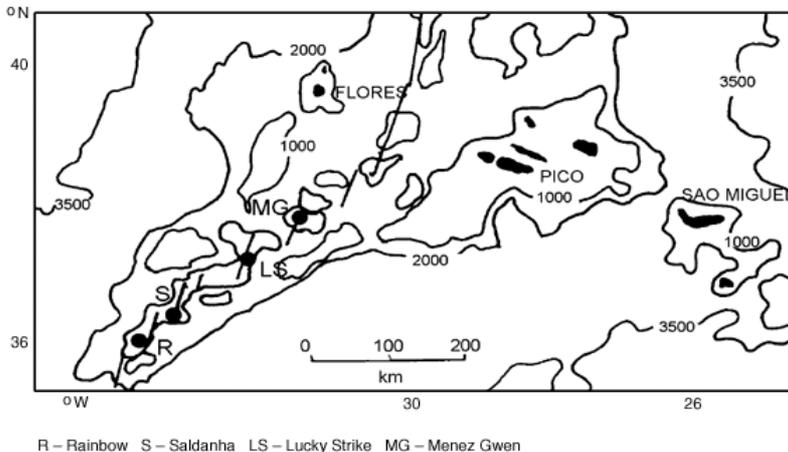
Menez Gwen (37°51'N, 30°02'W)

The Menez Gwen vent field lies in particularly shallow water at a depth of 855m extending over approximately 200m² which is a much smaller area than the other vent fields so far discovered on the mid-Atlantic Ridge. The fauna is dominated by mussels but is also colonised by crabs. It has been suggested that the hydrothermal activity at this site is relatively recent which provides an opportunity to study the early stages of hydrothermal activity at a slow spreading ridge. (MOMAR webpage).

Lucky Strike (37°18'N, 32°16'W)

The Lucky Strike vent field was discovered in 1993. It covers an area of approximately 150,000m² with 21 active chimney sites, making it one of the largest known hydrothermal areas discovered so far. The site extends over a depth range of 1,620-1,730m with the chimneys around a fossil lava lake in the central caldeira of an axial volcano. The marine life is concentrated on areas of the sea-bed where warm water emerges from cracks and chimneys and is dominated by dense mussel beds of a previously undescribed species. In some locations large numbers of small mussels were observed attached to large mussels indicating a recent recruitment event (Van Dover *et al.*, 1996).

Figure 20: Known vent fields to the west of the Azores.



Twenty-five invertebrate taxa are listed from the Lucky Strike hydrothermal area. Four are shared with other hydrothermal vent systems on the mid-Atlantic Ridge and seven are previously undescribed new species closely associated with hydrothermal activity. Several taxa, typical of eastern Pacific vents or western Pacific back-arc hydrothermal systems (tubeworms, vesicomid clams and alviniconchid gastropods for example), are absent. Sixty-six species have been described from this site to date. The vent communities at Lucky Strike have a sufficiently unique fauna to be considered as representing a different biogeographic hydrothermal province to those previously described (Van Dover *et al.*, 1996).

Rainbow (36°11'N, 33°57'W).

This site, which is at a depth of 2,300m, has about 10 groups of very active black smokers. The hydrothermal fluids have a very high particle content and temperatures (360°C), enriched in copper, nickel, zinc and cobalt. Thirty-two species have been identified at the site which is dominated by shrimps. Many of the chimneys have no animals around them (MOMAR webpage).

There is an apparent long-term stability of the vent fields in the Atlantic. Lalou *et al.*, (1995) identified numerous cycles of venting using radiometric ageing of sulphids in the TAG vent field which suggested sporadic activity spanning a period of nearly 150,000 years. Fossil examples of vent communities have also been found indicating that there were marine communities associated with active sulphide mineralisation as far back as the Lower Carboniferous, at least 350 million years ago.

At the present time there are four known vent fields in the OSPAR area. These are the Menez Gwen, Lucky Strike, Saldanha and Rainbow vents (figure 20). In the Atlantic, the hydrothermal vents are associated with the mid-Atlantic Ridge and have been reported over a range of depths. The Menez Gwen vent field (37°51' N, 30°02' W) to the west of the Azores is a particularly shallow example at only 850m, whereas the TAG vent field (26°08' N, 44°49' W) further south is at a depth of 3,650m. The most recently discovered site is the Saldanha field at 2,200m and which was first encountered in 1998. Seawater has been observed emerging directly from the seafloor rather than through chimneys at this site but further exploration of the area is needed to confirm its main characteristics.

2.5 CORAL REEFS

The existence of corals in the deep sea has been known for more than a century. Precious corals (*Corallium* spp.) solitary stony corals (for example, *Flabellum goodei* & *Desmophyllum dianthus*) and colonial corals (for example, *Solenosmilia variabilis* & *Lophelia pertusa*) have all been found at a great depth and some, such as *Lophelia*, *Madrepora*, *Desmophyllum*, and *Solenosmilia* are found world-wide (Wilson, 1979a; Gage & Tyler, 1991; Koslow & Gowlett-Holmes, 1998). This section describes reefs formed by *Lophelia pertusa* although other hard corals such as *Madrepora oculata*, *Dendrophyllia cornigera* and *Solenosmilia variabilis* may also be present.

Plate 2: *Lophelia pertusa* polyps (close-up)



*Photograph by Pal B. Mortensen and kindly donated by Jan Helge Fossa, Institute of Marine Research, Bergen, Norway. The polyps of *Lophelia pertusa* have nematocysts which form batteries, visible as small white grains on the tentacles. By means of the tentacles and nematocysts the corals catch animals for food. As they grow, the polyps form the typical doomshaped framework. On the external surface a mucus-like sheet is found but it is not known if the polyps have any form of communication or metabolic transport through this layer. The skeleton is repeatedly closed by walls in the bottom of the corallites, thus there is no internal contact between the individual corallites.*

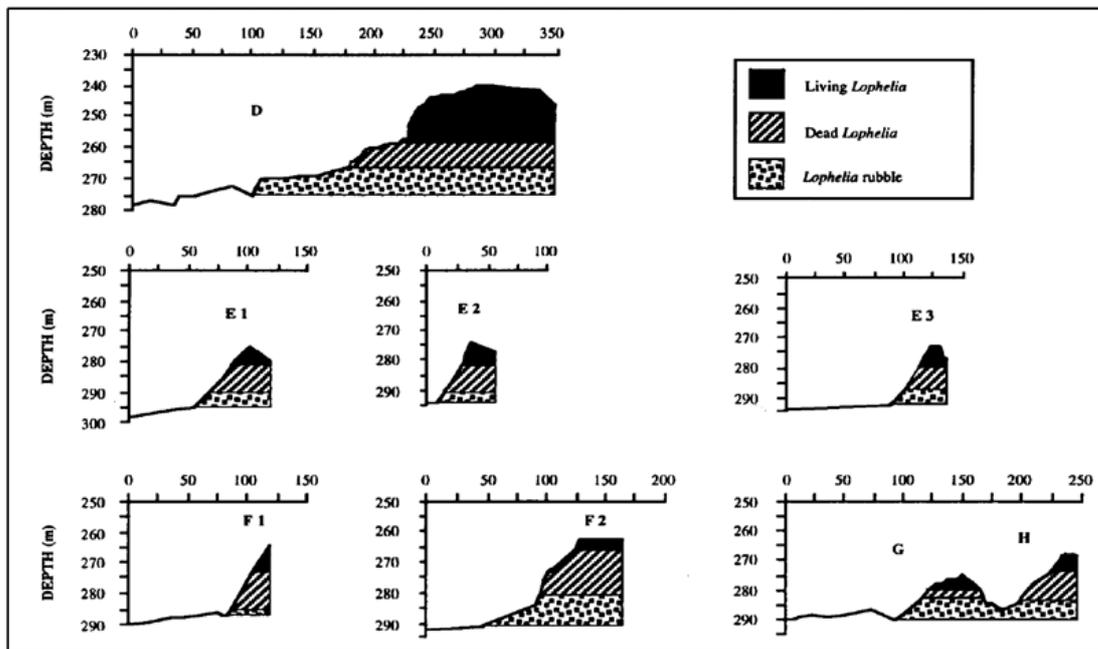
Colonies of *Lophelia* have been reported from the continental shelf, shelf slopes between 200-400m and offshore banks and troughs as well as in shallower waters in the fjords of western Norway and on the Swedish west coast. They are often found in areas where the local topography accelerates the water flow. The coral forms a hard, branched, external skeleton of calcium carbonate which protects individual polyps that extend their tentacles into the water to feed on phytoplankton, zooplankton and detritus. Because some colonies occur in areas where hydrocarbons seep into the water column from the sea-bed it has been proposed that chemotrophic bacteria thrive and provide the corals and other suspension feeders with a substantial and reliable food source but it remains unclear whether this is the case (Hovland & Thomsen, 1997; Hovland et al., 1998; Sumina & Kennedy, 1998).

Four different microhabitats of *Lophelia* colonies have been described: the smooth surface of living *Lophelia*, the detritus laden surface of dead *Lophelia*, the cavities inside dead *Lophelia* made by boring sponges, and the free space between the coral branches (Mortensen, 1995). Transects across coral structures in the Haltenbanken-Froyabanken area off the coast of Norway revealed that there was generally a basal area of *Lophelia* rubble overlain by dead *Lophelia* and then a covering of living coral (figure 21). The basal area of dead *Lophelia* was on average 7.6 times larger than that occupied by living *Lophelia*. The smallest structure was 1,500m² and the largest 50,600m².

The development of patches of the coral on the Rockall Bank was studied in the early 1970s and led to the suggestion that an initial colony, which requires a hard substrate on which to settle, gives rise to a ring of young colonies as sections break off, perhaps weakened by the activities

of boring sponges or damage from fishing gear. The smaller pieces may then provide a hard surface for colonisation of subsequent colonies (Wilson, 1979b). The reports from the Rockall Bank and Bay of Biscay are of hummocks rarely more than 1m high, but much more extensive structures can develop. Those off the Norwegian coast, for example, are known to be several kilometres long and more than 20m high.

Figure 21: Examples of depth profiles of transects across coral bioherms off the coast of Norway (from Mortensen *et al.*, 1995).



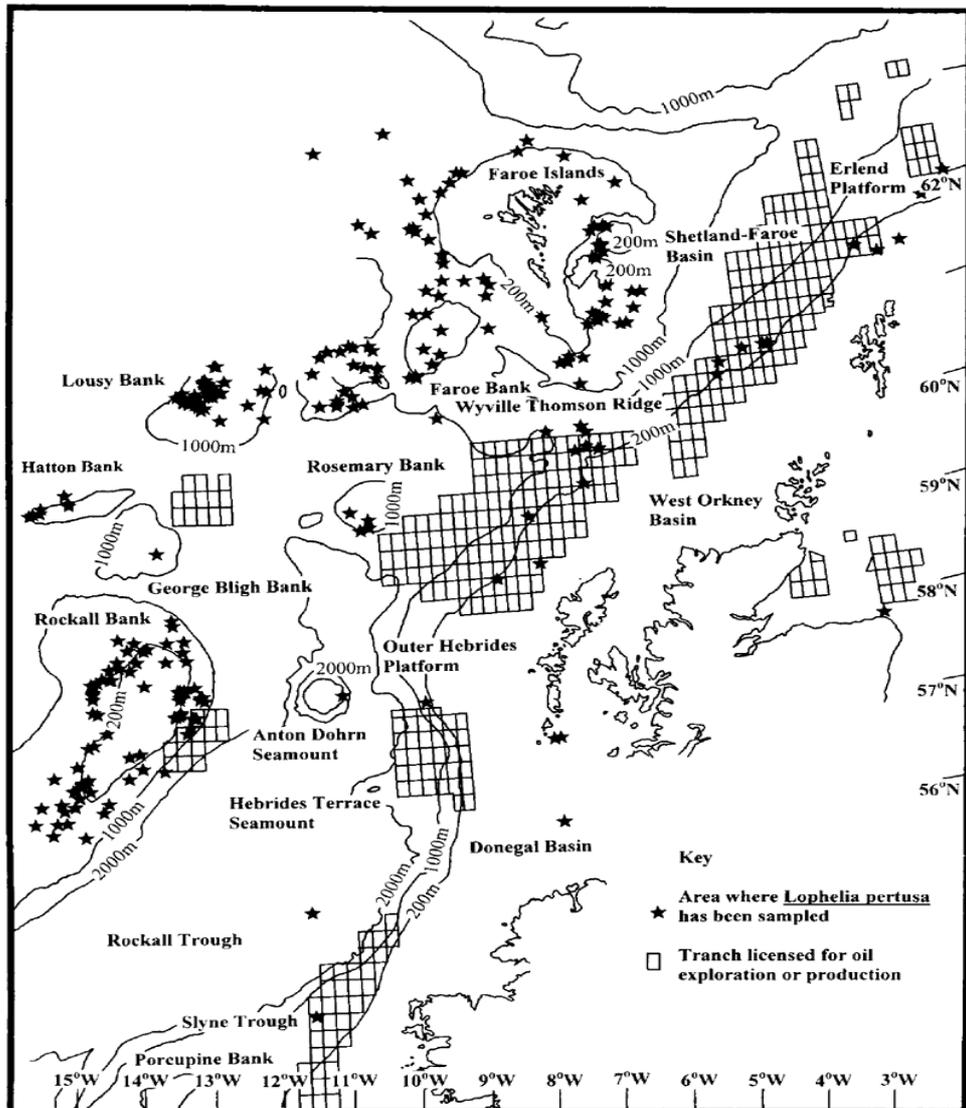
Almost all growth of the coral is thought to occur by asexual budding and to be more or less continuous while conditions are suitable. Limitations to the sizes of colonies are therefore thought to be dictated by factors such as the mechanical strength of living, growing branches, water flow through the colony and rate of weakening of the dead portions of the colonies for example as a result of the burrowing activities of clionid sponges (Wilson, 1979b). Using the growth rates of colonies on cables (average of 7.5mm/yr) as a basis for calculation, it has been estimated that the reefs on the Rockall Bank may have taken between 200-366 years to reach 1.5m height. The 15m high reefs off the Norwegian coast might be at least 2,000 years old (Mortensen *et al.*, 1995). A combination of geophysical, visual, geochemical, radiocarbon and other data relating to the coral banks off mid-Norway suggest that at least some of them have been forming in the same locality for over 8,000 years (Hovland *et al.*, 1998).

2.5.1 Occurrence in the OSPAR maritime area

L. pertusa is widely distributed in the north-east Atlantic having been reported from the Bay of Biscay, Porcupine Bank, west of Ireland, Rockall Bank, north and east of the Faeroe Bank, and in Norwegian waters (Wilson, 1979). As it has been recorded from the continental shelf of the north-east Atlantic more frequently than from other parts of the world, the area may be regarded as of global significance for the species (Rogers, 1999). Some reports are of isolated or small

thickets of corals, and in other cases, of extensive reefs. Hummocks of the coral up to 1m high are fairly common on the flanks of Rockall Bank between 130 and 400m for example, thickets 6-8m across have been mapped in the Bay of Biscay, and extensive reefs, some up to 31m high have been reported at depths between 200-400m off the Norwegian continental shelf (Fossa *et al.*, 1999; Mortensen *et al.*, 1995). Trawl haul records and information on fisheries charts show that the coral was present on the Scottish continental shelf and slope, north and west of Shetland and Orkney, on the shelf edge west of the Outer Hebrides and on various offshore banks (figure 22). The patches around the Rockall Bank tended to occur mostly within the zone of the slope that has been furrowed by icebergs. New records for *Lophelia* and other hard corals continue to be made as deep sea surveys extend into new areas or look at previously mapped sections of the sea-bed in more detail. It may also be that *Lophelia* was more extensive with colonies being lost due to naturally occurring slumps and erosion.

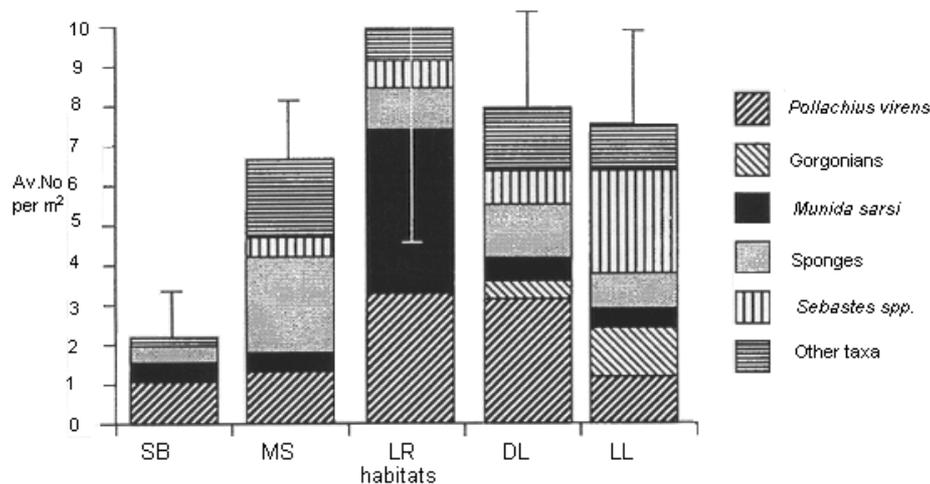
Figure 22: Areas where *L.pertusa* has been sampled and approximate position of licensed areas for oil exploration and production to the north and west of the UK (from Rogers, 1999)



2.5.2 Coral reef communities

The coral provides a three-dimensional structure and variety of microhabitats that provide shelter and a surface for attachment to other species. Boring sponges, anemones, bryozoans, gorgonians, polychaetes, barnacles and bivalves have all been recorded within and among the corals (Wilson, 1979b; Mortensen *et al.*, 1995). Other hard corals such as *Madrepora oculata* and *Solenosmilia variabilis* may also be present and in surveys in the Porcupine Bight living *M. oculata* was in fact more abundant than living *L. pertusa*. Mobile species also appear to be attracted to the coral reefs. Dense aggregations of the redfish *Sebastes viviparus* have been observed on the *Lophelia* reefs off the coast of Norway in May, many of which were gravid females with expanded bellies raising the possibility that the reefs may be used as spawning or nursery areas by some fish. Longline fishing catches showed catches of *Sebastes marinus*, *Molva molva* and *Brosme brosme* significantly higher in coral areas than on the surrounding sea-bed (Fossa *et al.*, 1999).

Figure 23: Average density of individuals/colonies in different habitats around *Lophelia* (Mortensen *et al.*, 1995)



About 886 species have been recorded living on or in *Lophelia* reefs in the north-east Atlantic and although much remains to be learnt, the diversity seems to be of a similar order of magnitude to that of some shallow water tropical coral reefs although different groups dominate the fauna (Rogers, 1999). Nearly 300 invertebrate species have been collected around *Lophelia* reefs near the Faroes (Jensen & Frederiksen, 1992) and 36 taxa represented in samples in and around the *Lophelia* reefs off the coast of Norway five of which were only found on the coral structures (Mortensen *et al.*, 1995). Sponges dominated the sessile fauna on the stones below the coral structures and the squat lobster *Munida sarsi* occurred in high densities on the *Lophelia*

rubble (figure 23). The fish fauna was dominated by saithe (*Pollachius virens*) and redfish (*Sebastes* spp.) with highest densities of saithe on the rubble and dead areas feeding on the bottom, but redfish most common in the living *Lophelia* zone (up to 8/10 per m²) and only a few on the surrounding soft sea-bed. It has been suggested that the squat lobsters are probably an important source of food for benthic fish species living near the corals whereas the redfish probably use them as shelter and feeding place. Saithe are thought to be a temporary member of the reef fauna.

The branching structure of dead coral under the living coral also provides a surface for attachment and consequently dead coral debris on the reefs supports a rich fauna of sponges, anemones and bryozoans including *Pyripora catenularia*, *Porella compressa*, *Diplosolen obelium*, calcareous polychaetes such as *Serpula vermicularis*, *Hydoirides* sp. and *Filograna* sp. brachiopods including *Crania anomala*, *Terebratul retusa* and *Macandrevia cranium*, bivalves and the echinoids *Cidaris cidaris* and *Echinus* species. It also provides shelter for scavengers such as *Munida rugosa* and *Ebalia tuberosa* (Wilson, 1979b; Suminda & Kennedy, 1998).

2.5.3 Conservation issues

The delicate structure and slow growth rate of *Lophelia* make these coral reefs particularly vulnerable to physical damage. Bottom trawling, where heavy fishing gear is dragged along the sea-bed is therefore a major concern. Damage to reefs from the activity of trawlers has been documented off the coast of Norway where there have also been many anecdotal reports of trawlers using their gear, wires, chains and trawl doors to crush the corals to clear the area before fishing starts. (Fossa *et al.*, 1999). There are also reports of coral being brought up in trawls off the Rockall Bank (Wilson, 1979). It has been suggested new colonies can grow from broken fragments but this may be countered by suspension of sediments by trawling activity which can smother and affect feeding as well as potentially inhibiting the settlement of larvae and therefore the colonisation of previous disturbed areas (Rogers, 1999).

The advent of oil exploration and production in deep sea areas where *Lophelia* is known to occur is another concern. The effects of drill cuttings, water-based and synthetic drilling muds, and the variety of chemicals and contaminants including dissolved and dispersed oil which are known to enter the environment around offshore oil operations, may have lethal and sublethal effects on corals (Rogers, 1999) This is particularly relevant in the north-east Atlantic as oil exploration is taking place in areas where *L. pertusa* is known to occur.

Because of the slow growth rate of the coral, recovery from such impacts could take hundreds of years even if areas remain undisturbed after the initial damage.

Plate 3: Undamaged

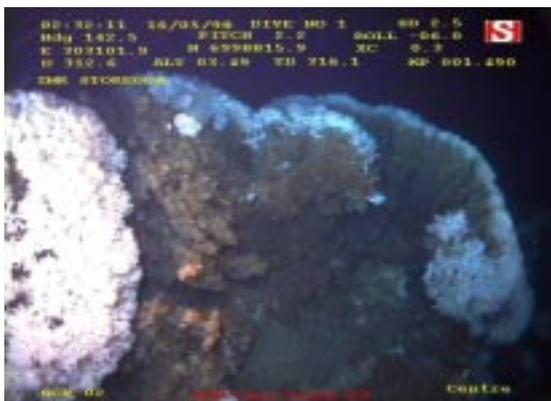


Plate 4: Damaged



Photographs by Pal B. Mortensen and published with kind permission of Jan Helge Fossa, Institute of Marine Research, Bergen
plate 3: Video photograph from the Norwegian continental shelf north of Haltenbanken (17 May 1999). Plate 4: Video photograph from the Norwegian continental break at 220m depth (16 May 1998), showing a barren landscape with spread, crushed remains of *Lophelia*-corals. This is an area that is subject to considerable bottom trawling. A track can be seen stretching from bottom-left to up-right of the photograph, indicating the path of a trawl.

2.5.4 Conservation actions

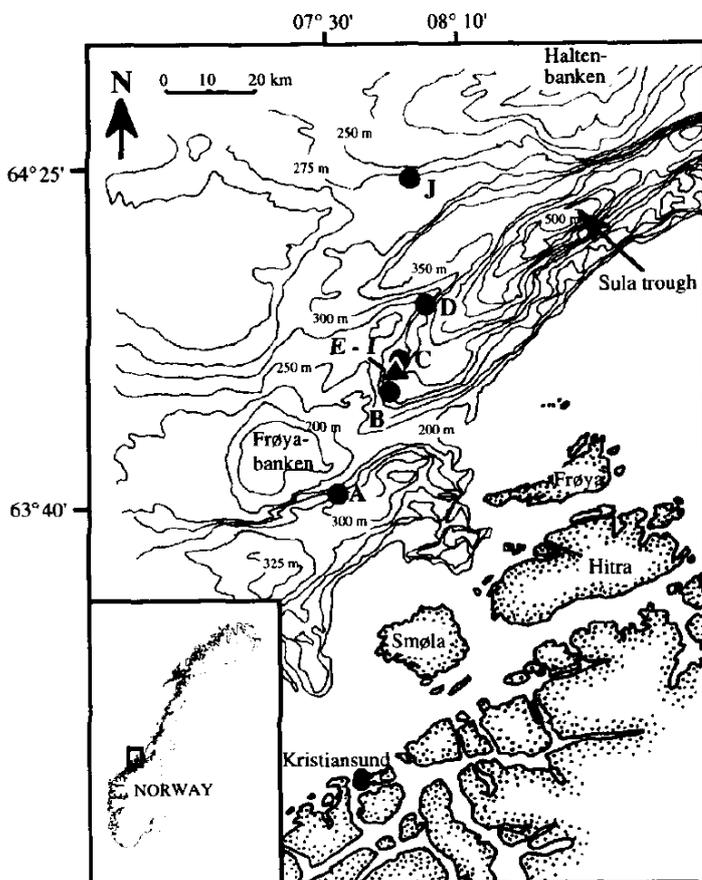
Conservation of deep sea coral reefs requires a range of types of action. Like shallow water reefs, the protection of defined areas will be a valuable tool as this can limit the direct impacts on the reef structures. This type of action has been taken by the Norwegian government which established a protected area around the Sula Ridge reefs in 1999. More general measures have also been introduced prohibiting all intentional destruction of coral reefs wherever they occur in Norwegian waters (WWF, 1999).

Indirect measures to safeguard water quality and sedimentation around *Lophelia* reefs is another important action that should be taken. This is particularly important in the areas where offshore oil exploration and production activities are proposed or already underway. If stringent standards cannot be achieved, the most appropriate course of action may be to prohibit or close down such operations.

The Sula Ridge

This site lies off the west coast of mid-Norway in a trough between the Froya Bank to the south-west and the Halten Bank to the north-east. There are numerous coral banks in depths of around 300m with the reef complex about 13km long and the largest reefs 35m high and 700m wide. The site is believed to have the best developed deep-water coral reefs in the north-east Atlantic and WWF has, therefore, proposed it as a potential MPA (WWF, 1999). In 1999 the Norwegian government gave specific protection to the coral reefs in this area.

Figure 24: Map of the Haltenbanken-Froyabanken area with coral areas investigated by Mortensen *et al.*, 1995)



2.6 FRONTS

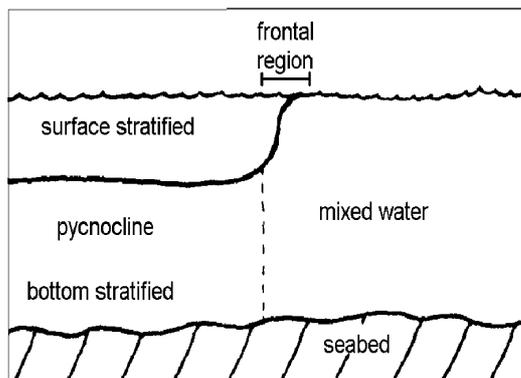
Fronts are distinctive oceanographic features that mark the boundaries between water bodies with different characteristics. They are lateral zones above or below which there is localised and sometimes vigorous vertical movement of water. Fronts can form at salinity boundaries or where there are temperature differences between two water masses. They may also be caused by topographic features both above and below the surface. The best known fronts are tidal fronts, shelf-break and upwelling fronts, and estuarine fronts which form in coastal areas but deep sea fronts, which form in the open ocean, have also been described (Owen, 1981). Where fronts are vigorous for their size or meet an obstacle, flow becomes unstable and frontal meanders may pinch off and become eddies (see section 2.7).

Fronts occur on a number of scales. They may only be a few meters in extent and persist for hours or, at the other extreme, they may extend for thousands of kilometres and persist for years. The temperature differences which cause tidal fronts are related to the amount of mixing that takes place within coastal and oceanic waters. Coastal waters are greatly influenced by tides and this, combined with their shallow nature, mixes the system. In oceanic waters where tidal stirring is weak, the water column is poorly mixed so during the summer months the upper

layers are warmed but remain isolated from the cold bottom waters. The boundary between the upper and lower layers, where the temperature change is greatest, is known as the thermocline, the presence of which indicates that the water has become stratified. Well-mixed waters do not show such marked temperature changes and remain cool throughout. Where these two types of water body meet there is a marked difference in the temperature of surface waters creating a front.

Three distinct water masses can be identified around tidal fronts: surface stratified water, bottom stratified water and mixed water (figure 25) Apart from temperature differences, nutrient levels vary in the vicinity of coastal fronts. The well-mixed coastal waters are rich in nutrients derived from recycling in the sediments, whereas oceanic waters, following nutrient depletion in the spring bloom of plankton are relatively sterile (Beardall *et al.*, 1982).

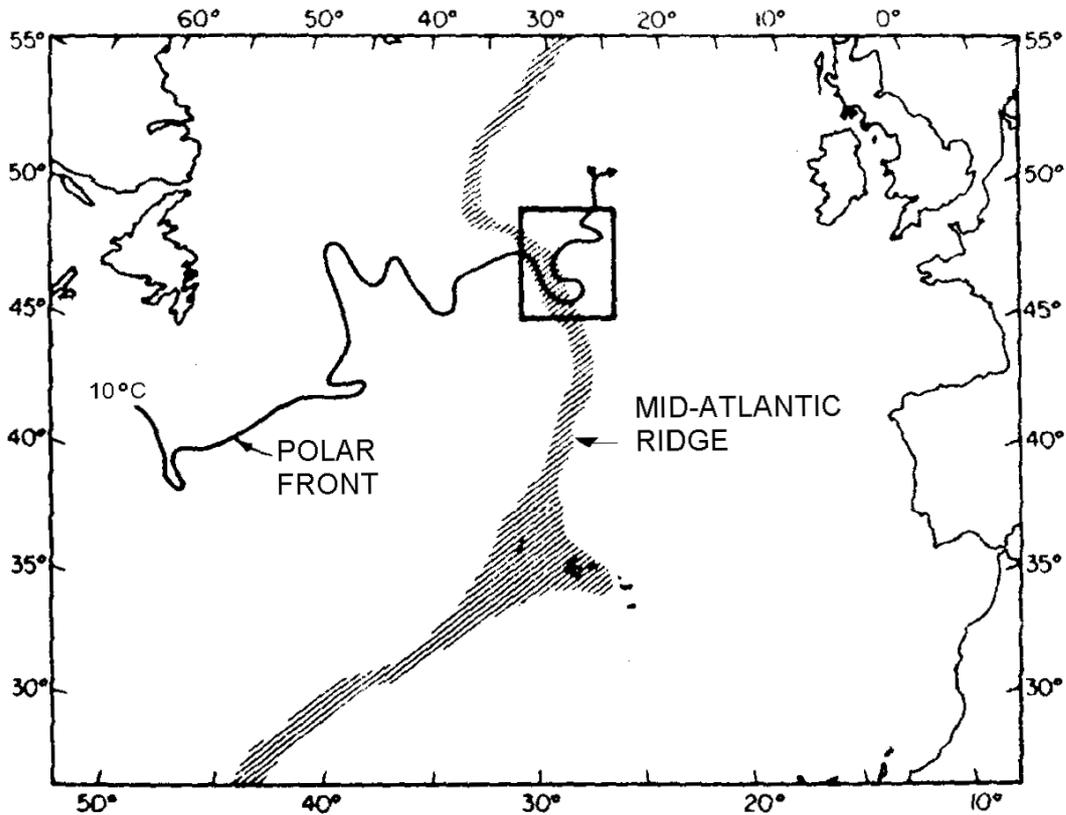
Figure 25: Cross-section through a tidal front showing different water masses (from Fogg *et al.*, 1985)



Another area where fronts form is where the gradient of the continental shelf steepens to become the continental slope. These fronts either separate more saline shelf water from offshore water and arise by upwelling on the continental shelf, or separate less saline shelf water from offshore water and are the result of shelf-water dilution from terrestrial runoff and thus predominate off large coastal watersheds (Owen, 1981). An important aspect of upwelling fronts is their periodic relaxation or breaching and subsequent release into offshore water of nutrients and plankton previously accumulated in the shelf water. This will take place if the upwelling ceases which might occur seasonally or episodically.

Deep sea fronts tend to form when waters of different mixing histories meet. The North Atlantic polar front, which is the product of the seaward extension of the Gulf Stream axis into mid-Atlantic, is one example. This front is defined by the large temperature gradient between cold shelf or sub-Arctic water to the north, and warm Sargasso seawater to the south. There is a marked weakening of the temperature and salinity gradients of the front in the vicinity of the mid-Atlantic Ridge which also causes it to meander at this point (figure 26).

Figure 26: The oceanic polar front (from Dietrich, 1964)



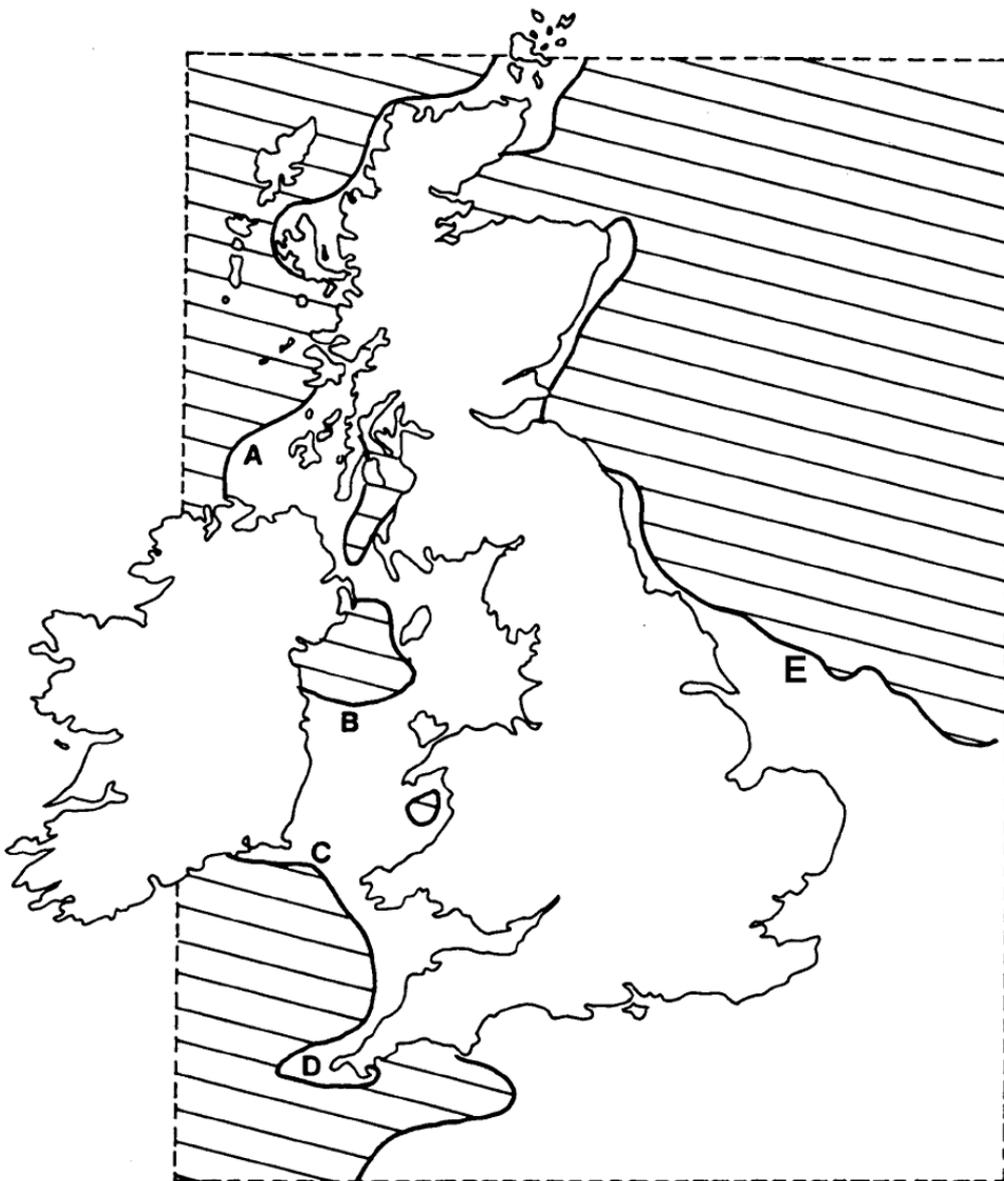
2.6.1 Occurrence in the OSPAR maritime area

Each summer, tidal fronts develop in specific locations which are remarkably constant from year to year. Once developed they are also virtually static (Simpson, 1981). Infra-red satellite imagery has revealed the extent and location of fronts and research vessels have recorded temperature differences of as much as 1°C/m across them (Lee & Ramster, 1981). The positions of the main fronts, which form around the British Isles, are shown in figure 27. Other examples are the fronts which form off the coast of southern Norway, in the vicinity of the shelf-break to the west of Ireland and along the Iberian margin where a permanent subsurface front appears to be present off Cape Finisterre and convergent fronts close to the coast including off Cape Oretgal (Bode *et al.*, 1996).

Figure 27: Fronts which form around the British Isles (from Lee & Ramster 1981)

- A – Islay Front
- B – W.Irish Sea Front
- C – Celtic Sea Front
- D – Isles of Scilly Front
- E – Flamborough Front

 Stratified water
 Well-mixed water



2.6.2 Marine communities associated with fronts

At a front where the two water bodies meet and where the thermocline is at the surface, eddies and upwellings release nutrients into the surface waters. This availability of nutrients combined with the greater light levels increases phytoplankton production in these areas (Beardall *et al.*, 1982). Zooplankton concentrations have also been observed in these areas. These concentrations are exploited by fish, which appear to congregate near fronts and they, in turn, provide food for birds such as puffin, shearwater and tern which may also concentrate their feeding activity in these areas (Pingree *et al.*, 1974). Rees & Jones (1982) for example recorded rafts of Manx shearwater and razorbill in the immediate vicinity of the western Irish Sea front, whereas there were virtually none of these species in the mixed water areas away from the front. They suggested that the shearwaters were taking advantage of the fact that food concentrated above the thermocline was more accessible, and that the razorbills had easier access to sub-thermocline food in the vicinity of the fronts.

A more recent study analysed the distribution of seabirds in relation to sea surface temperature and salinity which were taken as markers of the surface features of the Irish Sea front (Begg & Reid, 1997). This confirmed the importance of the area for seabirds as it revealed that Manx shearwater occurred in disproportionately high numbers at the surface expression of the front where the horizontal temperature gradient was greatest. Guillemot and razorbill distributions were more closely related to sea surface salinity. They expressed the view that the distribution of the birds is probably directly related to the distribution of their prey rather than to physical features of this environment.

Marine mammals are also known to exploit the biota of tidal and other fronts. Gaskin (1976) cited feeding by minke whales on herring or capelin aggregated in coastal tide slicks of eastern Canada and fin whales feeding on surface concentrations of euphausiids in a convergence in the Bay of Fundy which had been forced to the surface by mackerel schools. Deep sea fronts also appear to be 'hotspots' for marine life. Species which have been reported in high concentrations at various deep sea fronts include squid, flying fish, lantern fish and albacore tuna (Owen, 1981).

The localised enrichment at fronts may also affect the benthos. Investigations of the sea-bed around the western Irish Sea front revealed particularly dense beds of the tubes of the polychaete *Ampharete falcata* (approx 3,000/m²) with considerable numbers of *Parviardium ovale* (around 27,000/m²), *Nucula tenuis*, *Abra nitida*, *Pandalus montagui* and *Crangon allmani* (Holme & Rees, 1986). This unusual and rich community was restricted to a narrow band of depth and distance.

2.6.3 Conservation issues

The formation, persistence and location of fronts has important ecological implications (box 5). The enhanced productivity and concentration of marine life in these areas makes the associated communities particularly vulnerable to exploitation as well as impacts which might be focused in these areas such as pollution incidents and accumulation of marine litter in the vicinity of fronts which may have a disproportionate impact because of the focus of marine life around fronts.

BOX 5: Ecological effects of fronts and eddies (from Owen, 1981)

Mechanically affect local concentrations of organisms
Juxtapose populations that would not otherwise interact
Create new 'communities'
Conserve and translocate selected species ensembles and concentrations
Attract and sustain large motile animals
Serve as reproduction refuges
Mechanically limit dispersal of meroplankton or neritic populations
Induce/sustain higher local production of organisms
Modify migration patterns as diverse as annual, trans-oceanic
fish movements and diel vertical migrations of motile phytoplankton
Collect surface active and particulate substances.

2.6.4 Conservation actions

Frontal systems are difficult habitats on which to focus conservation measures because they are water column features and also because they are not necessarily present all year round. Because of this, general measures to safeguard water quality where these features form will be important, particularly as pollutants could be retained within frontal systems. The regularity of the occurrence of some fronts in the same location presents the possibility of site protection as well. Measures could be introduced to minimise the risk of pollution incidents by siting offshore operations away from such features or introducing ship's routing measures for example, or ensuring that fisheries are not concentrated in these areas. One such site which has been well studied and could be considered as a potential marine protected area is the western Irish Sea front (Gubbay, 1996).

Western Irish Sea front

The western Irish Sea front forms every year in the late spring (March/April) and persists through the summer until September or October. It marks the boundary between tidally mixed water, to the south-east, and stratified water to the north-west. The front remains in a relatively static position throughout the summer and develops particularly well along the southern and eastern edge. The surface stratified waters appear to be an area of intense biological activity, especially where the front meets the coastal current off the Kish Bank on the Irish coast (Beardall *et al.*, 1982). The regular supply of organic material sinking onto the sea-bed may have enhanced the local richness of the benthos while on the surface the front attracts Manx shearwaters, razorbill and guillemot to feed. Basking shark have also been reported concentrating feeding activity along the front.

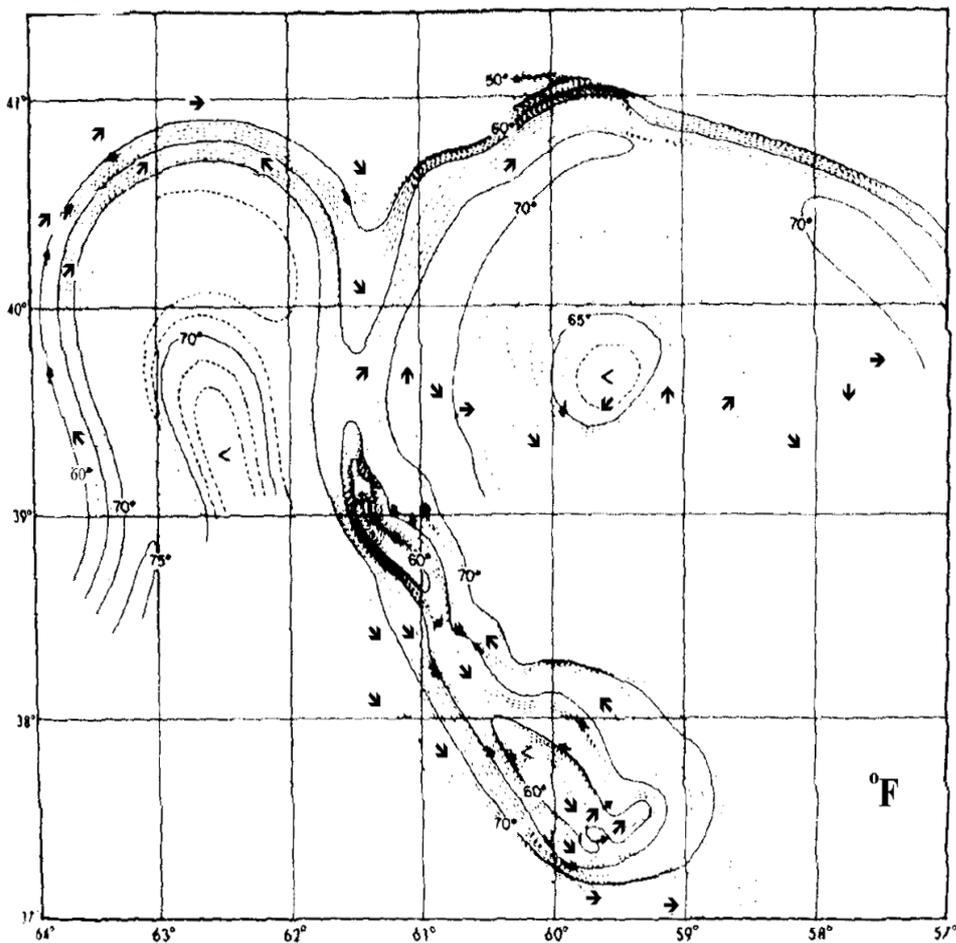
2.7 EDDIES

Eddies are localised zones of horizontal water circulation in a relatively closed system where vertical motion is induced or sustained. The vertical water movement compensates for lateral flow into or out of the circulation and is upward in cyclonic eddies and downward in anticyclonic eddies. Another distinction is that cyclonic eddies have cool core temperatures whereas the core in an anticyclonic eddy is warm. The upward water movement in large cyclonic eddies has been estimated to be of the same order as sinking rates of some phytoplankton and detrital particles and on a scale that can transport substantial nutrient

supplies upward (Owen, 1981). Because the vertical movement of water in eddies is slow and generally spread over larger areas than fronts (see section 2.6), the gradients in temperature and salinity with surrounding water are generally not as sharp.

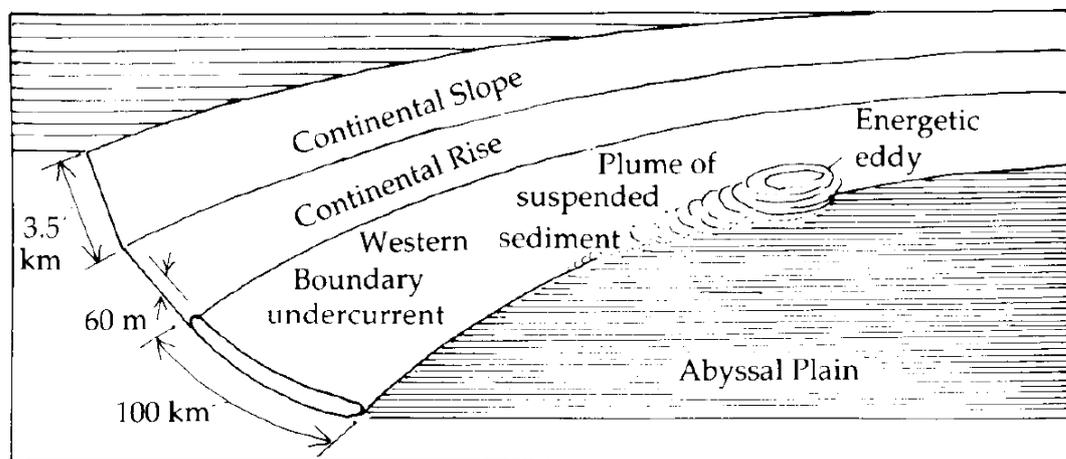
Islands, seamounts and headlands act as obstacles to sea and air flow and cause the sorts of instabilities that can develop into eddies. Large eddies can therefore form off continental margins and as they move offshore may influence sea areas well beyond the continental shelf and slope. This can be seen as patterns in satellite thermal imaging which show the temperature differences associated with eddies in locations well offshore. Eddies, which form around coastal areas or deep sea topographic features, may be stationary, “attached” to the obstacle or, with increased flow or obstacle size, may be shed in series (Owen, 1981). They may also form in association with currents or fronts in situations where the water flow meets an obstacle and becomes unstable. Frontal meanders may then pinch off, becoming eddies (figure 28). Many large-scale eddies are also generated off ocean currents.

Figure 28: Cyclonic eddy genesis from a polar front meander (from Owen, 1981)
[Temperature current vectors (→) delimit a cold core meander and eddy pattern]



Eddies show a great variation in size and may also form at any depth. Large examples can be several hundred kilometres across and persist for months or even years whereas smaller eddies, perhaps a few kilometres across may only persist for a few weeks. Mesoscale eddies are at the larger end of the spectrum, measuring 50-200km across. They are believed to be common even far out on the abyssal plain and are thought to contain up to 100 times the energy of the surrounding water (Gage & Tyler, 1991). Eddies such as these are typically thrown off strong surface flows such as the Gulf Stream or formed by wind stress in stormy areas. The energy is transmitted to the deep sea giving rise to benthic storms which can last anything from a few days to weeks when the circulating water suspends and transports large amounts of sediment which is later re-deposited when the storm dies out (figure 29).

Figure 29: Interaction of mesoscale eddy with the sea-bed to form a benthic storm (from Gage & Tyler, 1991).



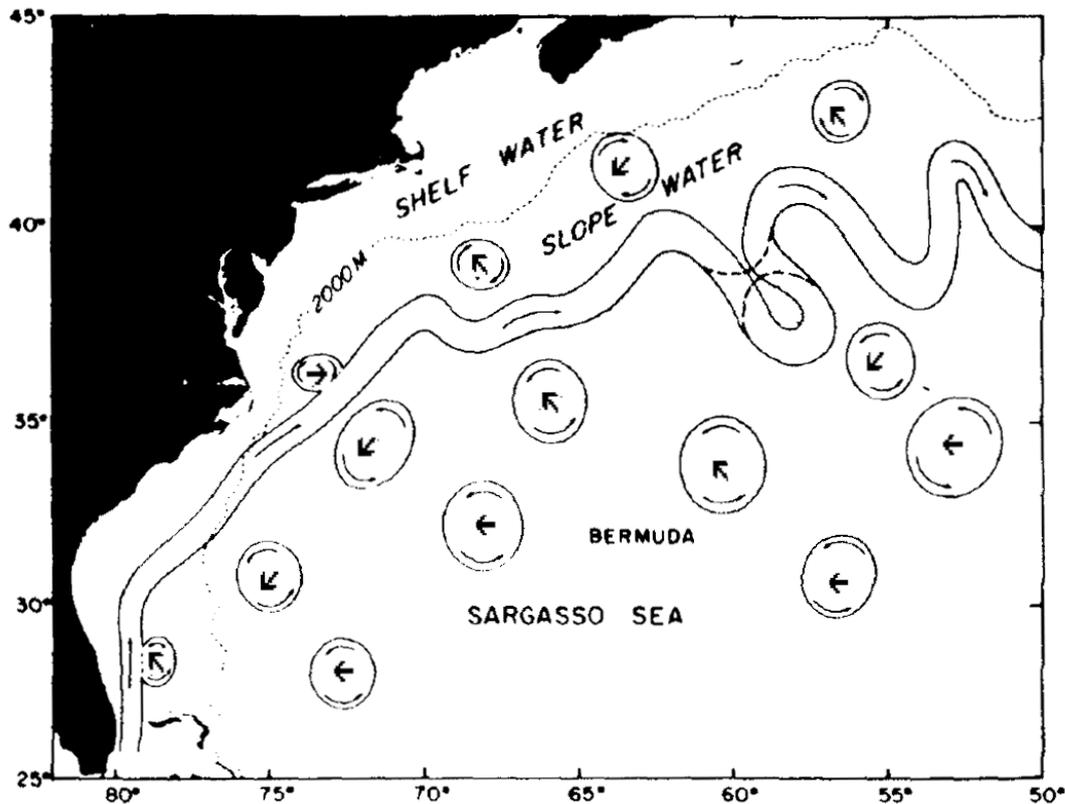
2.7.1 Occurrence in the OSPAR maritime area

Eddy formation occurs in many parts of the OSPAR maritime area. One region where this has been well-documented is along the North Atlantic polar front whose eastern extent is within the OSPAR area. The front weakens in the area of the mid-Atlantic Ridge with the instability periodically producing a large meander that is subsequently shed as an eddy. If shed south or east of the front it contains colder water from the north side and is cyclonic whereas warm-core, anticyclonic eddies spin off into colder water to the north and west (figure 30). Cyclonic eddies form in this way several times a year and are physically identifiable for as much as two years. Eddies forming off the North Atlantic polar front have been known to be 300km across and extend from the sea surface to 3km depth although not all examples extend to the sea surface.

The Faroe-Shetland channel is another area where eddy generation appears to be a fairly common phenomenon, particularly on the southern Shetland side of the channel where strong mesoscale eddies have been observed (Sherwin *et al.*, 1999). The slope current flows northwards in this area carrying warm water into the Nordic seas. Five principal water masses occupy the channel; two at the surface, two at intermediate depths and a bottom water. One eddy in this area which was studied in detail was about 42km across at the surface and around

57km across at a depth of 300m (Sherwin *et al.*, 1999). A sharp drop in temperature was recorded within this cold-core eddy suggesting that warm saline North Atlantic water in the region had been replaced by a fresher cooler surface water (modified North Atlantic water). The authors suggest that eddies may travel up this channel every 14 days or so.

Figure 30: Schematic representation of the path of the Gulf Stream and the distribution and movement of ring eddies (Richardson, 1976)



Other regions in the OSPAR area, where eddy formation and their effects have been studied, are in the Bay of Biscay. Here eddies develop as a result of the interaction of the current (which runs along the continental slope) with the topography of the sea-bed along the coast of Norway. They also develop around the Azores where the Azores current generates persistent anticyclonic eddies along its northern flank and shorter-lived cyclonic features along its southern flank.

2.7.2 Marine communities associated with eddies

Eddies can form at any depth and affect populations of organisms at all trophic levels, including benthic forms, from great depths to the littoral zone (Owen, 1981). The main way in which they do this is by maintaining and transporting contained populations and substances. The effects of eddies are not as significant if they are small and weak but they can still have an important influence, for example by crossing or reducing the strength of larger scale hydrographic features and therefore disrupting rather than creating patterns.

The potential for eddies to contain biota is illustrated by the Southern California eddy which is a particularly persistent feature from the upwelling zone north of Point Conception. The feature appears to collect and recirculate biota appearing to be a reproductive refuge for the *Euphausia pacifica*. There was an unmistakable correspondence between the eddy and patterns of concentration of both sardine eggs and diatom concentrations as well as brining nutrients up to the surface layers in the eddy.

Mesoscale eddies can have significant faunal impact. Gulf Stream rings, for example, are of sufficient size to carry with them organisms and nutrients typical of the core water which can function well enough to support the detached small ecosystem, including larger organisms, for some time. The contained fauna can be found down to depths of 800m and can persist for several years if the ring is very large. In the Gulf Stream, more cold-core rings (about 10 per year) are formed than warm-core rings (which are generally smaller) and these on average have a lifetime of about a year (Merrett & Haedrich, 1997).

A study of cold-core eddies from the polar front revealed the importance of eddies in retaining the biomass and community structure of plankton, which becomes isolated within them as they form (Wiebe *et al.*, 1976). These eddies had relatively higher plankton biomass as well as species assemblages that were distinguishable from the surrounding Sargasso seawaters and, although the different physical and biological characteristics became less obvious with time, the biological communities may still be distinguishable many months later. For example, consistently higher zooplankton stocks and distinctive euphausiid species were evident in cold core eddies even a year after their formation. The daily migration patterns of several zooplankton species also appear to have been affected by the presence of the eddies. Daytime depths reached by warm-water euphausiid species that migrate, was consistently and markedly deeper beyond than within a cold-core meander of the polar front. The polar front was also shown to be an effective thermal barrier to some oceanic plankton species but cold-core eddies shed from them cross the barrier by transporting plankton far south of where they would otherwise occur. Reduced numbers and the nutritional condition of individuals in older eddies indicated that expatriate populations attenuate in time by starvation.

When the influence of eddies extend to the seafloor they can cause benthic storms. These are geologically significant in transporting high suspended sediment loads, perhaps along with fauna not normally adapted to water-borne dispersion, across the deep ocean basins. Biologically, they are important as a source of repeated major perturbation within the lifetimes of benthic fauna thus affecting the structure of the benthic community (Gage & Tyler, 1991)

2.7.3 Conservation issues

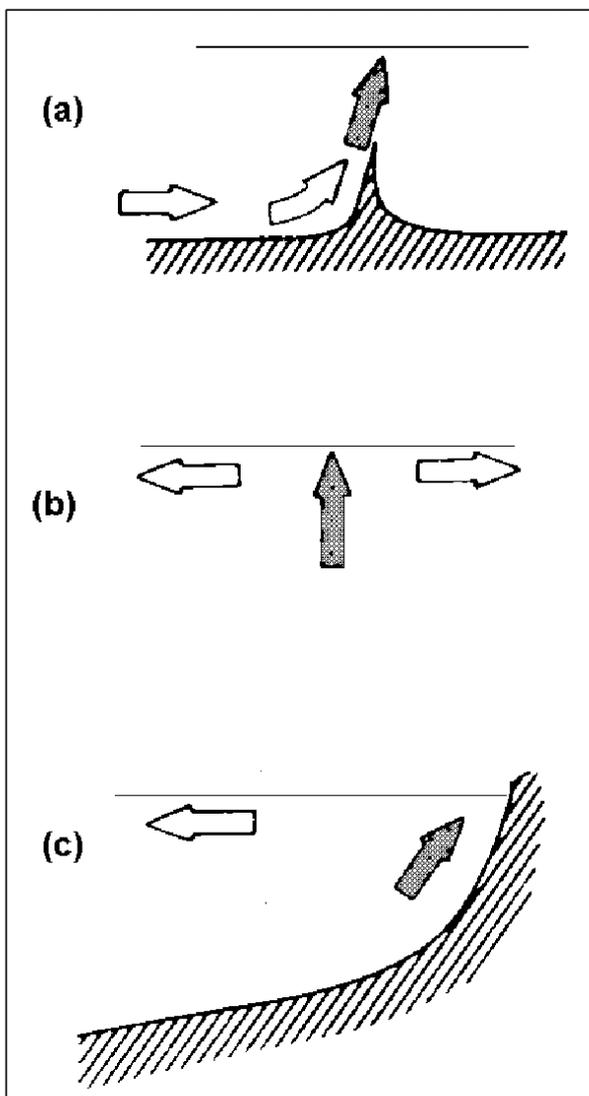
The formation, persistence and location of eddies has important ecological implications which are similar to those which may be linked to the formation of fronts (see box 5 in section 2.6). They are particularly significant in transferring or maintaining particular biological characteristics as well as changing the environmental conditions through changes in temperature and salinity, for example. They can enhance primary production by bringing nutrients to the surface and can therefore be attractive areas for marine life. At the same time it is possible for contaminants to become entrained in eddies for significant periods of time and perhaps be transported significant distances to affect other areas.

2.7.4 Conservation actions

Eddies are difficult environments on which to focus conservation measures because they are water column features and because of their ephemeral, although sometimes very persistent nature. Because of this, more needs to be known about their method of formation, effects on the local ecology, persistence and areas in which they are consistently generated. General measures to safeguard water quality where these features are known to form will be important, because of their potential to retain and transport pollutants.

2.8 UPWELLING

Figure 31: Upwelling mechanisms consequent on (a) an underwater ridge (b) divergent surface currents; (c) the movement of water away from a coastline (from Barnes & Hughes, 1982).



The term upwelling is used to describe the movement of water from relatively deep in the ocean into the photic zone. It can occur as a result of the deflection of deep currents when they meet an obstacle such as a mid-ocean ridge, the movement apart of two water masses, or when water is driven away from a coastline by wind action creating a 'hole' which is filled by water being drawn to the surface (figure 31).

The eastern margins of oceans in the tropics and subtropics are particularly prone to coastal upwelling because of the prevailing winds, although upwelling also occurs beneath currents moving along the continental slope. These are particularly apparent on the western margins of continents and may result in strong localised offshore flows, or 'squirts', typically associated with 'filaments' (elongate bodies of water at the surface with uniform characteristics that differ from their surroundings) (Merrett & Haedrich, 1997). Such filaments have been observed associated with Gulf Stream eddies in the mid-Atlantic Bight as well as other places.

2.8.1 Occurrence in the OSPAR maritime area

The main areas of upwelling are along western coasts where the north-east trade winds in the northern hemisphere and the south-east trades in the southern hemisphere drive water away from the coasts. They also develop along the equator as a result of the divergence of water masses and around Antarctica and the Arctic due to differences in the temperature and salinity of water immediately adjacent to the ice, which creates density-driven current systems. None of these fall into the OSPAR maritime area but smaller upwelling features do occur off the Atlantic coasts of Spain and Portugal where there is a pattern of seasonal upwelling

Upwelling filaments first appear off the Iberian Peninsula in June. They develop as a result of persistent northerly winds and are most obvious in the period from late July to September by which time they may extend 200-250km offshore. There may be five or six in any one year (Merrett & Haedrich, 1997). Most of the upwellings on the north-western Spanish shelf develop close to the coast but they have also been observed in the mid- and outer shelf areas (Bode *et al.*, 1996).

In the case of the system off the coast of Spain, the upwelling modifies the vertical structure of the water column during the thermal stratification period (May to September) affecting phytoplankton distributions in relation to the gradients of temperature and nutrients (Bode *et al.*, 1996). In contrast, upwelling events during spring and autumn are influenced by local circulation patterns caused by poleward currents flowing parallel to the shelf-break front. These currents have a major influence on the development of phytoplankton blooms normally occurring in temperature coastal seas as reported for the Cantabrian coast.

2.8.2 Marine communities associated with upwellings

The ecological importance of upwellings lies in the fact that they transport nutrients from depth into surface waters and, as a result, increase primary productivity at the surface. This has a cascading effect up the food chain leading to increased concentrations of fish and seabirds in these areas. This pattern has been detected in the seasonal upwelling system off the north and north-western Spanish shelf. Cold, nutrient-rich deep waters have been detected near the surface throughout March to November, especially in the north-western shelf and are known to be an important source of inorganic nutrients for primary production in that area (Bode *et al.*, 1996).

2.8.3 Conservation issues

Coastal upwelling occurs in five major regions of the world and, while these regions together constitute only about one per cent of the total area of the ocean, their importance can be judged by the claim that they supply some 50 per cent of the world's commercial fish catches (Merritt & Haedrich, 1997). The enhancement of primary production makes them 'hotspots' for marine life and hence the targeting of these areas for fisheries.

2.8.4 Conservation actions

Upwellings are difficult environments on which to focus conservation measures because they are water column features and because of their ephemeral, although sometimes very persistent, nature. General measures to safeguard water quality where these features form will be important but there is also the possibility that they could be included in marine protected area programmes. The most significant management action must be directed at the exploitation of resources in these areas. Their rich and productive nature makes them a target for fisheries exploitation in particular, the level of which needs careful management.

2.9 SEABIRDS

Large numbers and a great variety of seabirds occur in the OSPAR maritime area. They include gannets, gulls and auks as well as fulmars and petrels which are true ocean species, coming ashore only for short periods to raise their young. The adjacent land may be used for roosting, nesting and rearing young but it is the maritime area that provides the food to sustain these populations.

Seabirds use a variety of techniques to feed. They can take food from the surface or just below it while on the wing, exploit the surface layer while swimming and pursuit diving, capture food by deep plunge-diving and swimming at depth as well as scavenging food on the surface. Shearwaters, for example, often combine plunge-diving with surface swimming. Cory's shearwater (*Calonectris diomedea*) forage day and night often in large concentrations taking prey driven to the surface by predatory fish and sea mammals. Their main food are fish, cephalopods and crustaceans which are taken while flying close to the surface and plunge-diving. Gannets are plunge divers, perhaps penetrating up to 10m but usually remaining submerged for less than 10 seconds during which time they swallow their prey. Because of their weight and strength they can cope with powerful fish such as large mackerel.

Apart from feeding on fish, other components of seabird diet can include surface-living crustaceans, cephalopods, and jellyfish as well as offal and discards from fisheries. Birds are attracted to areas where there are rich natural concentrations of such food such as at fronts and upwellings (see sections 2.6 & 2.8) as well as to areas where food levels are enhanced by human activity such as behind fishing boats.

The isolated islands and archipelagos in the north-east Atlantic as well as coastal cliffs, headlands and sea stacks are an important base for many seabirds. The area as a whole also supports a large proportion of the global population of some seabirds. St Kilda, off the north-west coast of Scotland, is the site of the most important seabird colony in the north-eastern Atlantic. It has the largest gannetry in the world, the largest Leach's petrel and puffin colonies in the eastern Atlantic as well as having populations of fulmar, storm petrel, kittiwake,

guillemot and razorbill that are important in a European context (Tasker *et al.*, 1990). The storm petrel (*Hydrobates pelagicus*) is a more widely distributed species in contrast but is virtually endemic to Europe with the largest populations in the Faroes, Iceland, Republic of Ireland and UK with the total of birds breeding in these countries probably amounting to 90 per cent of the world population (Tucker *et al.*, 1994).

2.9.1 Distribution in the OSPAR maritime area

The importance of different parts of the OSPAR maritime area for seabirds depends on the time of year because of seasonal movements to and from nesting colonies, foraging activity and migration patterns. The changing patterns of distribution are particularly well illustrated in the findings of seabird surveys of the area to the west of Britain (Tasker *et al.*, 1990). In June, most of the birds using offshore waters to the west of the British Isles are associated with breeding colonies in western Scotland. Guillemots and razorbills from St.Kilda, for example, feed over a large tract of continental shelf towards the main part of the Outer Hebrides while Leach's petrels are found beyond the edge of the continental shelf to the west (figure 32). Birds start to leave colonies from July and some, like the gannet, move south to warmer waters spending winter in waters between the Bay of Biscay and western Africa. During winter, many seabirds become less attached to their nesting sites and range considerable distances in search of food but then start to move back into the area in appreciable numbers from February. Kittiwakes, for example, are present in western waters in larger numbers than earlier in the winter and are found around trawlers near the continental shelf edge as well as off Dublin. Gannets also start to be seen in increased numbers many returning to waters near their colonies at this time of year but also feeding near the trawlers at the shelf edge. (Tasker *et al.*, 1990).

The Azores are a more remote group of islands but nevertheless important for seabirds. The status and threats to seabirds in this area are poorly known compared to other Atlantic Islands but species which regularly breed on the islands include Bulwer's petrel (*Bulweria bulwerii*) Cory's shearwater (*Calonectris diomedea borealis*), Maderian storm petrel (*Oceanodroma castro*), common tern (*Sterna hirundo*) and roseate tern (*Sterna dougallii*) (Monteiro *et al.*, 1996). There have been dramatic declines in population levels for most species and regression in breeding distributions since the 15th century to the point where most species now only breed on the small islets. The birds seem to feed opportunistically on a wide variety of shoaling fish and squid with the terns and Cory's shearwater often feeding in association with dolphins, tuna and other fish that drive potential prey to the surface.

2.9.2 Conservation issues

Many of the issues that need to be tackled for effective seabird conservation relate to threats to seabirds while on land. Loss and damage to nesting and roosting habitat, predation of chicks by vermin and disturbance and capture by humans are some of the main examples. In the offshore environment, abundance, quality and availability of prey, incidental capture, and impact from pollution incidents, particularly oil spills, are the major issues. Tackling such issues is made more complicated by the fact that seabirds not only cross national boundaries but may in fact spend much of the time in international waters.

Lack of food has been implicated in the sudden and substantial declines in seabird numbers such as the common guillemot in the late 1980s when capelin stock was very low, and puffin numbers following the collapse of Norwegian spring-spawning herring stock. Reproductive

success can also be affected and prolonged periods of low prey biomass may lead to significant decreases in seabird populations size (see examples in Jennings & Kaiser, 1998). In other cases, population numbers have increased and have been linked to the greater availability of food for scavenging birds that take offal discarded from fishing boats. The number of seabirds potentially supported by fishery waste in the North Sea has been estimated to be 5.9 million individuals (Garthe *et al.*, 1996). The large gulls in particular appear to take advantage of this food source but the wholly pelagic bird species, such as the northern fulmar (*Fulmarus glacialis*), northern gannet (*Morus bassanus*) and black-legged kittiwake (*Rissa tridactyla*), do not use the fisheries waste to the same extent.

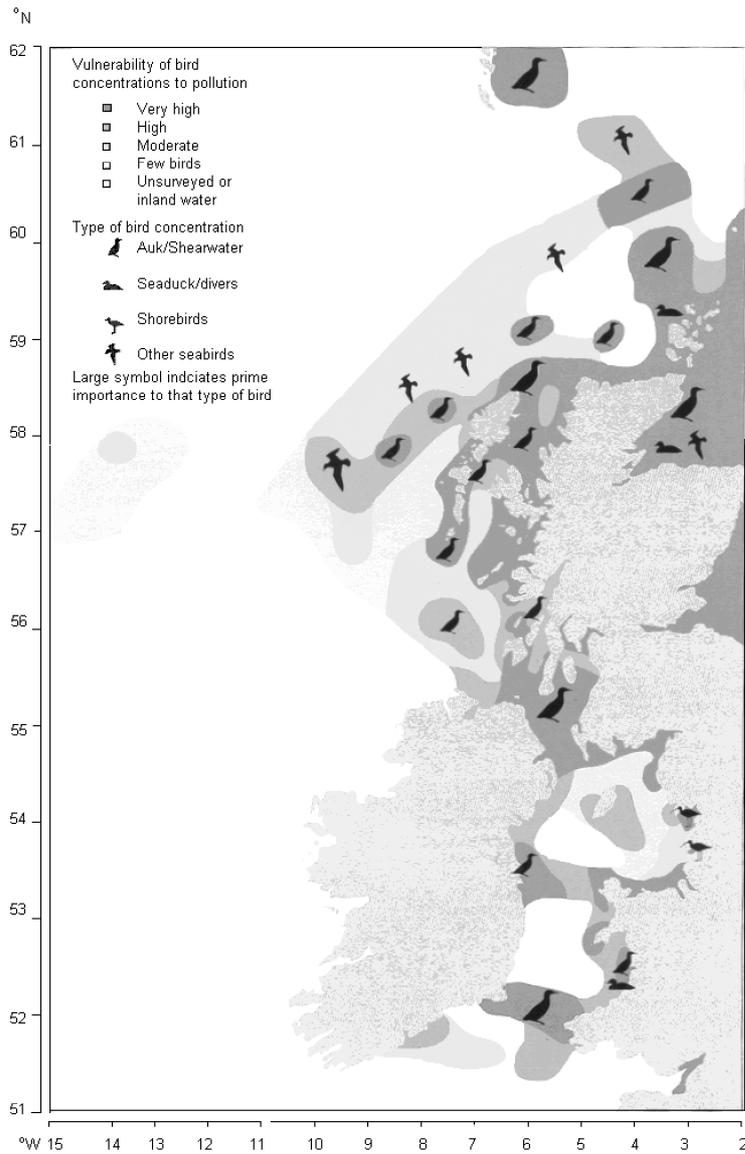
Seabird mortality can also be attributed to direct catch. Entanglement, particularly in gill nets and other set nets, is a hazard and cause of mortality to diving seabirds in inshore waters. In northern Norway, the breeding populations of guillemots at two sites were estimated to have declined by 95 per cent from the early 1960s to 1989 - a figure which could be explained entirely on gill net mortalities based on observed catch rates. In the open ocean longlining, which can involve the deployment of many thousands of baited hooks in a single operation, is known to catch northern fulmar (*Fulmar glacialis*) and possibly gannets and kittiwakes. In the OSPAR maritime area, these fisheries take place in the south-west Celtic Sea, on the upper slopes of the north-eastern Atlantic, north and west of Shetland, and round to the west of the Hebrides. (Dunn, 1997). In the southern hemisphere longlining is pushing many albatross species into chronic decline (Dunn, 1995).

The vulnerability of birds to marine pollution incidents such as oil spills, depends on the species in question and whether they occur in the area at the time of an incident or while the area is likely to remain contaminated. This information has been mapped for the North Sea and sea areas to the west of Britain (Carter *et al.*, 1993; Tasker *et al.*, 1990).

2.9.3 Conservation actions

Three types of actions are generally needed for successful seabird conservation. Actions focused on the animals themselves, site-based measures to protect areas that are important to seabirds such as nesting and roosting sites, and wider measures to maintain the quality of the environments used by seabirds. Although generally viewed in a terrestrial context, all of these measures can and should be applied for seabirds at sea. Work has already been undertaken to assist the focus on species through international convention and European Union directives. Species of European Conservation Concern (SPECs) have also been identified by BirdLife International (Tucker *et al.*, 1994; BirdLife International 1999) (box 6) and those which occur in the OSPAR maritime area put forward for consideration on the lists of species requiring conservation action currently being developed by OSPAR. Activities which pose actual or potential threats to such species need to be tackled. One example of the way in which this is being done is the FAO global accord to reduce the incidental killing of seabirds in longline fisheries. This proposes that nations should assess their longline fisheries impact on birds and, if there is a problem, develop and implement a national plan of action by 2001. Modifications of equipment are also under development such as an underwater setting funnel and bird scaring lines.

Figure 32: Vulnerable concentrations of seabirds to the west of Britain in May (from Tasker et al., 1990)



Site conservation measures for seabirds have been almost exclusively focused on land to protect birds at their nesting and roosting sites. More recently there has been interest in extending such protection not only to the adjacent areas of sea where large numbers of birds may rest on the surface or feed but also sites further from land which are the focus of their feeding activity at sea (RSPB, 1997). These can be important sandbanks, frontal zones, areas of upwelling, and current swept areas where there may enhanced productivity or concentration of food.

Wider environmental measures that will benefit seabirds include those which are designed to safeguard and improve water quality, controls on substances entering the marine environment which are toxic, persistent and liable to bioaccumulate, fisheries management which takes

account of wider environmental impacts including depletion of seabird prey species and implications for ecosystem function, and actions which minimise the risk of pollution incidents at sea. All these measures are relevant to seabird conservation in the OSPAR maritime area.

2.10 DEEP SEA FISH

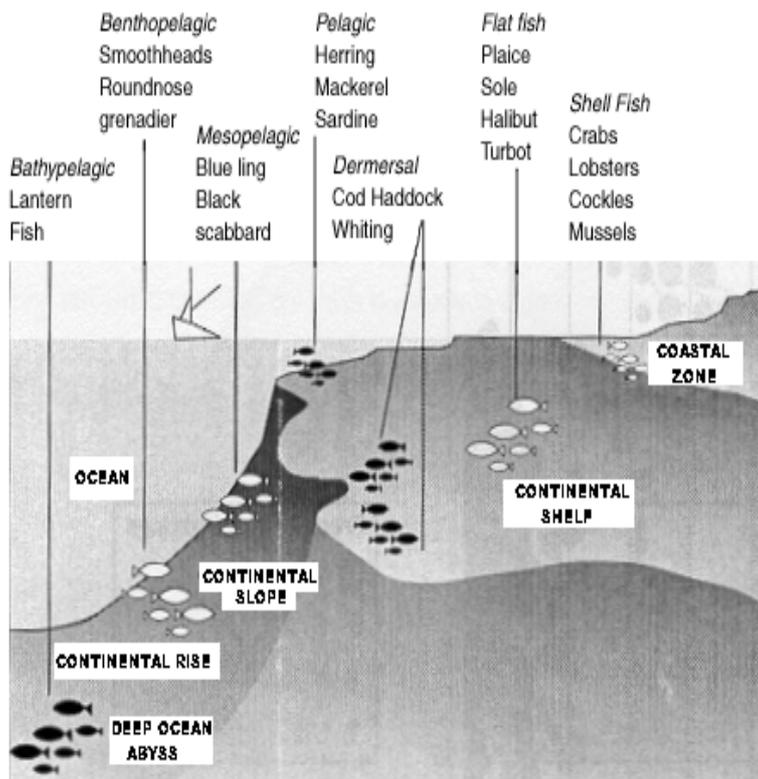
This section of the report is principally concerned with deep sea benthopelagic fish. These are species that are associated with, or live close to, the sea-bed and that are found in the deepest parts of the ocean, the bathyal and abyssal zones (below depths of 1,000m) where sunlight does not penetrate. Reference is also made to some mesopelagic species, that occupy a twilight zone between 150m-1,000m which extends from the edge the continental shelf to the bathyal zone (figure 33).

Box 6: Examples of marine birds occurring in the OSPAR maritime area which are species of European Conservation Concern and/or are listed on Annex I of the EU Birds Directive (from BirdLife, 1999).

Note: Species are listed in order of increasing conservation concern on SPEC ranking
 'T' indicates that a species registers for any given ranking
 EC Birds 1 = Annex 1 of EU Birds Directive
 SPEC 1-4 = Species of European Conservation Concern

Common Name	EC Birds 1	SPEC 1	SPEC 2	SPEC 3	SPEC 4
Steller's eider		T			
Fea's petrel	T	T			
Zino's petrel	T	T			
Cory's shearwater	T		T		
Manx shearwater			T		
Storm petrel	T		T		
Gannet			T		
Common gull			T		
Sandwich tern	T		T		
Black guillemot			T		
Puffin			T		
White-faced storm petrel				T	
Red-throated diver	T			T	
Black-throated diver	T			T	
Bulwer's petrel	T			T	
Little shearwater	T			T	
Leach's storm-petrel	T			T	
Madeira storm-petrel	T			T	
Scaup				T	
Velvet scoter				T	
White-tailed eagle	T			T	
Little gull				T	
Gull-billed tern	T			T	
Caspian tern	T			T	
Roseate tern	T			T	
Little tern	T			T	
Shag					T
Great skua					T
Mediterranean gull	T				T
Lesser black-backed gull					T
Great black-backed gull					T
Razorbill					T
Great northern diver	T				
Slavonian grebe	T				
Red-necked phalarope	T				
Common tern	T				
Arctic tern	T				
Guillemot (Iberian race)	T				

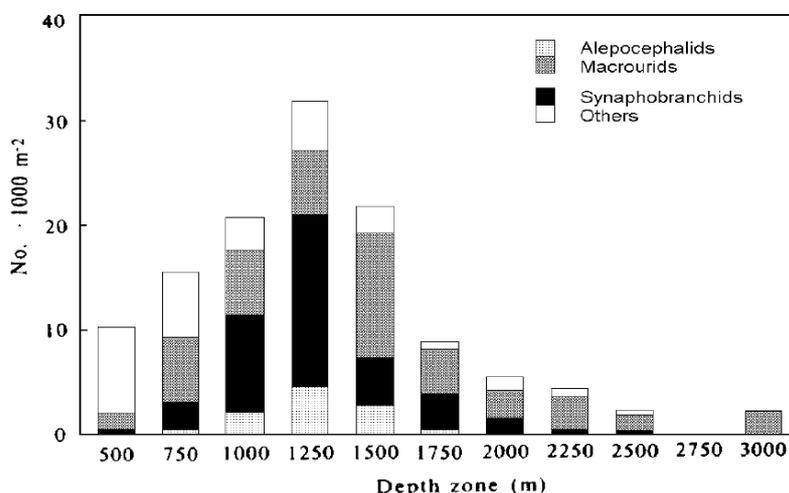
Figure 33: Diagram of fish species on continental shelf continental rise and deep-ocean abyss (from Greenpeace 1997)



Nearly 1,000 species of bottom-dwelling fishes are known as a result of trawling the deep sea bottom (Gage & Tyler, 1991). They include hagfishes, gulper eels, grenadier fish, tripodfish, skates and species of bony fish such as the flatfish and angler fish. The relative abundance of the different groups varies with depth with the macrourids (rat-tails & grenadiers) often the most abundant and, like many benthopelagic fish, being most diverse and numerous on the continental slope, particularly in middle to low latitudes (Gage & Tyler, 1991).

Changes in abundance of different groups of deep sea fish with depth is particularly well illustrated by the work of Gordon & Mauchline (1990) who studied the three main groups of bottom-living fish in the Rockall Trough. Their analysis of the numbers and biomass of alepocephalids (smoothheads, slickheads), macrourids (grenadiers, rat-tails) and the synphobranchids (arrowtooth eels, cut-throat eels) shows a peak in the numerical abundance of fish as 1,250m (mostly due to the presence of the deep sea eel, *Synphobranchus kaupii*) and a peak in biomass in the same depth zone but, in this case, mostly due to the presence of the smoothhead *Alepocephalus bairdii*. (figures 34 & 35). The vertical distribution of deep-water species in the water column is nevertheless still poorly understood.

Figure 34: Estimated abundance of fish in different depth zones of the Rockall Trough (from Gordon & Mauchline, 1990).

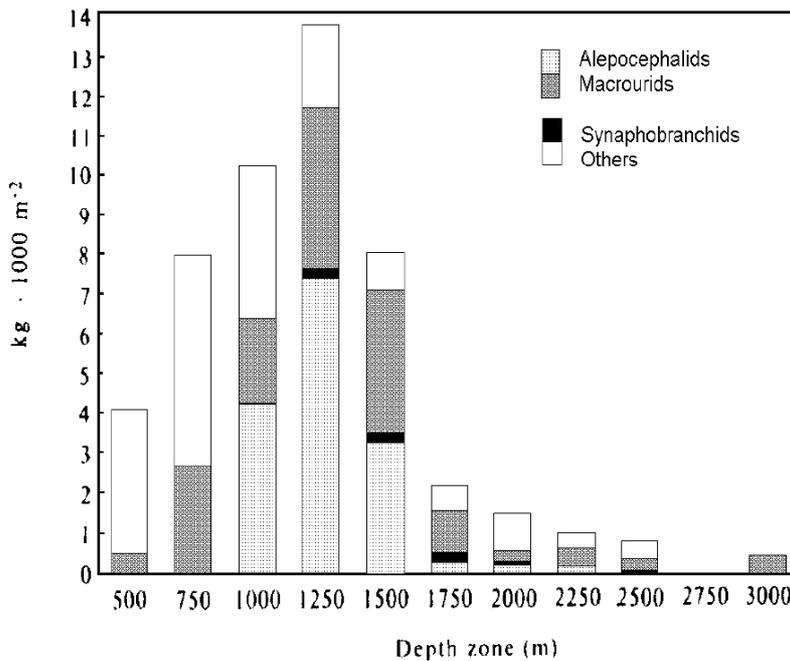


Many deep-water fish tend to be long-lived and slow growing with a relatively high age of maturity. Orange roughy, *Hoplostethus atlanticus*, for example, are believed to live more than 120 years, maturing after 25 years, and the roundnose grenadier, *Coryphaenoides rupestris* maturing at around 10 years with a longevity of around 60 years (summary table from Koslow *et al.*, in press). Adaptations to the deep sea environment include elongate body forms, neutral buoyancy, long-based dorsal and anal fins sustained by many fin rays, overall darkening in body colour by black or red pigmentation, and reduced metabolic rates (Marshall, 1972; Merrett & Haedrich, 1997). Deep sea fish also exhibit a variety of feeding strategies such as scavenging, active predation, or ambushing prey in what is generally a food-poor environment. Some species, such as the roundnose grenadier feed on migrating zooplankton as they descend during the day and so, although a benthopelagic species, take pelagic prey.

The main components of the diet of deep sea bottom-living fish in the north-east Atlantic are generally species which live close to or on the sea-bed rather than the benthic infauna. They include other fish, copepods, amphipods, decapods, euphausiids and cephalopods. The most numerous prey items for bottom-living fish at nine depth zones between 500m and 3,000m in the Rockall Trough, for example, tended to be fish in the upper levels (500m, 800m & 1,000m), while unidentified material was important at greater depths (figure 35) (Gordon & Mauchline, 1990). The importance of fish in the diet can be accounted for by the abundance of the fish eating *Aphanopus carbo* and the increase in the importance of copepods in the 750mm zone, mainly due to the dominance of the roundnose grenadier *Coryphaenoides rupestris*, which has a very diverse diet. Although fish and copepods remain important dietary components in the 1,000m zone, unidentified material is increased: about 80 per cent attributed to Baird's smoothhead, *Alepocephalus bairdii* being the dominant species in this zone, of which a significant part may be salps and or ctenophores. The dominant species at the 2,250m zone is *Coryphaenoides guentheri* which accounts for most of the copepods consumed while the prey

composition in the 3,000m zone reflects the typically diverse diets of macrourid fishes which were most abundant in this zone.

Figure 35: Estimated biomass of fish in different depth zones of the Rockall Trough (from Gordon & Mauchline, 1990).

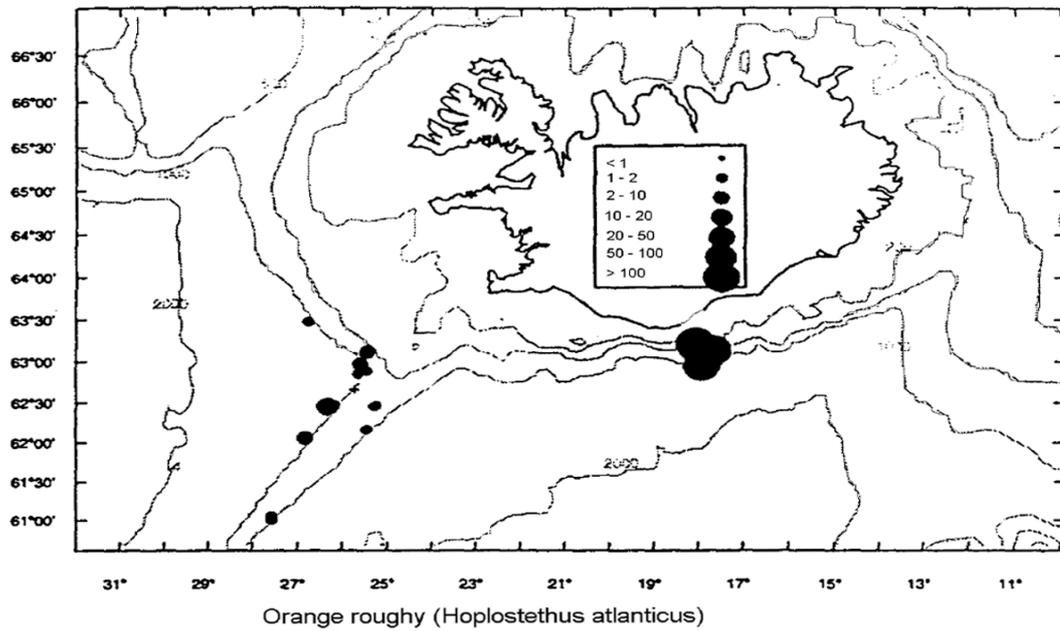
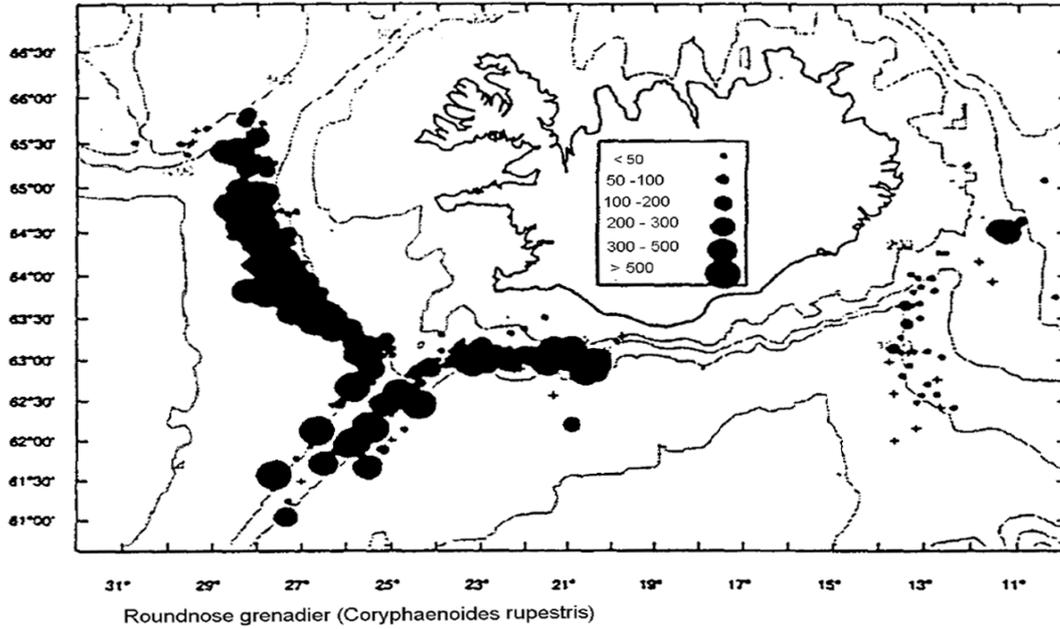


2.10.1 Distribution in the OSPAR maritime area

Detailed knowledge about the distribution of many deep-water species remains poor but some areas, such as the continental slopes of the North Atlantic have been well studied. They reveal both geographic and depth distribution patterns for deep sea fish.

The Norwegian Basin is very cold (0°C or less below 500m) but quite productive with the deep-water fish in this area most similar to those reported off Iceland and the Rockall Trough. Characteristic species include *Raja hyperborea*, *Macrourus berglax*, *Anarchichas denticulatus*, *Cottunculus microps*, *Careproctus reinhardti*, *Reinhardtius hippoglossoides* and *Lycodes* spp. which have been identified as part of an Arctic deep-water fauna off Iceland (Merrett & Haedrich, 1997). The Iceland-Faeroe Ridge, which separates the Norwegian Basin from the Iceland Basin, acts as a major faunal barrier for deep-water fish to the extent that none of these species range widely outside the immediate area of the Norwegian Sea and the majority of the small number of macrouridae from this basin appear to be endemic (Gordon, 1986; Rass *et al.*, 1975 in, Merrett & Haedrich, 1997).

Figure 36: Distribution of roundnose grenadier and orange roughy around Iceland (from Magnusson & Magnusson, 1995).



Around Iceland the Reykjanes Ridge area appears to be particularly significant because of its importance as a spawning and nursery ground for several species of deep sea fish (Magnusson & Magnusson, 1995). The macrouridae are common in the deep waters around Iceland with the roundnose grenadier widely distributed and common off the south and west coasts of Iceland as well as being common on the western slope of the Iceland-Faroe Ridge. The area off the southwest coast, particularly from the Reykjanes Ridge north to 64°N and between the Westman Islands and the Reykjanes Ridge is thought to be a nursery ground for this species and the ridge a spawning ground for blue ling (*Molva dypterygia*), and black scabbard fish (*Aphanopus carbo*). In contrast, the orange roughy (*Hoplostethus atlanticus*) has a very localised distribution (figure 36).

Further south, the Rockall Trough lies at the northern end of the range of a faunal region which may extend to around 20°N where the Mediterranean outflow and proximity to the region of the West African upwelling are major influences (Gordon, 1986). The deep sea fishes of the Rockall Trough include rays, smooth-heads, lizardfish, spiny eels, grenadiers and cuskeels (box 7). The dominant species on the slope is the roundnose grenadier *Coryphaenoides rupestris*, but there are also large numbers of the deep sea eel *Synaphobranchus kaupi* and alepocephalids especially Baird's smoothhead (*Alepocephalus bairdii*) (Gordon, 1986; Gordon & Mauchline, 1990). The Porcupine Sea Bight has a number of species which are exclusive to the area or very rare in the Rockall Trough like the macrourid *Trachyrincus trachyrincus*, and increased diversity of alepocephalid fishes possibly related to the greater influence of Mediterranean water in the Porcupine Sea Bight (Gordon & Mauchline, 1990).

Around the archipelago of the Azores, the most recent checklist of fishes covers 460 species (Santos *et al.*, 1997). This includes epipelagic, mesopelagic and bathypelagic species such as grenadiers (for example, *Coryphaenoides guentheri*, *Nezumia aequalis*), smooth-heads (for example, *Alepocephalus rostratus*, *Bellocia koefoedi*), arrowtooth eels (for example, *Histiobranchus bathybius*, *Synaphobranchus kaupi*) and roughy (*Hoplostethus atlanticus*, *H. mediterraneus*).

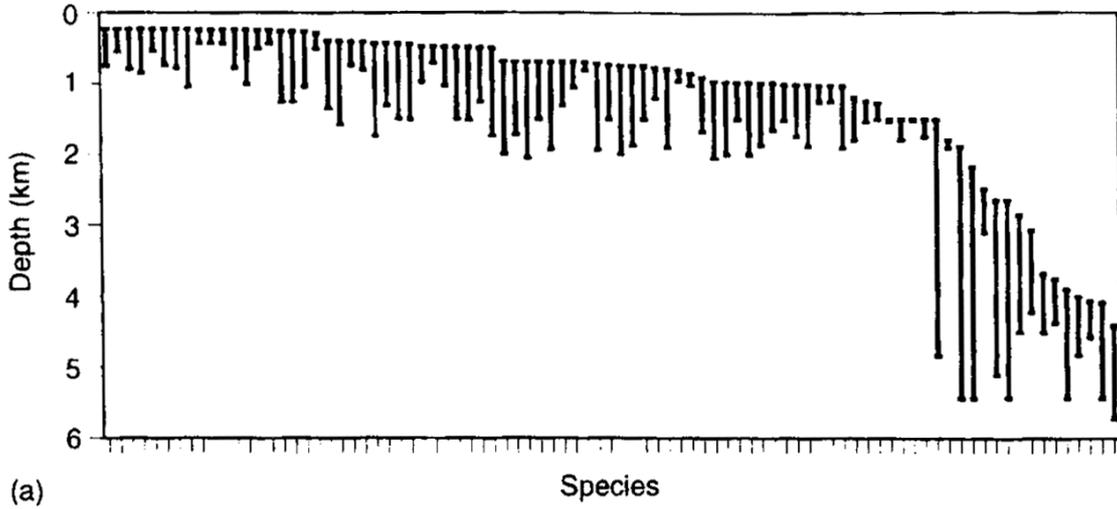
Apart from the Iceland-Faroe Ridge, the southern boundary of the OSPAR maritime area may also be an important biogeographic boundary for deep sea fishes. Analysis of data available in the late 1980s by Merrett (1987) suggested a distinct change in abyssal demersal fish between 34°N and 41°N. Further sampling confirmed a northerly abyssal fish assemblage in latitudes of 41-49°N and another group between 31-38°N (Merrett, 1992). More recent analysis with additional fish records suggests that the northerly group of stations remain relatively discrete but coalesces with a group of stations from intermediate latitudes (Merrett & Haedrich, 1997). Other studies support the hypothesis that this is a zone of transition. It corresponds with an area where there is a marked change in the depth of winter mixing for example, which will affect the seasonality of production in the water column. As with many aspects of deep sea biology, this is clearly a subject which will need ongoing assessment as more records become available.

All well as differences in geographic distribution, individual species are also known to occur over bathymetric ranges from a few hundred to thousands of metres (figure 37).

Box 7: Species of demersal fish occurring at the 2200, 2500 and 2900m bathymetric zones in the Rockall Trough (from Gordon, 1986)

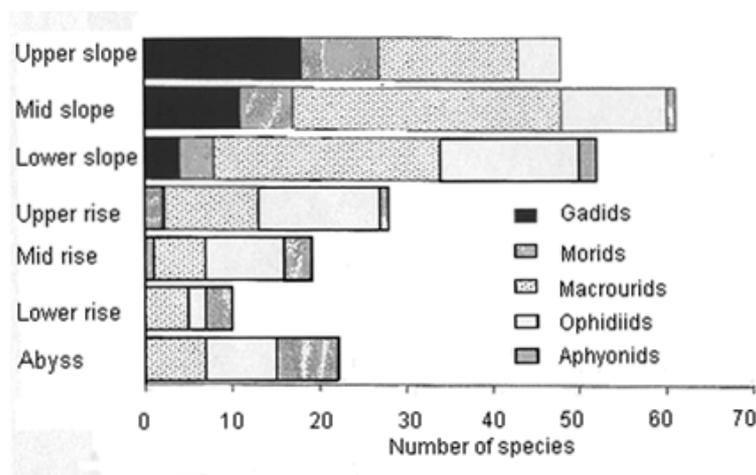
	2200	2500	2900
Rajidae			
<i>Raja (Amblyraja) sp.</i>	+		
<i>Raja (Rajelia) bigelowi</i> Stehmann, 1976	+		
<i>Bathyraja pailida</i> (Forster, 1967)	+		+
Alepocephalidae			
<i>Alepocephalus agassizi</i> Goode & Bean, 1883	+	+	
<i>Alepocephalus bairdii</i> Goode & Bean, 1879	+		
Synodontidae			
<i>Bathysaurus agassizi</i> Goode & Bean, 1883			
<i>Bathysaurus mollis</i> Gunther, 1878		+	+
Synaphobranchidae			
<i>Synaphobranchus kaupi</i> Johnson, 1862	+	+	
<i>Histiobranchus bathybius</i> (Gunther, 1877)		+	+
Halosauridae			
<i>Halosauropsis macrochir</i> (Gunther, 1878)	+	+	+
Notacanthidae			
<i>Polycanthonotus rissoanus</i> (Filippe & Verany, 1859)	+	+	
<i>Polycanthonotus africanus</i> Gilchrist & Von Bonde, 1924	+		
Macrouridae			
<i>Coryphaenoides guentheri</i> (Vaillant, 1888)	+	+	
<i>Nematonurus armatus</i> (Hector, 1875)	+	+	+
<i>Chalinura brevibarbis</i> Goode & Bean, 1883	+	+	+
<i>Chalinura leptolepis</i> (Gunther, 1879)	+	+	
<i>Chalinura mediterranea</i> Giglioli, 1893	+	+	
<i>Lionurus carapinus</i> (Goode & Bean, 1883)	+	+	+
Moridae			
<i>Antimora rostrata</i>	+	+	+
Zoarcidae			
<i>Lycodes atlanticus</i> Jensen, 1902	+		
<i>Lycodes sp.</i>	+		
Ophidiidae			
<i>Spectrunculus grandis</i> (Gunther, 1877)	+		
Bythitidae			
<i>Cataetyx laticeps</i> Koefoed, 1927	+		
Liparidae			
<i>Paraliparis bathybius</i> (Collett, 1879)	+		

Figure 37: Individual bathymetric ranges of deep demersal fish species on the slope and rise of the Porcupine Sea Bight and Abyssal Plain (from Merrett & Haedrich, 1997)



The gadids are fishes of the shallow depths with numbers declining across the slope and none in deeper waters of the Atlantic Basin (figure 38). The alepocephalidae, macrouridae and ophiidiidae are the dominant families at all depths and although most species within these groups have a limited depth distribution, some range over thousands of metres. The cut-throat eel *Synaphobranchus kaupi* is one such example as it is known to occur from depths of 230m to more than 2,000m (Merrett & Haedrich, 1997).

Figure 38: Number of species in different families over different depth zones in the North Atlantic Basin (Merrett & Haedrich, 1997)



2.10.2 Conservation issues

Commercial fisheries have been targeting deep sea species since the 1950s with global landings after the initial period of rapid expansion generally varying between 800,000 to one million tons (FAO figures from Koslow *et al.*, in press). In the last two decades, the serious impacts of this activity on fish stocks have become particularly apparent with a shift in focus of the fisheries to different species as stocks or areas have become depleted. The bycatch associated with bottom trawl fisheries and discards of unwanted fish are another concern as is the fact that many of these fisheries take place in international waters making it difficult to regulate and enforce any management measures.

The life-history characteristics of many of the species targeted by deep sea fisheries make them particularly vulnerable to over-exploitation. These are generally low growth rates, later maturity, extreme longevity, highly episodic recruitment and often an aggregating habit on restricted topographic features. As a result, deep sea fisheries have been referred to as analogous to a mining operation where an ore body is exploited to depletion and then new sources are sought (Merrett & Haedrich, 1997). It has also been stated that most of the targeted species are already overfished or in danger of depletion (Koslow *et al.*, in press). Another area of concern is about possible shifts in species composition caused by taking out species that are dominant in mid-to upper trophic levels. There is no evidence for this at the moment but because of the longevity, slow growth and later maturation of many deep-water species, it may be too early to assess whether this is taking place (Merrett & Haedrich, 1997; Koslow *et al.*, in press). What has been seen, however, is a downward shift in the size structure of deep sea fish assemblages which is a classic sign of fishing pressure on a stock. There have also been declines in landings and shifts in the species caught as stocks become depleted.

In the north-east Atlantic, for example, 40 per cent of the landings of the redfish *Sebastes* spp. in the 1980s was *S. marinus* but this has largely been replaced by the deeper and more oceanic *S. mentella*, while roundnose grenadier *Coryphaenoides rupestris* catches in the north-east Atlantic peaked in 1971 at over 80,000 tonnes then declined quickly to only a few hundred tons in 1997 (Koslow *et al.*, in press). Other species in the north-east Atlantic which are particularly vulnerable are smoothheads (*Alepocephalidae* spp.) which can make up a large percentage of catches on the continental slope to the west of Scotland but which are discarded, argentine (*Argentina silus*) where a crash in catches in the Irish directed deep-water fishery in an area west of the Hebrides was reported in 1990, blue ling (*Molva dypterygia*) which are fished while aggregating during the spawning season, black scabbard (*Aphanopus carbo*) which are caught west of the British Isles in bottom trawls but for which there is a lack of basic life-history information, and deep-water sharks, some of which are bycatch and others the specific target of fisheries (Greenpeace, 1997).

2.10.3 Conservation actions

The vulnerability of many deep sea fish stocks to over-exploitation, lack of information about the biology of most species, rapid declines in landings of even relatively recently exploited stocks, pressure to discover and exploit new stocks, and poor regulation of existing deep sea fisheries have led to an increasing number of calls to slow-down and, in some cases, to stop deep sea fisheries. Options which have been discussed include the establishment of deep sea reserves in areas where species aggregate to spawn (Koslow *et al.*, in press), an interim suspension of deep sea fishing while information is collected on which to base a management

regime (House of Lords, 1996) and a total ban on deep-water fisheries to the west of the British Isles to protect the remaining highly vulnerable species (Greenpeace, 1997). Merrett & Haedrich (1997) suggest that the only possible deep sea fisheries that might be viewed as continued and sustainable operations are those that operate on a small scale with searching done very locally and which take a very small volume of high-quality fish. They refer to the black scabbard fishery in Maderia as an example of such an operation.

It has been said that the success of any management scheme can only be measured after the passage of several fish generation times which could be at a minimum of 150-200 years for deep sea fish (Merrett & Haedrich, 1997). Clearly it is therefore essential that such fisheries should only proceed under very conservative regimes, if at all.

2.11 Xenophyophores

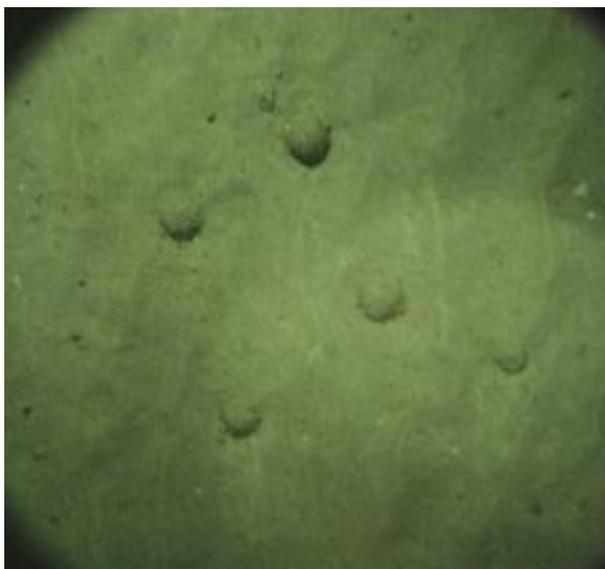
Deep sea samples often contain sediment balls, faecal pellets, and concretions of foraminiferan tests, spicule balls and organic detritus. Since the last century it has been known that some of these structures contain animals but it is only in recent years that they have been studied in any detail. One such group of animals is the xenophyophores. They were described in a monograph in the early 1970s (Tendal, 1972), and include species such as *Maudammina arenaria*, *Galatheimmina calcara*, *Psammmina globigerina*, *Reticulammina labyrinthica* and *Cerelasma massa*.

Xenophyophores are unusually large protozoans. Individuals can grow to more than 20cm in diameter and, although they are often fragile, their relatively large size has made them easier to study when compared to other protozoans found in the oceans. Their size also means that they can be categorised as part of the macrofauna of the deep sea. Most species have been observed on the surface of the sea-bed where they form part of the benthos but at least one species, *Occultammina profunda*, is known to consist of branching tubes buried 1-6cm deep in the sediment (Gage & Tyler, 1991).

A characteristic feature of xenophyophores is that they glue together sediment particles and other materials such as the tests for foraminiferans, to form a test which protrudes above the sea-bed. This contains the protoplasm but also extensive accumulations of faecal pellets known as stercomes. Particles are collected from the environment, accumulated in loose masses of 'ingested material', then gradually transferred into stercomes which are present as strings or masses (Tendal, 1979). These are deposited outside the plasma but within the test and are enclosed by membranes. It is this characteristic of agglutination of sediment particles to form large tests which has resulted in the name xenophyophore, derived from the Greek meaning "bearer of foreign bodies". They are thought to feed using pseudopodia, which collect food from the surface of the sediment or by trapping particles suspended in the water column.

The colour and shape of xenophyophore tests varies a great deal. Using photographs of specimens taken at depths of between 1,000-4,000m, Tendal & Gooday (1981) described a number of different growth forms. These could be categorised into branched, reticulate, platy, and various intermediate forms. Some of the differences were thought to be due to local conditions, which would determine the composition and grain size of the sediment particles used to form the test for example.

Plate 5: Xenophyophores on the Darwin Mounds tail.



Photograph courtesy of DEEPSEAS Group. © SOC.

Levin & Thomas (1988) have suggested that the shape of the test and its orientation varies to increase feeding efficiency and that some tests function as elaborate particle traps. They note that flattened fan-shaped xenophyophores often orientate parallel to flow when currents are uni or bidirectional, which would expose the maximum surface area to any food in the currents. Hemispherical, reticulate forms exhibit local variations in the size and shapes of the divisions which may enhance particle trapping under different flow conditions. For example the tendency of xenophyophores exhibiting this growth form to be concentrated near features such as basalt pillows which protrude from the sea floor may be because the currents generated around them provide better conditions for feeding. There is presumably some upper limit of suitability, however, as that they appear to be less abundant in areas where the water flow is strong enough to transport sediments and produce ripples on the sea-bed.

Little is known about the biology of xenophyophores, particularly how they feed or their mode and manner of growth. In the early 1990s, three specimens of *Reticulammina labyrinthica* in the abyssal north-east Atlantic were observed over an eight month period using time-lapse photography (Gooday *et al.*, 1993). Growth occurred episodically in several distinct phases, each lasting two or three days, separated by fairly regular periods of about two months with sediment collected and incorporated into the test throughout the two months between growth phase. These phases were when the organisms showed little obvious activity. It was not clear whether the periodicity and apparent synchronisation of these events in all three specimens was caused by some external environmental cue or if the growth was controlled internally and the synchronisation arose by chance.

Apart from feeding by collecting particles from the sea-bed and the water column, it has been proposed that the xenophyophores ferment micro-organisms on the masses of stercomata which they hold within their tests (Tendal, 1979). These provide the substrate for commensal

microflora which multiply to such an extent that the animal can re-digest the stercomata to take advantage of this food source. This process could be repeated several times and may be part of the strategy that allows them to gain enough food in a poor environment where there is considerable competition for food.

The large numbers of xenophyophores found in particular areas suggest that they may dominate and influence the ecology of certain deep sea benthic communities (Tendal & Gooday, 1981). This view is reinforced by studies that have found filter-feeding, deposit-feeding and carnivorous animals within their tests of xenophyophores and an increased abundance of some species in the sea-bed in the immediate vicinity. Godday (1984) reported sipunculans, polychaetes and nematodes within tests of xenophyophores and nematodes and harpacticoid copepods the dominant groups in larger eastern Pacific xenophyophores. He has suggested that they may be using the test as substrate, refuge, feeding site or breeding ground.

During investigations of deep seamount benthos in the Pacific, Levin *et al.*, (1987) reported that xenophyophores provided a habitat for 16 major metazoan taxa. This included also a family grouping of 10 isopods (*Hebefustis* sp.) within the largest test, suggesting that the tests may provide a semi-permanent residence for some species. Others, such as certain amphipods and polychaetes were highly mobile forms, so are unlikely to be resident.

The sediments immediately surrounding the animals also had higher faunal densities and species richness compared to sediment one meter from the tests (Levin *et al.*, 1987). Amphipods were exclusively associated with the tests or sediments beneath them while molluscs, and some crustaceans and echinoderms were three or four times more abundant under the xenophyophores than in control cores. Total faunal density and species richness were enhanced in the core with xenophyophores.

Interactions between xenophyophores and large epifauna have also been studied (Levin & Thomas, 1988). From short-term observations it appears that the most apparent interaction was the consistent presence of one or more large ophiuroids beneath most xenophyophore tests observed on seamounts in the Pacific (Levin & Thomas, 1988). On sandy sediments the arms typically protruded from beneath the tests and occasionally ophiuroids were on top of the tests. Photographs taken in quiet muddy settings showed urchin and scaphopod tracks that circled xenophyophore tests suggesting some form of attraction.

Another result of xenophyophore activity may be an increase in the particle flux of fine-grained material to the sea-bed and enhancement subsurface mixing. In this way they may be altering the hydrodynamic conditions. Radiochemical studies support the idea that xenophyophores are focii of sediment deposition. Particle selection for test construction and feeding may be an important source of the heterogeneity in texture and composition of seamount sediments.

2.11.1 Distribution in the OSPAR maritime area

Xenophyophores are confined to the deep sea but occur throughout the world's oceans. They were once thought to be rare as few specimens survived early sea-bed sampling techniques but they are now known to be widespread and especially abundant in regions of high surface productivity and on topographic features such as seamounts, ridges, canyons, troughs and continental slopes (Levin & Thomas, 1988). They are a common element of the epifauna at

depths greater than 500m in regions of the Atlantic, Indian and Pacific oceans and some species have widespread distributions that extend into the Arctic. Their physical dominance of the macrofaunal of deep sea sediments in the north-east and north-west Atlantic, as well as the eastern, central and south-west Pacific, is reflected in the fact that they have been reported in densities of hundreds per 100m² to more than 2,000 per 100m² (Tendal & Gooday, 1981).

2.11.2 Conservation issues

The widespread distribution of xenophyophores, their synecology, and the fact that they can occur in very high densities has led to the suggestion that they are an important source of sedimentary and faunal heterogeneity and as such may contribute to maintenance of benthic diversity in the deep sea.

2.11.3 Conservation actions

Xenophyophores occur throughout the OSPAR maritime area and consequently no sites are singled out here for particular attention. If areas are found to be of special importance for this species in the future, conservation efforts may need to be focused on such locations. The more likely scenario is for xenophyophores to be one element of the benthos to be safeguarded through general conservation measures applied to the deep sea.

2.12 DEEP SEA MUD

Contribution by Maria C. Baker and Brian J. Bett. DEEPSEAS Group, George Deacon Division, Southampton Oceanography Centre (2001).

This directory covers a number of interesting and exciting deep-water habitats, biological communities and species. By contrast deep sea mud may seem a little “dull”. Plain deep sea mud is nevertheless the dominant habitat in the OSPAR maritime area; indeed it is the dominant habitat on this planet. Despite its apparently featureless nature, recent research has shown that deep sea mud supports a previously unexpected wealth of biological diversity. It is quite possible that the majority of animal species on this planet live in deep sea mud. Of the tens of millions of animal species that probably live on Earth today, it is quite possible that over 75 per cent of them will be found on the deep sea floor – although to date we are only aware of a tiny fraction of this diversity.

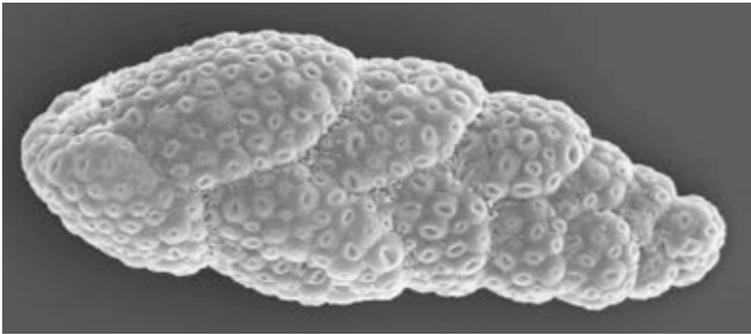
Muds and other deep sea sediments

Marine sediments are classified on the basis of the most abundant particle type found in a particular deposit. The abundance of a particle type is dependent upon: (1) the rate of its supply to the sediment, (2) the degree to which it is preserved in the sediment, and (3) the rate of sedimentation of other particles (Libes. 1992). In the deep sea, exposed hard rock is rare, being found only on steep continental slopes, seamounts and along mid-ocean ridges (Gage and Tyler, 1991). The only other substantial sources of solid substrata are: a) the polymetallic nodules or crusts that may form in some regions (for example, around the Goban spur in the north-east Atlantic, Karpoff et al., 1985), and b) glacial erratics (iceberg dropstones) that, for example, provide a significant habitat on the upper slope of the UK continental margin (Bett, 2001).

Deep sea sediments are primarily composed of clays or biogenic oozes, depending upon the productivity of overlying waters. Abyssal clay covers most of the deep-ocean floor. It

accumulates very slowly (1mm per 1,000 years), and it is mostly made up of clay-sized particles from the continents, carried by wind or currents. Biogenic oozes are derived from the remains of planktonic organisms and may be calcareous (from foraminiferans, pteropods and coccolithophores; see plate 6) or siliceous (from diatoms or radiolarians).

Plate 6: A benthic foraminiferan that uses planktonic coccoliths to construct its test (shell).



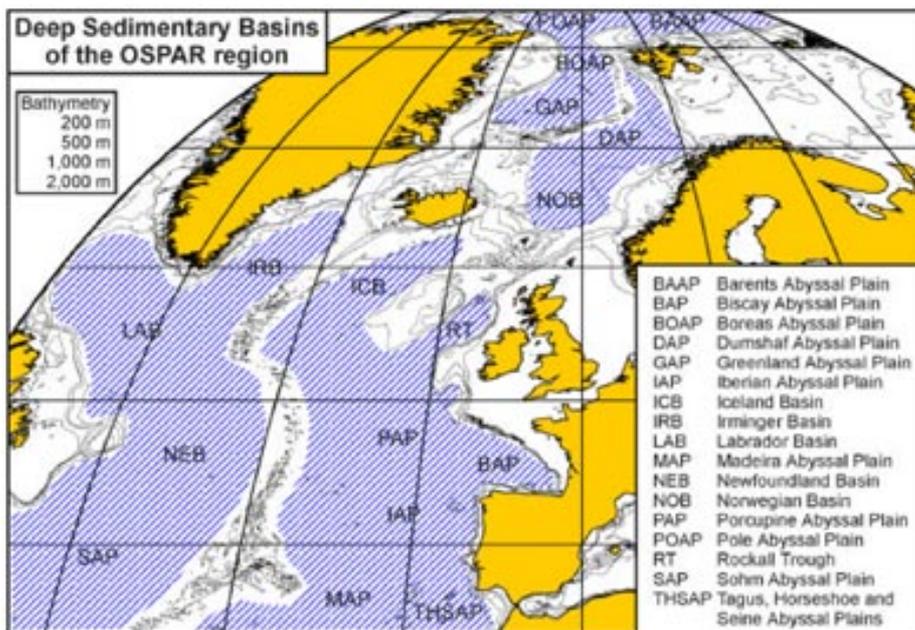
Photomicrograph courtesy of A. Hughes and A. Gooday, © SOC.

Accumulations of these oozes differ in thickness and distribution, governed mainly by primary production and water depth. Chemical, biological and physical processes in the ocean have the ability to destroy a large fraction of particles before they reach the deep sea floor. On abyssal plains the sediment blanket may be thousands of metres thick. The study of these thick layers of deep sea mud is used to answer questions about climate change, as these sedimentary layers preserve a unique record of past change (for example, Zahn, 1992, 1994; Thomas et al., 1995).

2.12.1 Occurrence in the OSPAR maritime area

A substantial part of the deep sea OSPAR maritime area is characterised by almost feature-less abyssal plain, comprising relatively flat areas that are located either side of the mid-Atlantic Ridge. Three main basins exist – the Newfoundland Basin in the north-west, the Porcupine Abyssal Plain (about 165,000 km²) in the east and the Iberian (about 107,000 km²) and Tagus abyssal plains (about 41,000 km²) in the south-east. All of these plains are >4,500m deep. Other basin and deep sea areas in the region are shown on figure 39.

Figure 39: Chart showing main sedimentary basins and deep sea areas of the OSPAR region.
(Provided by B. Bett, SOC)



Bottom sediment accumulations vary according to the topography and the local current regime but are generally between 0.1km and 2km thick (OSPAR Commission, 2000). Pelagic ooze sediments (predominantly those rich in calcium carbonate) have been built up over millions of years, along with minor amounts of aeolian atmospheric dust and turbidity current sediments. Turbidity currents periodically transport terrigenous muds and pelagic sediments to the ocean basins. Major turbidity currents, originating from underwater landslips, may have a catastrophic and long-lasting effect on the fauna (Huggett, 1987). In addition, volcanic processes, ice rafting and bottom currents may have added to the sediments (Emery and Uchupi, 1984; Andrews, 1998). Deep, contour-following currents may produce significant local variations in sediments and consequently influence faunal distributions (Bett, 2001). In general, sediments become progressively finer with increasing depth and distance from land (Lampitt et al. 1986) except for some areas which have coarser sediments deposited via canyons onto the continental slope and rise (Mart et al. 1979). Consequently, the presence of canyons can have a significant impact on the composition of deep sea biological communities. An extensive network of submarine canyons and channels exist in the OSPAR region (see example in figure 40).

2.12.2 Deep sea mud communities

The deep sea fauna is essentially composed of animals similar to those found in coastal sediments, with many deep sea species belonging to the same families or genera as their shallow-water counterparts (Gage, 1997). The abundance of the benthic fauna generally decreases with reduced food supply and therefore decreases with increased depth. Consequently, the deep sea muds often harbour relatively low densities of fauna (Gage and Tyler, 1991).

Figure 40: Bathymetry of the Porcupine Sea Bight, showing an extensive canyon/ channel system. (Provided by B. Bett, SOC).



Megafauna

The most common surface-dwelling deep sea megafauna (larger animals) in the OSPAR region are the echinoderms, including holothuroidea (sea cucumbers, see plate 7), ophiuroidea (brittle stars), Echinoidea (sea urchins) and Asteroidea (sea stars). In the Rockall Trough, the brittle stars make up 27 per cent of the echinoderm species collected, and numerically they far outnumber (63 per cent) any other megafaunal group (Gage and Tyler, 1991).

Plate 7: Sea cucumber (Holothurian, *Psychropotes semperiana*) photographed at 4,000 m.



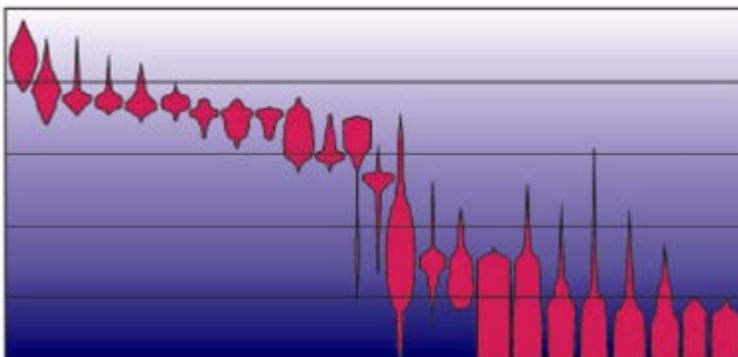
Photograph courtesy of DEEPSEAS Group, © SOC.

Sibuet (1985) found that holothurians were abundant in the Norwegian, Lofoten and Greenland Basins (depth range 2500 – 3700 m), occurring in densities of over 7,000 individuals per hectare (10,000 m²) in some areas. Studies on the Porcupine Abyssal Plain have shown that

holothurians, actinarians and, to a lesser degree, asteroids, constitute a major proportion of the invertebrate megafauna both in terms of abundance and biomass (Thurston et al., 1994). In addition to the echinoderms, various types of ‘worms’, sea spiders, amphipods and decapod crustaceans inhabit the deep sea-bed. Sessile fauna also inhabit deep sea muds, including the sponges, hydroids, sea pens, sea fans and deep sea corals (see also the chapters on corals and sponges in this directory).

Bathymetry, current velocity, sediment type and bottom water-mass distribution all seem to have a significant influence on the distribution and composition of megafaunal communities (Levin and Gooday, in press). Many, if not most, megafaunal species have quite narrow bathymetric (depth) ranges and exhibit ribbon-like distributions along continental margins (Billett, 1991; see figure 41). Consequently, there is more or less continuous change in megafaunal species composition with depth, although there may be particular depth bands within which there are greater rates of change in species composition (Gage, 1986; Billett, 1991). These bands of increased change in the megafauna mark the boundaries of deep sea depth “zones” (see Carney et al., 1983). These zones may be useful in defining deep sea biogeographic boundaries for environmental / conservation purposes (see further below).

Figure 41: Schematic representation of the depth distributions of the dominant holothurian species (sea cucumbers) in the Porcupine Sea Bight, depth range shown is 0-4,850 m. (Adapted from Billett, 1991, provided by B. Bett, SOC).



Before leaving the megafauna, it is also worth noting that there may be distinct megafaunal communities in ‘high energy’ (higher current speed) sandy habitats in the deep sea, although this habitat type is currently little known in the deep sea. Bett (2001) noted the presence of a highly unusual community of sediment surface dwelling megafaunal enteropneusts on a sandy contourite sheet at about 900 m in the Faroe-Shetland channel. Other studies in this area and the adjacent Faroe Bank channel have revealed other sand, and even gravel, dominated deep sea habitats (Bett and Jacobs, 2000), including a field of barchan sand dunes at 1,200 m inhabited by numerous small anemones (Wynn et al., in press).

Macro- and meio-fauna

In terms of the smaller size fraction of animals associated with deep sea muds, the main macrofaunal groups are the polychaetes (see plate 8), ‘other worms’, amphipods, tanaids,

isopods, bivalves and gastropods. Bett (2001) found that the macrofauna of the Rockall Trough and Faroe-Shetland channel was dominated by polychaetes and amphipods.

The ecology of this region is strongly controlled by hydrography with the temperature contrast between different water masses exerting a major influence on the distribution and diversity of the macrobenthos. A time-series study of macrofauna in the Rockall Trough at depths of 2,200 and 2,900 m showed a mean standing crop of >1,700 individuals per m² (Gage, 1979). Polychaetes were the dominant taxon (59.1 per cent of individuals) followed by tanaids, bivalves, isopods, scaphopods, amphipods and nemerteans. The meiofauna of the deep sea muds in the north-east Atlantic comprise a diverse assemblage of nematodes (see figure 42), copepods, ostracods and foraminiferans (Gage and Tyler, 1991; Vincx et al., 1994). Around 50 per cent of the meiofauna in the Porcupine Sea Bight is made up of a highly diverse community of foraminiferans (Gooday, 1986).

Plate 8: Macrobenthos; the “quill worm” (Polychaete, *Hyalinoecia tubicola*)

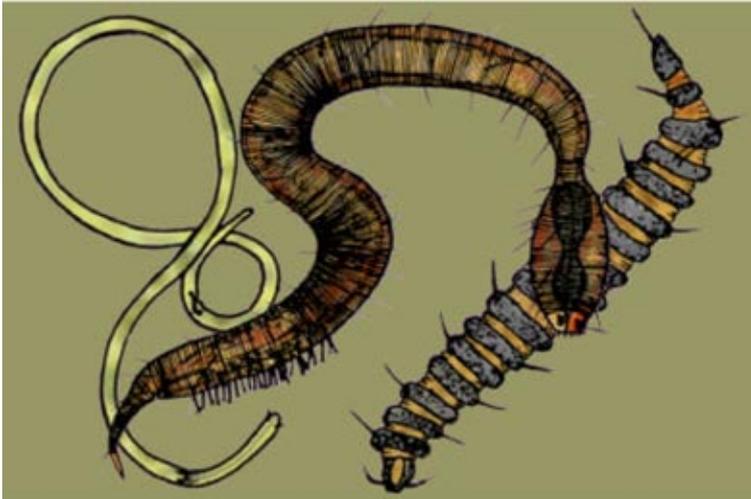


Photograph courtesy of DEEPSEAS Group, © SOC.

Despite the generally low densities of fauna associated with deep sea muds, it has been suggested that the species diversity of deep sea macrobenthos rivals that of tropical rain forests and coral reefs (Grassle et al., 1990; Grassle and Maciolek, 1992). It is estimated that there are up to 10 million species in the deep ocean (Grassle and Maciolek, 1992). Recent investigations have also indicated that the diversity of the deep sea meiobenthos (in the Rockall Trough) is also very high. In just a few small sediment cores from the deep Rockall Trough, Lamshead et al. (1995) recorded almost 100 species of free-living nematodes. Deep sea sediment dwelling nematodes may make up three quarters of all the planet’s animal species, previously estimated at about 30 million (Pearse, 1995). The high species diversity of macro- and meio-fauna inhabiting deep sea muds is thought to be maintained by biologically generated habitat heterogeneity (for example, bioturbation, see plate 9) and patchy food resources at the metre to centimetre scale (Grassle and Maciolek, 1992). Much of the deep sea-bed is covered with animal traces such as pits, burrows, mounds, tracks, faecal casts and resting traces resulting from the movement, burrowing, feeding, defecation or dwelling-construction by benthic

invertebrates and fish (Hollister et al., 1975). These traces can also provide crucial evidence of large, rare organisms living hidden below the sediment surface (Bett et al., 1995). It has also been suggested that hydrodynamic effects and variations in sediment type may play major roles in determining the local species richness of the animals inhabiting deep sea sediments (Etter and Grassle, 1992; Gage, 1997).

Figure 42: Meiobenthos; morphological variety in free-living marine nematodes
(Provided by B. Bett, SOC).



Demersal fish

Demersal fish may also be a significant component of the fauna associated with deep sea muds (see refer to section 2.10 specifically on deep sea fish). Studies of biomass in the Porcupine Sea Bight have shown that demersal fish have similar biomass values to the invertebrate fauna, and exhibit a similar decline in biomass with depth. The dominant families of demersal fish in the deep sea are the slickheads (alepocephalidae), grenadiers or rattails (macrouridae, see plate 10) and cusk eels (ophidiidae) (Merrett and Haedrich, 1977). The 505 species recorded from areas beyond the 200 m contour in the North Atlantic, represent 39 per cent of all known deep sea species (Merrett, 1994). On the Porcupine Abyssal Plain, three grenadier species and the synphobranchiid eel *Histiobranchus bathybius*, dominate the fish fauna and these are all large benthopelagic species.

Temporal variability in deep sea communities

Merrett and Haedrich (1997) suggested that in abyssal, open ocean settings in the North Atlantic, seasonal inputs of phytodetritus (the degraded remains of surface ocean plankton blooms) have a marked effect on the distribution of demersal fish species. This type of temporal variability in the deep sea is an important, though poorly known, issue for environmental protection / conservation.

Plate 9: Evidence of bioturbation on the deep sea floor



Photograph courtesy of DEEPSEAS Group, © SOC.

Plate 10: Rattail fish (*Coryphaenoides rupestris*) photographed at 1,100 m



Photograph courtesy of DEEPSEAS Group, © SOC.

A number of studies have found that the flux of organic carbon to the sea-bed is the primary control on mega-, macro- meio-faunal abundances in the deep Atlantic (see Levin and Gooday, in press). Areas of the Atlantic with the highest organic flux support the greatest infaunal densities and biomass. Patterns of species richness, dominance, taxonomic composition and abundance all seem to be influenced by the supply of organic matter to the deep sea floor (Gooday and Turley, 1990; Rice and Lamshead, 1994). Food supply to the deep sea floor has been shown to vary seasonally and inter-annually (Billett et al., 1983; Denser, 1986; Smith et al., 1994; Baldwin et al., 1998). Many studies have shown that the spring phytoplankton bloom is more intense and widespread in the North Atlantic than anywhere else in the ocean, leading to a greater degree of seasonality in surface production and to relatively predictable seasonal

inputs of phytodetritus to the deep sea-bed (Rice et al., 1994; Lampitt et al., 1995; Longhurst, 1998; Levin and Gooday, in press). This phytodetritus is composed of the remains of organisms from the upper water column and contains rich populations of bacteria (Lochte and Turley, 1988). The phytodetritus is prone to aggregation in depressions or behind mounds or obstacles on the sea floor (Thiel et al., 1990; Rice et al., 1994) and is easily re-suspended and redistributed by currents (Lampitt, 1985).

The benthic fauna of deep sea muds respond to this seasonal input of organic matter. Seasonal growth and reproduction have been noted in a number of deep sea invertebrates in the North Atlantic, including sponges, actinarians, brachiopods, protuberant bivalves, echinoids, asteroids, ophiuroids, spider crabs and hermit crabs. Evidence suggests that these characteristics may be linked to the seasonal variations in the availability of food (Gage and Tyler, 1991). In addition, dramatic changes in populations of megafauna have been observed on decal scales in the abyssal north-east Atlantic (Billett et al., in press; Bett et al., in press). For example, on the Porcupine Abyssal Plain the holothurian *Amperima rosea* exhibited a massive increase in abundance from four to 6,500 individuals per hectare between the periods 1989-1994 and 1996-1999. It is thought that these long-term changes are correlated with changes in the quantity and/or quality of phytodetrital flux to the sea floor. Knowledge of the scope for these natural seasonal and long-term changes in the fauna of deep sea areas is essential to the appropriate management of the deep sea mud habitat.

2.12.3 Conservation issues

Our knowledge of large-scale patterns of diversity in the deep sea is restricted to a few major taxa and based on very limited sampling and geographic coverage (Rex et al. 1997). The invention of the box corer enabled marine biologists to retrieve a quantitative sample of deep sea sediment and compare species number and type to other parts of the world's oceans. However, to date, only about 500 m² of a total of 270 million km² of deep ocean floor has been sampled in a quantitative manner.

Given declining natural resources in shallow waters and the increased demand for ocean products, deep sea environments are now considered more seriously for exploitation. In the past, the deep sea environment has been exposed to the disposal of industrial wastes, munitions, radioactive wastes, sewage sludges and dredged spoils, all of which were permitted to be dumped within the OSPAR region. Today, the main threats to this environment are from offshore hydrocarbon exploitation and deep sea fisheries. The offshore oil and gas industry is still in its early stages. Impacts on benthic communities from drill cuttings are largely confined to the immediate vicinity of drill sites. Localised contamination by drilling fluids has been detected in deep sea sediments to the west of Shetland (Faroe-Shetland channel), although the dominant hydrocarbon signal in the area originates from surface vessels and terrestrial sources (Bett, 2001).

The deep-water demersal trawling industry is already well developed in the OSPAR region (see Figure 43 and Plate 11). Evidence of trawling impacts has been reported in the deep-waters to the west of Scotland. These are characterised by sea-bed trawl marks and areas of disturbed sea-bed, likely a function of commercial deep-water trawling (Bett, 2000; Roberts et al., 2000). Deep-water corals located in open sediment areas (for example, the "Darwin Mounds") are already threatened by this activity (Baker et al., 2001). Widespread, unregulated exploitation

could severely impact deep sea mud communities. Around one third of the benthic species present in the deep waters of the Atlantic Ocean appear to be endemic (i.e. restricted to that environment), and the degree of endemism increases with depth (Vinogradova, 1997).

Figure 43: The physical scale of deep sea trawls. (Provided by B. Bett, SOC).

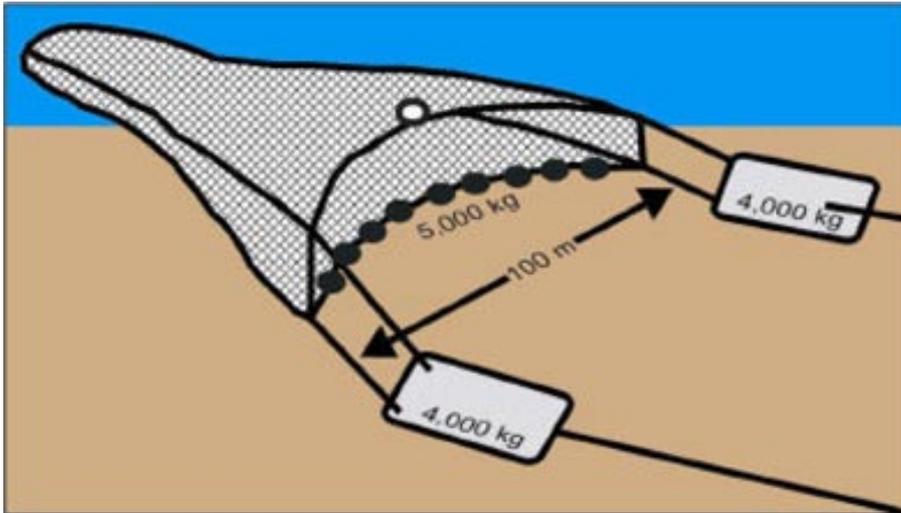


Plate 11: Greenland Halibut; a deep-water species targeted by the fishing industry in the waters west of the UK.



Photograph courtesy of DEEPSEAS Group, © SOC.

In addition to these two threats, pollution in the form of pesticides and PCBs have been found to be present in muds from remote parts of the deep ocean (Pain, 1996). Accumulations of trace metals have been detected in deep-water fish from the Rockall Trough (Mormede and Davies, 2001). Although most deep sea muds are remote from major land-based contaminant discharges,

shipping activities (past and present) have littered the sea-bed with debris. For example, clinker (burnt coal slag) from old steamships is present throughout the world's oceans (Heezen and Hollister, 1971).

There have been a number of significant studies of anthropogenic impacts on deep sea mud communities. One of the most detailed studies concerns the impact of the ocean dumping of 42 million tonnes of sewage sludge in 2,500 m of water, 106 nautical miles south-east of New York Harbour, between 1986 and 1992. This dumping impacted deep sea animal communities. It had significant effects on the metabolism, diet and faunal composition of organisms in the area (see <http://marine.usgs.gov/fact-sheets/sewage/title.htm> for further details of this study). There have also been notable studies on the potential impact of large-scale manganese nodule mining. For example, the DISCOL experiment in the Peru Basin (south-east Pacific) reported increased abundances of the benthic fauna that persisted for at least three years after the initial disturbance of the sea-bed (Thiel and Schriever, 1990). There were also significant changes to the sediment-depth distributions of macrofauna and reductions in species diversity (Borowski and Thiel, 1998). Although manganese nodule mining is unlikely in the OSPAR maritime region, the nature of the impact may be very similar to the, as yet unstudied, impact of deep sea demersal trawling that is evident in the region (Bett, 2000).

2.12.4 Conservation actions

Deep sea muds cover a substantial part, not only of the sea-bed in the OSPAR region, but also of the entire planet, and indeed may be regarded as the dominant habitat on our planet. The fauna associated with this environment play an important role in ecological processes. By implementation of conservation actions relating to other offshore habitats, communities and species within the OSPAR region, some of the deep sea mud habitat will be preserved automatically. However, it is clear from the extensive scientific investigations of the fauna associated with deep sea muds in the north-east Atlantic area that significant environmental and ecological variation occurs over a wide range of spatial and temporal scales. A network of MPAs may, therefore, be necessary to encompass all of the various biogeographic realms found in this region. For example, the UK continental margin encompasses two highly distinct deep-water provinces: the 'temperate' Rockall Trough and the 'arctic' Faroe-Shetland channel, which have correspondingly distinct ecologies (Bett, 2001).

2.13 SPONGE FIELDS

Contribution by Gerd Konnecker, Independent sponge expert, UK

Sponges (*Porifera*) are a unique group of aquatic animals with no relationship to any other living animal phyla. With the exception of a small number of species belonging to the order *Haploscleridae*, all sponges are entirely marine. There is an incredible variety of sponge species in the north-east Atlantic and globally that come in all sorts of shapes and sizes. Sponges are common in shallow water, but some species have been found to a depth of 2,500m. These deep sea sponges known collectively as pharetronidae exhibit an ancient trait – a massive internally fused skeleton. Geologists recognise them as important reef builders. Other sponges, *Hexactinellidae* are confined to waters that are generally several hundred metres in depth. The bulk of the sponge fauna are *Demospongiae*.

Sponge biology

Sponges do not possess a nervous system or internal organs. Water carrying small food particles are inhaled through sieve plates (ostria) and exhaled through larger openings (oscula). The water flows through chambers where special cells called choanocytes, equipped with whip-like flagellae, extract food particles and help propel the water along the canals proliferating within the animal's body.

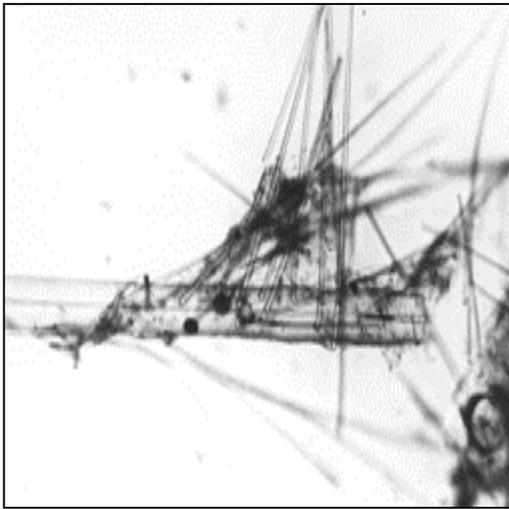
Plate 12: Large exhalent openings or oscula



Photograph by A. Freiwald

The body of a sponge is supported by a skeleton, made up of spicules, a horny substance called spongin, or a combination of both of these. In the class *Calcarea* there are three basic shapes of calcareous spicules, with two, three or four rays respectively. In the class *Hexactinellida* the skeleton consists of siliceous spicules with typically six rays at right angles to each other. The class *Demospongia* demonstrates the highest diversity of skeletal components ranging from simple diffuse masses of simple straight needle-shaped spicula to complex arrangements of several different shapes of large and small spicules (macroscleres and microscleres).

Plate 13: Young spricule of *Cliona celata* growing on and older tetractinellid spricule

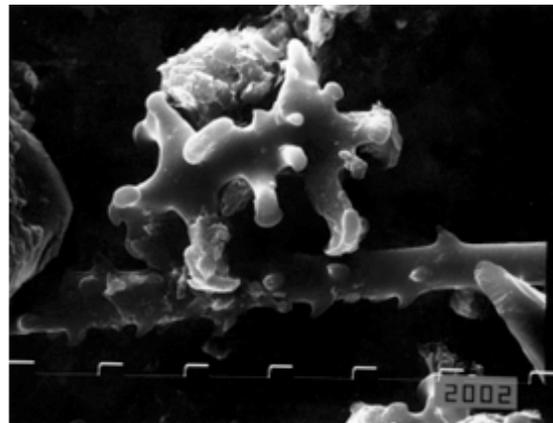
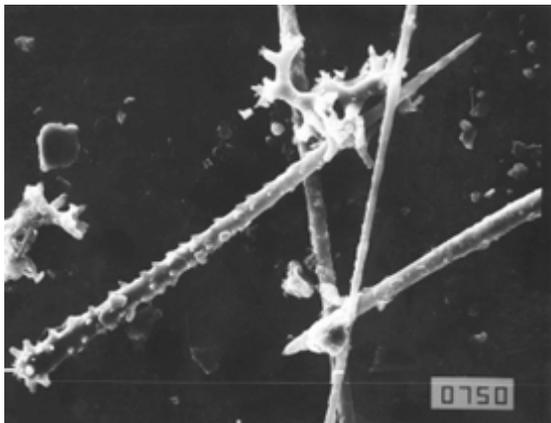


Photograph by Gerd Konnecker

The external shape of sponges is highly variable. It ranges from thin crusts less than a millimetre thick (for example, *Hymedesmia*) or various massive shapes that often depend on local conditions like current flow action.

Plate 14: (a) *Hymedesmia aenigma*

(b) *Hymedesmia* sp. (undescribed).



Photographs by Gerd Konnecker

Sponges can also be club-shaped, upright finger-like or cup-shaped. In almost all cases the sponge is attached to some sort of substrate ranging from the shell of a hermit crab to rooting in soft sediment by long spicule tufts.

Plate 15: Cup shaped and finger like sponges



Photograph by A. Freiwald

Two of the species found in soft sediments and well represented in the North Atlantic are *Asbestopulma* and *Cladorhiza*. They look and live more like seapens and the lack of a well developed canal system has puzzled many biologists. This puzzle was solved recently when it was shown that these sponges (dubbed “killer sponges” by the press) are carnivorous. Little crustaceans are trapped by a number of hook-like spicules (microscleres) and then surrounded by amoeba like cells and digested.

Examination of a large number of sponges by the author has shown apparent different age groups for a number of species. For the majority of encrusting species examined, a lifespan rarely exceeding four years seemed the norm. The fairly short life span of many sponges contributes to a very dynamic environment. There is intense competition for settlement space, further highlighted by the wide variety of substrates colonised.

2.13.1 Occurrence in the OSPAR maritime area

The composition of the sponge fauna of north-west Europe is boreal and overall rather uniform across west and north-west Europe. Sponge fields are generally associated with a water temperature range from 5°C to 10°C, with many species ranging from deeper waters near the Azores to northern Norway and Greenland.

The existence of sponge fields on the deeper Atlantic shelf and continental slope has long been known and documented. In fact most of the more detailed taxonomic records of deep sea sponge fauna go back to the 19th and earlier 20th century, when a number of major expeditions laid the foundations of our current state of knowledge. Sponges are a feature well known to fishermen, whose nets on occasion fill up with big specimens. Recent advantages in visual documentation, especially deep sea video and remotely operated vehicles (ROVs) has added much to our knowledge of the appearance and density of these group of animals in their natural habitat. The diversity of the sponge fauna is staggering and far exceeds that known from the shallow waters of the coastal shelf.

Sponge surveys in the OSPAR area

During 15 years of work, the author has built up a database of around 130 species along the Irish west coast, including numerous historical records. Data was obtained by diving and dredge collecting in waters to a depth of about 100 metres. The number of species in this Irish west coast study is similar to published lists from other locations, for example, the English Channel,

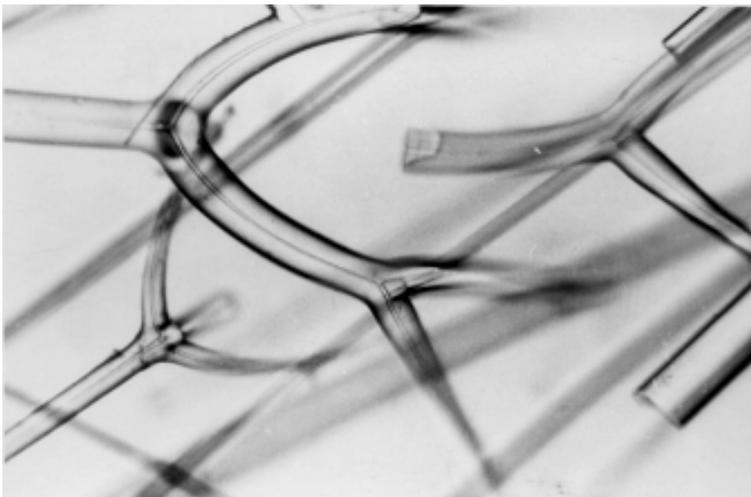
that have been compiled over lengthy periods of up to a century. The English Channel lists are comprehensive and cover larger areas from the in the littoral zone to a depth of about 100 metres. Occasional discoveries of new species are still added.

In contrast, the author has also analysed the fauna of one grab survey taken around an oil drilling site of northern Norway north-west of Tromsø (Tromsøflaket, 300 metres depth), an area known to be rich in sponges. The samples covered less than three square metres of fairly homogenous soft sediment with varying amounts of gravel. They yielded an astonishing 4,000 sponge specimens belonging to 206 species, of which 26 were undescribed. One single sample (0.04m²) yielded over 80 species out of approximately 200 specimens.

While the small sample size might not accurately represent the abundance of larger sponges, these were by no means absent from the material collected. Mostly they belonged to the subclass *Tetractinomorpha*, (Class *Demospongiae*). These are sponges with a radially arranged skeleton of often very long and densely packed needles, so-called trianes (refer to plate 15). The trianes have a shaft and a head of three rays, all arranged at 120 degrees to each other. *Tetractinomorpha* are sponges of high body density and spicule content. After their death their spicules remain and add substantially to the sediment. In the Tromsøflaket material, spicules belonging to the genera *Geodia* and *Thenea* formed large mats which made up a considerable part of the samples, with up to 3.5 kg of pure siliceous spicule material per m².

The staggering diversity found on the Tromsøflaket sponge field is recognised from several surveys and rivals that of tropical reef systems. The magnitude of diversity is also typical of the cold-water coral *Lophelia* reefs that are found in the same zone. The author also studied material taken from around the Magnus sponge field (northern North Sea, 230 metres) and other locations, where diversity and density of sponges is comparable to Tromsøflaket.

Plate 16: Heads of large trianes (Dichotriane)



Photograph by Gerd Konnecker

Thin encrusting forms of sponge covering rocks and pebbles (and in effect any hard surface) account for a large number of the sponge species. Many are from the genus *Hymedesmia*, with more than a hundred species in the north Atlantic and making up as much as a quarter of the species present. Little is known about the vast majority of encrusting sponges beyond the locality where they have been recorded. In many cases the only record is the information from when they were first described. The recorded localities of specific sponges are often separated by large distances, spanning hundreds or thousands of kilometres, but the generally short-lived larval stages do not lend themselves to easy dispersal. These facts point to there being widespread breeding populations of spongefields across the whole of the North Atlantic.

2.13.2 Sponge field communities

Sponges interact in many ways with their environment and influence the density and species of other animals present. Encrusting sponges occupy space on hard substrata which denies room to other sessile species such as Bryozoa. Larger and upright sponges influence the water flow near the sea bottom, acting as baffles. In turn they affect the food intake of other suspension feeders. Vagile organisms such as *ophiuroids* can use sponges as elevated perches. Many sponges offer shelter to the small vagile epifauna, especially in their oscula and canal system. Animals, particularly polychaete worms habitually found in certain species of sponge.

One study, concentrating on eleven species of large cup-shaped or massive sponges around the Faroe Islands, found 242 species associated with them. 225 were epifaunal, three infaunal and 15 both epi- and infaunal (Klitgaard, 1995). Of the associated species, 25 per cent were recorded for the first time from Faroese waters. The majority of massive sponges also occur in waters of the British Isles.

It is assumed that the association between sponges and other species is largely facultative. Other species are not confined to sponge fields, but just make use of an optimal environment. This study highlights the potential central role played by sponges in the continental slope environment.

The influence of sponges does not end by offering shelter or a settlement point. The virtually indestructible spicules remain in or on the sediment after their death forming dense mats, stabilising soft sediments or transforming others. These mats act as settlement points for other sponges and other sessile taxa such as Bryozoa. However the data from Tromsøflaket also indicated that the heaviest matting did not coincide with the highest diversity and density of benthic organisms, rather the reverse was true. The answer to this will require further research.

The mats of sharp tetractinellid spicules (spicules of several millimeters to a centimeter in length) are likely to interfere with feeding by demersal fish, including on benthic macrofauna, their staple diet. Equally the sharp spicules may hinder motile soft-bodied infaunal animals such as polychaete worms. Consequently, the associated fauna on Tromsøflaket was dominated by epifaunal elements; for example half the bivalve species recorded were byssus-attached and living above the sediment.

While much of the continental slope of north-west Europe offers substantial areas of hard substrate due to glacial remains and scouring by the strong water currents found in the area, deeper waters generally are characterised by very soft sediments. However, sediments in deeper waters can be transformed by dense populations of hexactinellid sponges and their residue of fragments and

spicule mats. A study in the Porcupine Sea Bight (south-west of Ireland, Bett & Rice, 1992) showed clearly the connection between a dense sponge population, the consequent spicule mats and enhanced macrobenthos. The animals above and below the belt of *Pheronema* (a hexactinellid sponge found between 1,000 and 1,300 m) were, by comparison, markedly impoverished and different animal species dominated.

2.13.3 Conservation issues

Sponge sensitivity

Due to their unique body structure, sponges are sensitive and vulnerable primarily in one aspect: the fine ostia through which the water is inhaled. Clogging of this inlet system will lead to death and decay, although some species have developed defensive strategies. Primarily this is their siting underneath overhangs or the underside of stones, which shelters them from sedimentation. Upright growth also prevents sediment adhering; in some species, for example *Thenea*, the ostia are confined to a groove underneath a mushroom-shaped upper body.

Some species are covered in a layer of mucus; this may help shedding accumulating sediment. It has also been demonstrated in some tropical species that these could regulate the water flow through their canal system and thereby ease the burden during times of high water turbidity, quite a feat considering their lack of a nervous system. No doubt other mechanisms will be discovered through future studies of sponges in their natural habitat.

This sensitivity should be considered as a priority when assessing the impact of human activity in the benthic environment. Any persistent construction activity that increases the sediment loading of the water column will have a major effect on these sponge fields and consequently other animals which rely on them for shelter or support. Large decaying tetractinellid specimens will add their spicules to any existing matting. While recolonisation by small encrusting forms is likely to be rapid, it will take much longer to restore the distinct and, for the associated fauna, more important large massive sponges which are so characteristic.

Very little is known of sponge tolerance to toxic pollution of the water column. Some anecdotal observations by the author however, indicate a higher than normal rate of abnormal and deformed spicules in a couple of species under such conditions.

Conservation value

The role of sponge fields as an important enhancer of the benthic environment and contributor to ecological processes has been discussed in detail. While none of the sponges found in the North Atlantic have applications like the bath sponge there may also be another direct benefit to mankind. Sponges have been found to be extraordinarily chemically active, with many different chemical compounds found in their tissues. The chemicals act as a defence or deterrent to other encrusting taxa. Many of the chemicals may have important pharmaceutical properties, especially as antibiotic and anti-cancer agents. Several major studies are underway to scan different species for metabolites useful to medical science, with exciting results expected. The studies require an understanding of the taxonomy of the species collected and a precise knowledge of their environmental requirements, both in order to be able to collect more specimens and maybe culture especially important ones in the future.

2.13.4 Conservation actions

The issue of whether any conservation action should be focused on the sponge fields that are thought to occur widely throughout the OSPAR area has not been given any specific attention to date. Currently, advances in our knowledge of this fascinating and important group is hampered by lack of interest in sessile epifauna, with scarce funding. Sponge fields do not offer easy answers as to their conservation status and conservation requirements, as required by government agencies to assess environmental impact of human activity. They require more effort than other groups for identification. The more their role as a key group in the benthos of the continental shelf and slope, however, becomes apparent, the more important it is that these shortfalls are addressed. Conservation programmes that seek to include representative examples of marine habitats and communities in networks of protected areas should include sponge fields in such sites.

3 Next Steps

The marine habitats, communities and species described in this directory show something of the richness, variety and uniqueness of the north-east Atlantic, as well as related conservation issues and potential conservation actions. The aim of presenting this information is to compliment the work of OSPAR and others in progressing marine conservation in this part of the world. Much remains to be done to support such action, and three important aspects of future work are discussed below.

3.1 KNOWLEDGE OF DEEP SEA HABITATS, COMMUNITIES AND SPECIES

There is a considerable amount of research, exploration and exploitation focused on the deep sea, yet it is also apparent that much remains to be learnt about the north-east Atlantic. Some of the challenges facing those working in this field are the need for long-term studies, *in-situ* observations, detailed taxonomic work, the need for international co-operation, the cost of deep sea research and the nature of the deep sea environment itself. It is a rapidly moving field with new discoveries being made all the time. At the same time, very basic information is lacking. Further work is both required and is being undertaken on many aspects. These include mapping and classification of deep sea habitats and understanding the way in which they are formed and maintained, as well as the ecology, taxonomy, life history characteristics and the biological, physical and chemical influences on deep sea communities and species. Improving our knowledge and understanding of the deep sea is essential for successful conservation of the deep sea environment.

The habitats, communities and species described in this directory are a tiny fraction of those found in the OSPAR maritime area but by bringing together this information in an easily accessible format, it is hoped to raise further awareness about the environment and the issues of concern. This is essential if progress is to be made with conservation of offshore areas and the deep sea.

3.2 CONSERVATION ISSUES

Identifying the key issues that need to be tackled for the conservation of deep sea habitats and species is another area which suffers from lack of knowledge. Our understanding of marine habitats and species in shallower waters makes it possible to gauge the likely consequences but detailed information for a particular habitat or species may not be available or only apparent after significant damage has occurred. Equally important is the need for data on offshore activities, such as the frequency, distribution and types of activities taking place.

The threats to the habitats and species described in this directory include those resulting from physical damage, direct exploitation, reduced water quality including pollution incidents and increased sedimentation, as well as indirect effects such as depletion of prey species or changes in ecosystem structure and functioning. The impact of fisheries stands out as being a major conservation issue for most of the habitats and species discussed in the directory because of the scale, widespread nature and type of impacts that result. Further information on conservation

issues will emerge from the regional assessments being undertaken by OSPAR but it is clear that there are already significant impacts which need to be addressed.

3.3 CONSERVATION ACTIONS

The directory describes potential conservation actions for a number of habitats and species giving particular emphasis to the identification of sites of marine nature conservation interest. Locations which are highlighted in the different sections are listed in box 8. The relative importance of these areas will become more apparent as more is learnt about the deep sea however, it is already clear that at least some will need to be included in any conservation programme which seeks to include examples of the full range of biodiversity in a network of marine protected areas.

The level of knowledge and understanding about the deep sea presents what is a common dilemma for those working in marine conservation: having limited information available but needing to ensure that adequate conservation measures are in place. A policy of waiting until there is a clear understanding of the features or species in question is rarely an option because of the threats and impacts which are already occurring. Conservation managers therefore advocate a precautionary approach that might mean anything from environmental assessment prior to approval of a new activity, management regimes that set limits or lay down procedures for operation, or even perhaps closing down existing operations. Site conservation is the principal action which has been considered for the habitats, communities and species described in this directory but this ultimately needs to be supported by measures applied to the wider marine environment as well as directed at particular activities regardless of where they occur. As most of the activities and management measures that need to be tackled for deep sea habitats occur on the high seas, legal competence, enforcement, and funding issues present additional difficulties. However, progress can be made and exemplified by international agreements that already exist to advance conservation on the open oceans as well as conservation measures introduced by individual nations in offshore waters under their sovereignty (for example, EEZs and other offshore limits).

Box 8: Examples of features referred to in th Directory

Location	Features referred to in Directory
Anton Dohrn	Seamount
Josephine	Seamount
Gettysburg	Seamount
Porcupine Sea Bight	Carbonate mounds, coral reefs, sponge fields
Rockall Trough	Carbonate mounds
Norwegian Trench	Pock marks
Witch Ground Basin	Pock marks
North Sea Plateau	Pock marks
Menez Gwen	Hydrothermal vents
Lucky Strike	Hydrothermal vents
Rainbow	Hydrothermal vents
Saldanha	Hydrothermal vents
Sula Ridge	Coral reefs
Rockall Bank	Coral reefs
Western Irish Sea	Front
Islay Front	Front
Celtic Sea Front	Front
Isles of Scilly Front	Front
Flamborough Front	Front
Iberian coast	Upwelling
Porcupine Abyssal Plain	Deep sea mud
Iberian and Tagus Abyssal Plain	Deep sea mud
Tromsøflaket	Sponge field
Magnus sponge field	Sponge field
Irish west coast	Sponge fields

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