OSPAR Commission

for the Protection of the Marine Environment

of the North-East Atlantic

Quality Status Report 2000

Region V Wider Atlantic

Quality Status Report 2000
Region V – Wider Atlantic

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FOREWORD

The Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR Convention 1992) requires that Contracting Parties shall 'take all possible steps to prevent and eliminate pollution and shall take the necessary measures to protect the maritime area against the adverse effects of human activities so as to safeguard human health and to conserve marine ecosystems and, when practicable, restore marine areas which have been adversely affected'.

To provide a basis for such measures, the Contracting Parties are required to undertake and publish at regular intervals joint assessments of the quality status of the marine environment and of its development. These assessments should also evaluate the effectiveness of measures taken and planned for the protection of the marine environment and should identify priorities for action.

The Ministerial Meeting at which the OSPAR Convention was signed also issued an action plan for the OSPAR Commission, with a commitment to prepare a quality assessment of the whole maritime area by the year 2000. A comprehensive quality status report on this scale has not previously been produced.

To implement these commitments the OSPAR Commission decided, in 1994, to subdivide the maritime area into five regions and to prepare, coordinated by the Environmental Assessment and Monitoring Committee, five detailed quality status reports. As a result, five regional task teams were set up to produce reports for the following areas (see inset in ***Figure 1.1***): Region I (Arctic Waters), Region II (Greater North Sea), Region III (The Celtic Seas), Region IV (Bay of Biscay and Iberian Coast) and Region V (Wider Atlantic). It was agreed that these reports should be developed in a scientifically sound manner and should be based upon an assessment plan and a scientific programme (covering monitoring, research and the use of assessment tools). It was also agreed that the information contained in the reports should reflect the outcome of the appropriate quality assurance procedures.

In 1995 the OSPAR Commission adopted a Joint Assessment and Monitoring Programme, to take over and build upon experience gained through its former Joint Monitoring Programme and the Monitoring Master Plan of the North Sea Task Force.

The findings of the five regional quality status reports ('the regional QSRs') form the basis of a holistic quality status report for the entire maritime area (the 'QSR 2000'). This regional report is thus part of an overall quality status assessment for the North-east Atlantic in the year 2000. The QSR 2000 will represent an integrated summary of the quality status of the entire OSPAR maritime area and will both fulfil the commitment made by the parties to the 1992 Convention and provide a basis upon which the future work programmes of the Commission can be decided. In the Sintra Statement, which concluded the 1998 Ministerial Meeting of the OSPAR Commission, importance was attached to the outcome of the QSR 2000 as a basis for identifying and prioritising future tasks at the Ministerial Meeting of the OSPAR Commission to be held in 2003.

The term 'OSPAR Commission' is used in this report to refer to both the OSPAR Commission and the former Oslo and Paris Commissions. The 1972 Oslo Convention and the 1974 Paris Convention were superseded by the 1992 OSPAR Convention when it entered into force on 25 March 1998.

The conclusions and recommendations contained in this report draw attention to problems and identify priorities for consideration within appropriate fora as a basis for further work. Within its sphere of competence, the OSPAR Commission will decide what follow up should be given to these conclusions, recommendations and priorities for action. The rights and obligations of the Contracting Parties are not therefore affected by this report.

THE PARTICIPANTS

Framework

The Environmental Monitoring and Assessment Committee (ASMO) has overall responsibility for the preparation of periodic quality status reports, assisted by a working group, the Assessment Coordination Group (ACG). ASMO outlined the basic arrangements for the quality status reports in the Joint Assessment and Monitoring Programme (JAMP). Further scientific and technical arrangements were prepared by ACG. Regional Task Teams (RTTs) were set-up for each of the regions of the maritime area. The lead countries for the respective RTTs were responsible for providing logistical support to the RTT.

Information relating to the entire maritime area was prepared in 1996 – 1998 by the following OSPAR working groups: the Working Group on Inputs to the Marine Environment (INPUT), the Working Group on Impacts on the Marine Environment (IMPACT), the Working Group on Concentrations, Trends and Effects of Substances in the Marine Environment (SIME) and its Ad Hoc Working Group on Monitoring (MON). This information constituted the basis of the five regional quality status reports, and was supplemented by relevant national information as appropriate.

Regional Task Team for the Wider Atlantic

The RTT for the Wider Atlantic had primary responsibility for drafting this report. The RTT worked under the leadership of Portugal and Iceland.

The report was drafted by Martin Angel working under the direction of an editorial committee. The editorial committee was chaired by Helgi Jensson (Iceland) and included Mário Alves (Portugal), Stig Carlberg (Sweden), Theresa Crossley (UK), Hartmut Heinrich (Germany), Paulo Machado (Portugal), Graça Noronha (Portugal), Maria Pitta Groz (Portugal), Roald Saetre (Norway) and Jan Visser (Netherlands). The committee met six times. Åke Hagström (Denmark), Janet Pawlak (ICES), Roland Salchow (Germany) and Teresa Vinhas (Portugal) were either observers or participants at one of the committee meetings.

A workshop was held in Lisbon in October 1998 to review and assess the preliminary drafts of the first five chapters and to make recommendations for the contents of Chapter six. The experts participating at the workshop and contributing extensively to the content of the report included Volkert Dethlefsen (Germany), Eduarda Goulart (Portugal), Willem Helder (Netherlands), Peter Koltermann (Germany), Ricardo Santos (Portugal), Gerd Schriever (Germany), Thomas Soltwedel (Germany), Roland Wollast (Belgium) and Walter Zenk (Germany). Hans Alexandersson (Sweden) contributed a paragraph on meteorology and Philip C. Reid (UK) a paragraph on climate change. A wide range of helpful comments were received from participating countries at all stages of the drafting.

The committee was particularly grateful to the UK's Department of Environment, Transport and the Regions for funding Martin Angel's work and to the European Union and the Portuguese Government for funding the Lisbon workshop.

ACG and ASMO – representation by Contracting Parties

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Chairmen of ASMO: Georges Pichot (1994 – 1997), Roland Salchow (1998 – 2000).
Contracting Parties' delegates to ACG 1994 – 1999: Belgium: Mia Devolder, Georges Pichot*, Wilfried Vyncke; Denmark: Jens Brøgger Jensen*, Henning Karup, Mikkel Aaman Sørensen; EC: Patrick McCutcheon*; France: Pascale Babillot, Marcel Chaussepied, Philippe Maire*, Jean-Marie Massin; Germany: Hartmut Heinrich*, Roland Salchow; Iceland: Helgi Jensson*; Ireland: Rick Boelens, Jacqueline Doyle*; The Netherlands: Lisette Enserink, Frans Feith, Kees Kramer, Bob Oudshoorn, Folkert Post*, Frank van der Valk, Carien van Zwol; Norway: Per Erik Iversen, Hein Rune Skjoldal, Rune Vistad*; Portugal: Antonio Macieira Antunes, Maria E. F. Avila Goulart, Graça Noronha, Irene Pereira, Joaquim Pissarra, Tereza Vinhas*; Spain: Victor Escobar, Pilar García, Argeo Rodríguez de León*; Sweden: Stig Carlberg, Sverker Evans*, Ingrid Jansson; United Kingdom: Mike Burn, John A. Campbell, Stephen Churley, Theresa Crossley*, John M. Davies, Andrew Franklin, Andrew J. Osborne, Philip C. Reid.
* also acting as Head of Delegation during ASMO(2) 1999 which adopted this report.

Observer organisations attending meetings of ACG and ASMO 1998 – 1999

Arctic Monitoring and Assessment Programme (AMAP), European Environment Agency (EEA), International Council for the Exploration of the Sea (ICES), Secretariat of the North Sea Conferences, Conseil européen des fédérations de l'industrie chimique (CEFIC), European Fertilizer Manufacturers Association (EFMA), Euro Chlor, World Wide Fund for Nature (WWF).

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OSPAR COMMISSION FOR THE PROTECTION OF THE MARINE ENVIRONMENT OF THE NORTH-EAST ATLANTIC

QUALITY STATUS REPORT 2000: REGION V – WIDER ATLANTIC

EXECUTIVE SUMMARY

Introduction

This report is one of five regional quality status reports prepared by the OSPAR Commission as part of its commitment to produce the first quality status report of the North-east Atlantic by the year 2000.

Region V, the Wider Atlantic, extends between 62° N and 36° N and from 42° W to 10° W off Iberia and France and the 200 m depth contour off Ireland and the British Isles.

The report is based upon the most recent information available from the scientific literature and, where available, national and international sources. The report was prepared by a Regional Task Team comprising representatives from Germany, Iceland, Norway, Portugal, Sweden and UK.

The physical environment

Region V represents the deep waters of the North-east Atlantic. Its topography ranges from continental slopes, through the sharply fluctuating seabed associated with seamounts, banks of fragmented continental rocks and the Mid-Atlantic Ridge, to extensive areas of almost featureless abyssal plain.

Movement in the upper layers of the water column is generally from west to east and is dominated by two major circulation cells; the subpolar gyre and the subtropical gyre. There are outflows to the Nordic Seas in the north-east, and these are important in maintaining a relatively mild climate in North-west Europe. In the deeper layers there are inflows of bottom waters from the Mediterranean Sea (originating in the Southern Ocean) and, most importantly, of cold waters spilling over the shallow banks from the Nordic Seas. At intermediate depths cold water also flows in from the Labrador Sea. These cold waters mix with the ambient waters to form a water mass known as the North Atlantic Deep Water which can be identified throughout all oceans. Its formation is one of the major driving forces for the thermohaline circulation of the world's oceans. Hence the North Atlantic is a pivotal region from which climatic fluctuations are rapidly transferred to all other oceans.

Another important current flows northwards along the slope to the west of the British Isles and may have continuity with a similar slope current flowing northwards along the Iberian Slope. These slope currents play a key role in carrying contaminants and biological organisms northwards and into the other OSPAR regions.

Bottom sediments vary according to the topography and the local currents. There is offshore transport of sediments from the continental margins, and in places strong currents can cause local scouring of the seabed. Where the topography is rugged, crustal rocks may be exposed, especially along the Mid-Atlantic Ridge where the seafloor was formed relatively recently. However, generally the seabed is covered with thick accumulations of sediment, derived partly from pelagic production, partly from dust blown in from the continents and partly from debris dropped from melting icebergs.

Throughout much of the region the prevailing winds are south-westerly. The winds in the region are influenced by depressions, which typically track across the region from the south-west. The frequency and violence of storms increase in winter, and from south to north. Cyclic fluctuations in atmospheric pressure between the high-pressure system centred over the Azores and the low-pressure centres over Iceland – the North Atlantic Oscillation (NAO) – provide indications that there are long-term (up to 7 years) oscillations in the weather patterns and hence in many oceanographic processes. These long-term oscillations, rather than fundamental climate change, may be responsible for some of the shifts in the weather patterns reported from other regions.

Sea surface temperatures decrease from south to north and to a lesser extent from west to east. There are marked seasonal fluctuations in sea surface temperatures associated with the seasonal fluctuations in solar radiation and stratification of the upper ocean.

Decadal variability in climate over the North Atlantic has been well documented and influences the hydrography of all five OSPAR regions. In Region V, some of these fluctuations have resulted in large-scale persistent anomalies in near-surface salinity and in sharp changes in the biological characteristics.

Human activities

Human population in the region is restricted to the Azores Archipelago. Improvements in local infrastructure resulting from European Union grants and the development of a thriving tourist industry have reversed a slow decline in population. However, tourism has created its own problems because seasonally the Islands' population can increase by as much as threefold.

The growth of the cruise industry has resulted in a considerable increase in the size of cruise ships crossing the region. Tourism is of considerable importance to the economy of the Azores. Inshore activities have increased, as has ecotourism especially whalewatching.

Fishing activities within Region V are highly diverse. Fleets include quite small vessels operating around the Azores, moderately large vessels catching deep-living stocks in a sustainable manner, and international fleets of vessels exploiting large pelagic species. A variety of vessels intermittently explore deep-living stocks throughout the region. There is a lack of compatibility between the areas and reporting procedures adopted by the various organisations seeking to regulate these fisheries. This makes it difficult, if not impossible, to obtain data for meaningful assessments of fishing effort, catch rates or for the status of the majority of the stocks.

Other human activities which may already be having, or might be expected to have, an impact on Region V include:

- sand and gravel extraction – only around the Azores;
- shipping;
- the laying of communication cables; and
- military activities.

Chemistry

The sources of contaminants to Region V can be broadly categorised as:

- direct inputs (mainly from shipping associated with exchanges of ballast waters, permitted discharges of wastewaters and biodegradable material, and the incineration of burnable wastes at sea. Also, discharges from offshore activities and, around the Azores, municipal outfalls);
- marine accidents; and
- atmospheric inputs (which although they are low throughout most of the region are overall likely to be equivalent to inputs from all other sources).

Inputs of lead have apparently declined since the general introduction of lead-free fuel in the US. Mercury levels while generally low, can be high in top predators. Similarly, concentrations of other organic and inorganic substances remain relatively low compared to levels generally found in coastal waters. However, there are insufficient data to assess where the main sources are, or whether the levels of contamination are changing.

There is also relatively little information on levels of persistent organic contaminants in the region, including pesticides, industrial chemicals and the by-products of combustion. Data obtained mostly from the scientific literature indicate low concentrations of contaminants in deep sea organisms, but the data are highly variable and the reasons for the variations are unclear.

Similarly, very low concentrations of artificial radionuclides are detectable throughout Region V and add less than 1% to the natural background levels of radiation. They are generally considered to pose no health risk to human populations or to the oceanic ecosystem. Inputs have been decreasing.

Concentrations of dissolved nutrients are generally much lower than in other oceanic regions and exhibit a pronounced seasonal cycle. With the possible exception of very localised inshore areas around the Azores, the production cycle is either light- or nutrient-limited for all but a very few weeks of the year; hence eutrophication is most unlikely to become a problem.

Biology

Region V is subdivided into two major biogeochemical provinces in which the faunas and ecology are quite different. Superimposed upon this basic subdivision is a north–south gradient in species distributions and community diversity, and vertical gradients that result in bathymetric zonation. Pelagic faunas are twice as diverse to the south of 40º N than to the north, but their biomass shows the reverse. The benthic communities are much richer in species than the pelagic communities, and show a similar latitudinal step in species richness. Maximum species numbers are generally encountered both in the water column and on the seabed, at depths of 1 km, whereas standing crops steadily decline with depth. Deeper-living species of fish are almost without exception slower-growing, longer-lived and less fecund than their shallow-living counterparts. These characteristics make them particularly susceptible to overexploitation. In addition, there have been recent discoveries of a number of different fragile deep-sea habitats (such as hydrothermal vents, carbonate mounds and sponge communities) which are being damaged by fishing activities.

The by-catch in deep-sea fisheries tends to be high and may be posing risks to some ocean species such as whales, turtles and seabirds. Although the risks to seabirds are probably small relative to the pressures they are under at their nesting sites, the by-catch of small whales and turtles by some of the deep-water fisheries is of concern.

There have been a few introductions of non-indigenous species in the Azores, but in the offshore waters of the region, introduced species have either failed to become established or there are insufficient background data for them to be identified.

Overall assessment

The assessment shows that the quality of the marine environment in the Wider Atlantic is generally good, although it is far from pristine. Gross ecosystem effects resulting from pollution have not been detected in Region V. However, there have been recent indications that global scale changes, possibly reflecting greenhouse gas and chlorofluorocarbon (CFC) emissions, are beginning to affect the region. Measures taken to reduce direct inputs from shipping appear to have been successful, such that these discharges are now a minor issue. Even so, further improvements in the safety of marine operations should still be pursued. Offshore transport of contaminants from coastal regions occurs but, likewise, is not thought to present significant risks to the deep-water communities. The main risks appear to be associated with atmospheric inputs, many of which have sources that lie outside the OSPAR area. However, the absence of routine monitoring in the open ocean precludes confidence in this assessment. It also means that any future decline in environmental health is likely to go undetected until conditions deteriorate to unacceptable levels. For example, the lack of evidence concerning the impact of tributyltin (TBT) on the ocean communities may reflect inadequate monitoring.

Despite this general assessment of good environmental quality, several issues are highlighted as being of particular concern, either due to their present impact or to their potential future impact.

Fishing

Overexploitation of many stocks continues to occur. Levels of by-catch and discards are very high and may be causing long-term damage to some components of the ecosystem.

Evidence of mechanical damage to some fragile habitats is becoming evident. The ecological impact of removing top predators on the structure and functioning of oceanic ecosystems has not been addressed.

Habitat changes

Although the most important impact on habitats is fishing activity, changes are occurring in the physical and biological characteristics of the region that seem likely to result from the impact of greenhouse gas and CFC emissions. It seems likely that increasing carbon dioxide concentrations in the atmosphere may induce changes in other ecological processes, eventually leading to shifts in the present community balance.

Offshore industrial development

The current expansion of the hydrocarbon industries offshore, and the likely future extension of the energy industry, needs to be undertaken with care.

Radioactive contamination

Although radiological assessments imply that the risks have declined, and will continue to do so, radioactive contamination continues to be viewed with concern by some countries.

Other issues

Other issues which may affect the region as a whole include:

- shipping, including TBT inputs, marine litter and polycyclic aromatic hydrocarbons (PAHs); and
- biotoxins, polychlorinated biphenyls (PCBs) and other persistent organic contaminants.

Lack of information

A number of gaps in information have been identified. These include:

- a lack of methodology for predicting climatological change and its effect on circulation and water mass formation;
- an insufficient understanding of how the North Atlantic Oscillation influences circulation within Region V and what causes the salinity anomalies recently identified circulating around the subpolar gyre;
- a limited understanding of how long-term cycles in the physical environment affect midwater and seabed communities and processes;
- the need for a greater understanding of the links between biodiversity, productivity and other ecological processes;
- the need to combine physical, biological and chemical models for operational use;
- a lack of information on the relative contributions of anthropogenic and natural inputs for many substances. This is compounded by a lack of information on contaminant pathways to the deep ocean and an absence of good baseline data;
- an incomplete understanding of the chronic effects of long-term exposure of marine biota to contaminants;
- an inadequate basic systematic knowledge about the majority of benthic taxa (particularly the smaller organisms), the distributions and life cycles of many keystone species, and the structure and dynamics of most deep-water food webs (including the role of micro-organisms);
- insufficient data to evaluate sustainable catch rates for many deep-sea species, particularly by-catch and discard data, information on stock structure and recruitment for many of the multi-species fisheries and the life histories for many of the exploited species; and
- an understanding of the environmental impact of fishing techniques on fragile deep-sea ecosystems.

chapter 1

Introduction

1.1 Aim and scope

Assessments of the quality of the marine environment provide a basis for protecting marine and coastal areas. They provide an opportunity to gather together and assess the results of scientific research and monitoring as well as information on the many human activities that can, directly or indirectly, change or damage the natural attributes of the marine environment. In combination, this information can be used to evaluate the causes and implications of change and to identify impacts that require early attention by policy-makers and environmental managers. Assessments are also used to review the effectiveness of existing measures to prevent degradation of the marine environment, to protect valued species and communities and to restore previously damaged habitats and ecosystems.

The value of environmental assessments depends to a large extent on the availability of reliable and up-to-date information. Thus it is essential that monitoring and other systems of recording marine environmental information are both ongoing and designed to yield high-quality data amenable to interpretation. In this context, assessments provide a means of reviewing the performance of monitoring programmes and of identifying important gaps in knowledge.

This report presents an assessment of marine environmental conditions in that part of the maritime area which, for assessment purposes, is known as the Wider Atlantic or Region V ***(Figure 1.1)***. This area extends from 62º N (just to the south of Iceland) to 36º N (i.e. the latitude of the Strait of Gibraltar). To the west the area is bounded by 42º W and to the east either by 11º W or the shelf-break (taken as being the 200 m depth contour) to the west of the British Isles. The land masses within the region comprise the Azores Archipelago in the southern sector and the tiny pinnacle of rock that atops Rockall Bank in the north-eastern sector. Together with similar quality status reports for the other four OSPAR regions, this report forms the basis of a holistic and integrated summary of the quality status of the entire OSPAR maritime area.

1.2 The assessment process

Some recent information has been used from national and international sources, including OSPAR committees and specialist working groups, the International Council for the Exploration of the Sea (ICES) and the International Commission for the Conservation of Atlantic Tuna (ICCAT). However, because there has been relatively little monitoring in the deep water regions, particular use has been made of information published in the scientific literature, notably publications resulting from:

- the recent series of international programmes targeting a better understanding of ocean circulation (e.g. the World Ocean Circulation Experiment (WOCE)) and carbon fluxes (e.g. the Joint Global Ocean Flux Study (JGOFS));
- collaborative research programmes co-funded by the European Union’s Marine Science and Technology (MAST) programme;
- programmes coordinated by ICES;
- oceanographic programmes conducted by individual nations; and
- the activities of the Nuclear Energy Agency’s Coordinated Research and Environmental Surveillance Programme, which have addressed specific issues concerning the radiological impact of radioactive waste management and associated questions of oceanic physics, biology and geochemistry.

These national and international contributions continue to add significantly to an understanding of the North Atlantic. Future plans include the establishment of a Global Ocean

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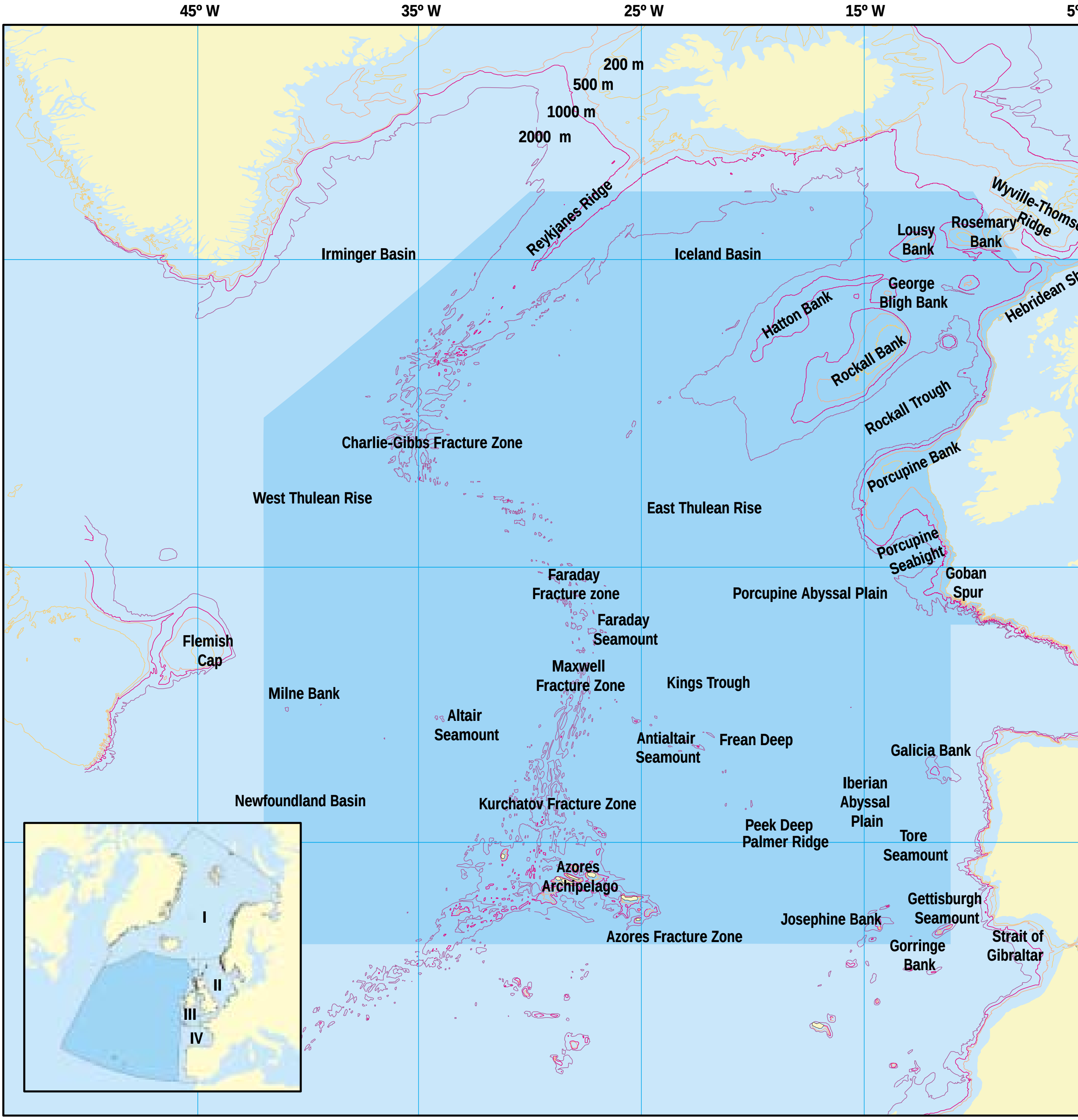
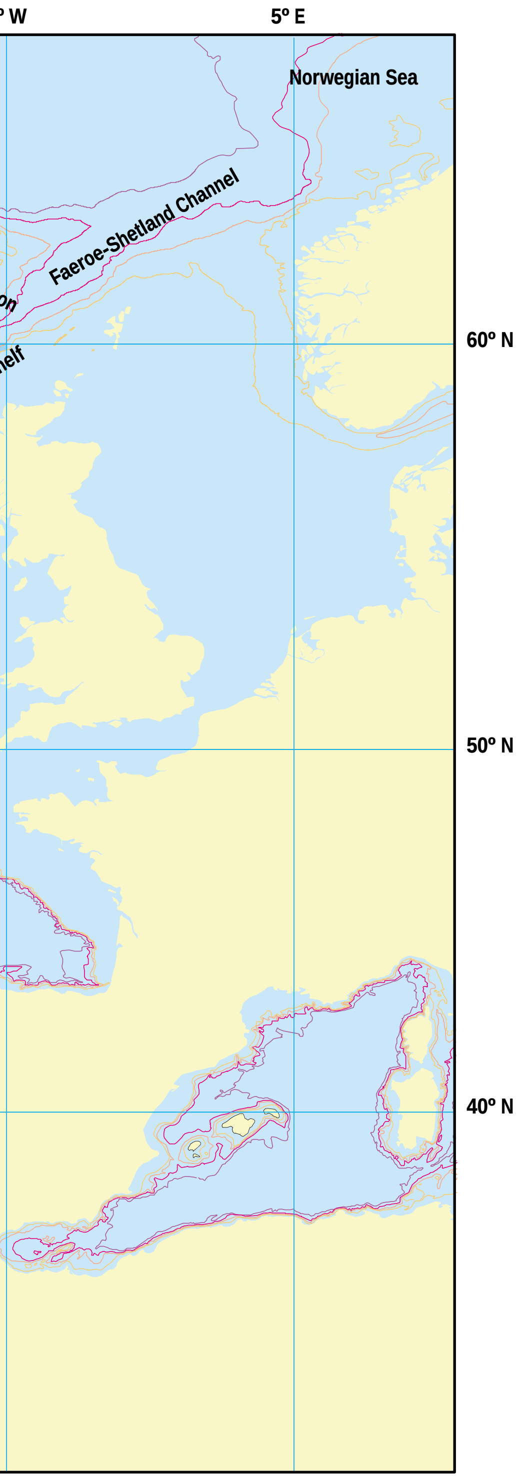
Figure 1.1 **Bathymetry and main topographical features of Region V. The inset shows Region V in relation to the other regions of the OSPAR maritime area.**





Observation System (GOOS), which offers the prospect of using data from monitoring programmes in conjunction with basin-scale models to improve operational oceanography and to provide forecasts of ocean climate. If GOOS is successful in achieving its goals, its forecasts will make significant contributions to the management of North-east Atlantic resources, will improve efficiency and safety in marine and coastal operations, and will contribute to many other environmental management issues.

Although most of the information in this report relates to the 1990s, some topics required the use of earlier data, either because the recent record was sparse or because trend analysis involved a consideration of historical conditions. While every effort has been made to ensure the comparability of data from different times and locations, methodologies may have differed considerably and thus some of these comparisons will inevitably be tenuous. Where such uncertainties exist they are indicated in the text. The general lack of detailed background information for Region V meant it was not possible to identify any Focus Areas.

1.3 Guidance to the reader

Chapter two gives a concise description of the physical characteristics of the area, including its geography, hydrography and climate, as these have an important bearing on the types and distributions of marine habitats and communities as well as on their sensitivity and exposure to environmental change. Chapter three examines the broad spectrum of human activities that, directly and indirectly, impinge on the region, its amenities and resources, identifying the localities and systems most affected and addressing any apparent trends. The next two chapters summarise information on the chemical and biological features of the ecosystems in the region, focusing in particular on the causes and implications of the changes that have been detected and those that can be expected to occur in the future. Finally, Chapter six draws on the preceding chapters to identify where improvements have been achieved, the major causes of environmental degradation within the area and, where appropriate, makes recommendations for the managerial and scientific actions needed to redress the impacts.

A multidisciplinary approach has been developed by cross-referencing specific issues between the various chapters. The chapters are accompanied by a list of references to the major sources of information. The terminology used has been kept as non-technical as possible, but where scientific and other terms have had to be used their meanings are both defined in the text and included in a glossary of terms.

chapter 2

The physical environment

2.1 **Introduction**

The North Atlantic began to form about 200 million years ago when the supercontinent of Pangaea began to break-up (Weijmars, 1989). The split between Europe (at Galicia Bank) and North America (at Flemish Cap) occurred about 105 million years ago, and the separation of Greenland from the Hatton and Rockall Banks and the formation of the Reykjanes Ridge only started in the Miocene Epoch. In the Middle Miocene, 10 – 15 million years ago, the Iceland-Faroe bridge subsided opening the connection between the North Atlantic and the polar seas. The North Atlantic continues to open, but at the relatively slow rate of about 2 cm/yr. Since the oceanic crust, originally formed along the Mid-Atlantic Ridge (see Section 2.4.1), is not sliding (being subducted) beneath the continents, no trenches have been formed along its continental margins and the deep ocean floor rises gently towards the steeper continental slopes.

The North Atlantic plays a key and dynamic role in the global circulation of water, described as the ‘Ocean Conveyor’ (Broecker, 1991) *(Figure 2.1)*. It is a pivotal region where the deep water mass characteristics of the global ocean are determined and the interactions between climate and oceans are at their most dynamic. In the upper layers, the Atlantic circulation is dominated by the subpolar and subtropical gyres. The subpolar gyre is fed from the south-west by the North Atlantic Current (NAC; Krauss, 1986), which is an extension of the Gulf Stream. Warm water from the NAC flows out of the region into the Norwegian Sea, so maintaining a much warmer climate in North-western Europe than is experienced at similar latitudes on the eastern seaboard of the North American continent. In the south, the Azores Current (AzC) is the northern border of the subtropical gyre and the major source of warm salty water reaching Region V. Circulation in the lower layers is linked to that in the upper layers because of the conservation of mass. Thus the northwards surface flow of the NAC is compensated for by inflows of cold, low salinity waters, which spill over, or flow in via the deep channels in the shallow banks between Greenland, Iceland, the Faroe Islands and Scotland that separate the Atlantic from the northern seas (Krauss, 1995). Until recently cold, relatively high salinity water from the East Greenland Sea was sinking deep into the western basin of the North Atlantic and forming Atlantic Bottom Water (McCartney, 1992). Within the last decade, this water has not been sinking to such great depths, so the rates at which the deep waters of the North Atlantic are being exchanged (ventilated) have reduced (Dickson *et al*., 1996).

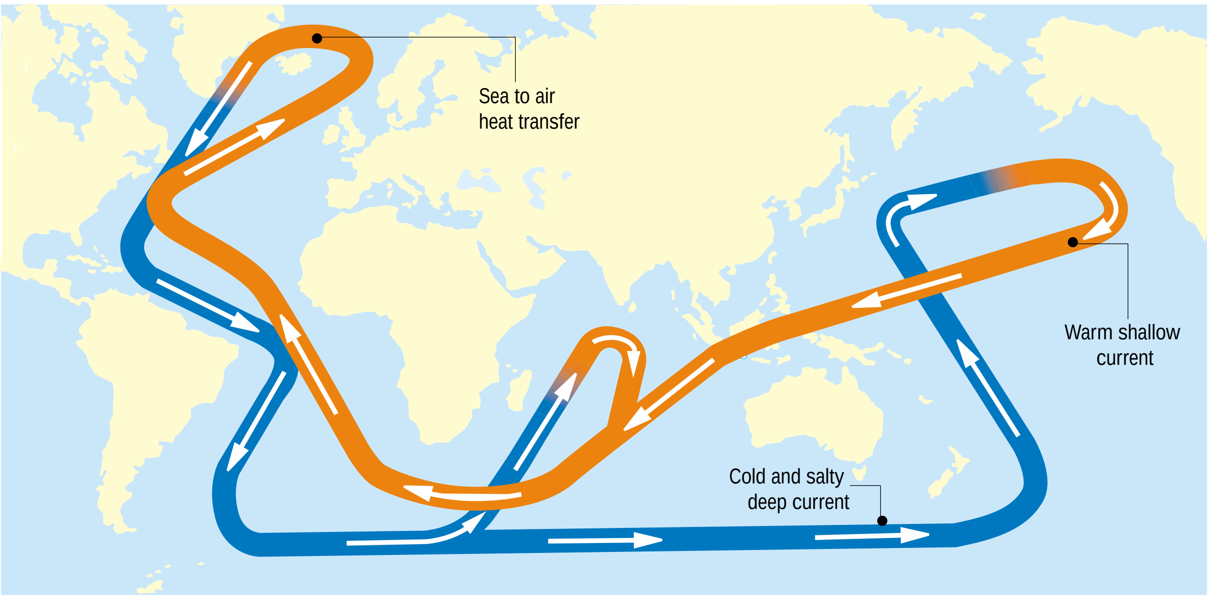
The region’s climate is dominated by oscillations in the strength of the south-westerly winds, which are reflected in the contrast between the atmospheric pressure in the low-pressure cell centred over Iceland and the high-pressure cell centred over the Azores (see Section 2.13). Atmospheric depressions tend to develop in the vicinity of Newfoundland and move north-eastwards towards Iceland. Their tracks vary seasonally, as the size and intensity of the Azores high-pressure cell fluctuates. These storms increase in frequency and severity as they move northwards and their winds bring rain to the maritime regions of Western Europe throughout the year.

Some of the physical, chemical and biological processes that occur in Region V are different in scale and character from those occurring in the other, predominantly inshore, OSPAR regions. Hence the priorities that emerge for actions needed to achieve OSPAR objectives tend to be somewhat different in this region relative to the others.

2.2 Definition of the area

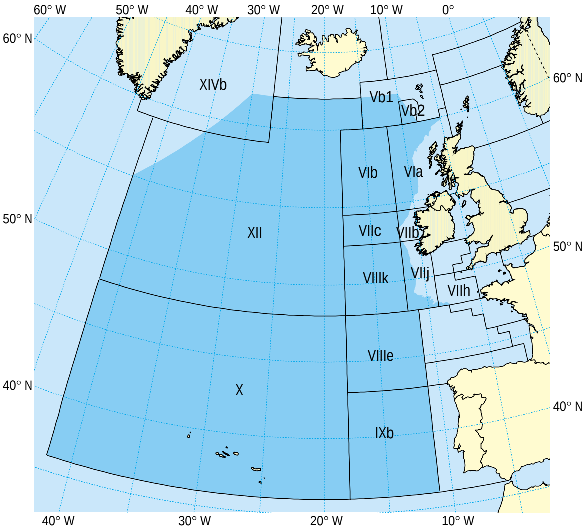
Region V includes most of the deep ocean (> 2000 m) within the OSPAR area that lies outside the Norwegian and Greenland Seas. Its geographical coordinates are given in Section 1.1. Topographically, the area is dominated by the Mid-Atlantic Ridge and several abyssal plains. In the eastern basin north of 51º N, the seabed shoals to the north and the north-east towards the banks between Greenland, Iceland, the Faroe Islands, Scotland and Ireland. Region V includes the open ocean areas that

Figure 2.1 **Schematic illustration showing the thermohaline circulation of the global ocean. Source: after Broecker (1991).**



bound Regions I – ‘Arctic Waters’, III – ‘The Celtic Seas’ and IV – the ‘Bay of Biscay and Iberian Coast’. It encompasses ICES Fishing Areas VIb, VIIc, VIIk, VIIIe, IXb and X in their entireties, the majority of area XII and small areas of Vb1, Vb2, VIa, VIIb, VIIh, VIIj, and XIVb *(Figure 2.2)*. The ocean depths are mostly well in excess of 1000 m; the maximum sounding recorded being just over 5800 m in the Peek Deep near 42º N, 20º W.

Figure 2.2 **ICES Sub-areas and Divisions in Region V.**



2.3 Bottom topography

The topography ranges from the continental slopes and rises along the eastern margin of the Atlantic, to abyssal plains and the underwater mountain ranges and isolated seamounts. In the west, the dominant features are the Mid-Atlantic Ridge, the abyssal plains of the Newfoundland Basin and a few seamounts that are outliers of the Ridge. In the north a segment of the Mid-Atlantic Ridge, the Reykjanes Ridge, extends south-westwards from Iceland for 1000 km and has a major influence on deep-water circulation and sediment transport. It ends at a major offset, the Charlie-Gibbs Fracture Zone, which provides a deep-water connection between the two sides of the Ridge and has a sill depth of 3600 m. There is a succession of other smaller fracture zones along the Mid-Atlantic Ridge as it extends southwards to the Azores Archipelago – the Faraday, Maxwell and Kurchatov Fracture Zones.

The Azores Islands are a group of active emergent volcanoes that sit astride a triple junction of major crustal plate boundaries. South of the islands, the ridge axis veers south-westwards and extends beyond Region V. To the east of the archipelago, the Azores Fracture Zone extends eastwards to the Strait of Gibraltar and marks the boundary between the Eurasian and African plates. Near its eastern end are two seamounts; Josephine and Gorringe Banks. Just west of Josephine Bank is Discovery Gap, which is the deep-water connection through which Antarctic Bottom Water flows into the Iberian Basin from the Canaries Basin to the south (Saunders, 1987).

The south-eastern sector of Region V is dominated by two abyssal plains; the Iberian and Porcupine (or West European Basin) Abyssal Plains. The former has extensive areas deeper than 5000 m. Just to the west of Lisbon lies the Tore Seamount; a conical feature resembling a submerged volcano with a very deep (5536 m) central crater. North-west of the Tore Seamount lies a linear feature, the King’s Trough, in which the region’s maximum depth of 5800 m occurs. Due east of the King’s Trough and close to the Iberian margin, lies Galicia Bank (492 m), an important fishing ground, which originated as a fragment of continental shelf. North of 45º N is the Porcupine Abyssal Plain, an extensive area of almost featureless topography, with depths ranging from 4800 to 4850 m. The north-eastern margin of this abyssal plain is flanked by the canyonated slope of the Goban Spur, the entrance to the Porcupine Seabight, and the Porcupine Bank, which is another outlying fragment of continental shelf. To the west is the East Thulean Rise – a mirror image of the West Thulean Rise. The bathymetry shoals north-eastwards from this rise towards the Rockall Trough and Plateau (another remnant of continental shelf). To the west of the East Thulean Rise there are deep-water connections between the Iceland Basin to the north, and the Western Basin to the west via the Charlie-Gibbs Fracture Zone. The Iceland Basin is flanked by the Reykjanes Ridge to the north-west, Hatton Bank to the south-east and the Iceland-Faroe Rise to the north. Associated with the Rockall Plateau is a series of shallow (< 100 m) banks; Rockall, Hatton, Lousy, George Bligh, Anton Dohrn and Rosemary. These banks are important fishing grounds and are underlain by oil-bearing rock-strata, they are also important hydrographically because of their influence on deep-water circulation.

2.4 Geology and sediments

2.4.1 The mid-ocean ridge

As in most oceans, there is a mid-oceanic ridge in the Atlantic with a median rift valley lying along its axis. The Mid-Atlantic Ridge is being formed continually as a result of the volcanic and tectonic processes associated with the spreading of the crustal plates; hence it has considerable topographical relief. In the North Atlantic, the spreading rate is relatively slow (*c*. 2 cm/yr) and so sometimes within the transform faults the crust gets displaced and so reveals the underlying mantle. As well as being associated with considerable seismic activity, the median rift valley contains hydrothermal vent fields usually associated with some of the faults *(Figure 2.3)*. High seismic activity is also experienced in the Azores and along the Azores Fracture Zone. The Mid-Atlantic Ridge has an important influence on the deep-water circulation, by separating the deep waters in the eastern and western basins.

2.4.2 Hydrothermal processes

Both the chemical properties of sea water and the mineralogical evolution (diagenesis) of the crustal rocks are strongly influenced by the chemical processes that are associated with the hydrothermal vents. As new ocean crust is formed by eruptions of lava within the rift valley, it cools, shrinks and cracks. These cracks form networks of channels that extend deep into the crust and fill with sea water that has percolated in through the flanks of the ridge *(Figure 2.4)*. The rocks are so hot that they superheat this water to 300 – 350 ºC, causing it to become highly corrosive. The water reacts chemically with the rocks through which it is flowing, and the chemical characteristics of both the rocks and the water are drastically modified. The superheated water is highly buoyant and rises back up towards the seafloor where it is vented into the oceans forming ‘black smokers’. This name results from the metals, which were stripped from the crustal rocks, being precipitated out as dense black clouds of sulphides as the fluids rapidly cool on being mixed with the cold ambient sea water. These precipitates form tall mineral chimneys around the vents and

Figure 2.3 **Hydrothermal vent fields so far discovered on the Mid-Atlantic Ridge in the vicinity of the Azores Archipelago.**

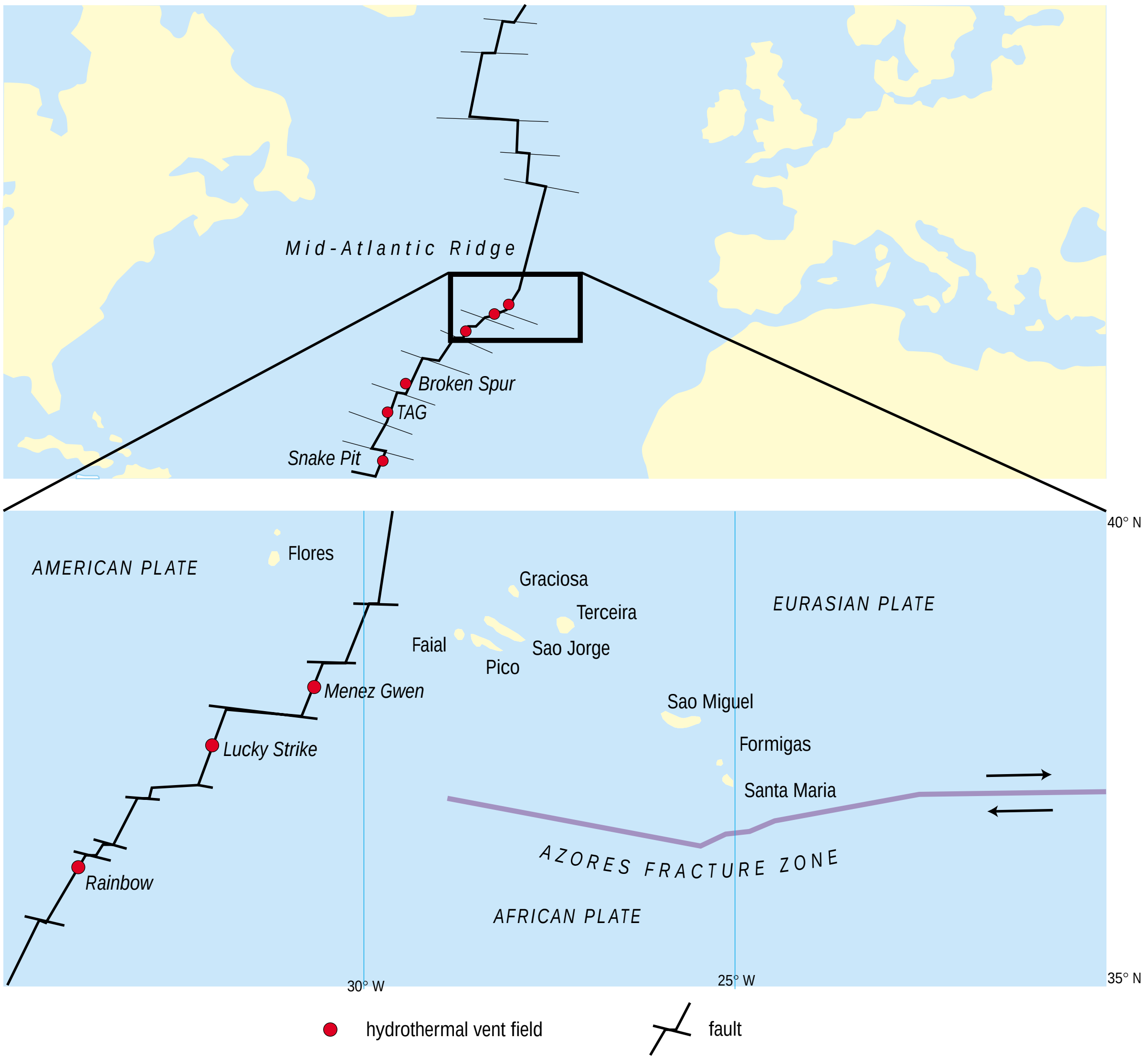
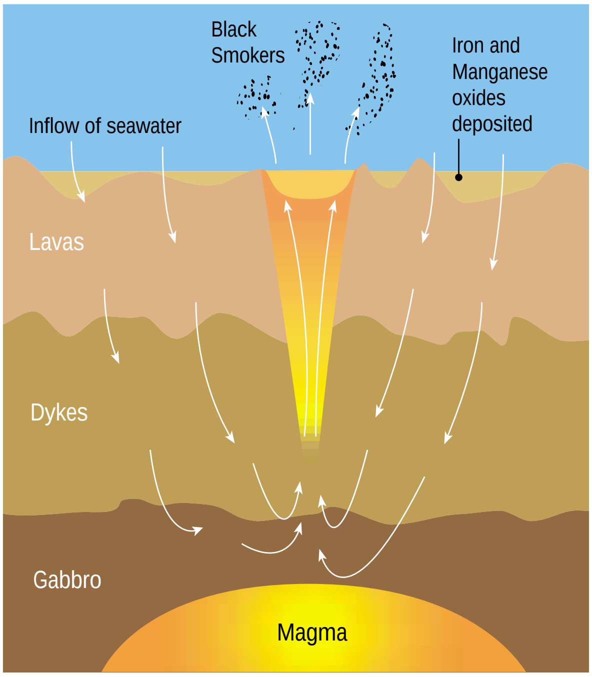


Figure 2.4 **Circulation within the crustal rocks associated with hydrothermal vents.**



deposit sediments of almost pure metallic sulphides around the vent fields. The metals involved include copper, zinc, manganese and cobalt that are regarded as highly toxic in shallow water. Even so, the immediate vicinity of the vents supports dense communities of highly specialised organisms (see Section 5.2.13). These vents are ephemeral features, either because an earthquake seals off the vent, or because the channels through the rocks become clogged with precipitates. As the flow is choked, the discharging fluids become cooler and the sulphides are precipitated within the rocks. These cooler discharges have a milky and shimmering appearance (so-called 'white smokers'). The vent waters are also rich in dissolved gases, including methane, carbon dioxide and helium, and these have been used as tracers to track the plumes of discharged water. Several vent fields have been found in the vicinity of the Azores *(Figure 2.3)*, mostly near non-transform offsets rather than in the centre of the individual ridge segments (German *et al*., 1996). Only three deep vents have been found so far within Region V (Radford-Knoëry *et al*., 1998) – 'Lucky Strike' at 37º 18' N, 32º 16' W (1620 – 1730 m), 'Menez Gwen' at 37º 50' N, 31º 31' W (855 m) and 'Rainbow Field' at 36º 14' N, 33º 54' W (~ 2300 m) – but several others have been found at shallow depths around the Azores *(Figure 2.5)*. North towards the Charlie-Gibbs Fracture Zone, the Mid-Atlantic Ridge remains unexplored (van Dover, 1995), but along the Reykjanes Ridge a vent site has been discovered, the Steinaholl vent field, which is just outside Region V in Region I.

2.4.3 Abyssal plains

There are extensive areas of abyssal plain in the three main basins; the Newfoundland Basin in the north-west, the Porcupine Abyssal Plain (*c*. 165 000 km^2) in the east and the Iberian (*c*. 107 000 km^2) and Tagus Abyssal Plains (*c*. 41 000 km^2) in the south-east. These plains are almost featurelessly flat, with slopes $< 1^{\circ}$ and soundings > 4500 m. Their underlying rough topography of crustal (magmatic) rocks has been smoothed by the accumulation of many millions of years worth of calcareous (limy) pelagic sediments. The upper layers of these pelagic sediments are intermixed with layers of siliceous ice-rafted deposits (see Andrews, 1998). Deep within the sediments the pelagic deposits are further interleaved with successive layers of turbidites; sediments which have periodically slipped in massive quantities either from the neighbouring continental slopes or from submerged Icelandic glacial deposits (see Section 2.4.4). After their formation along the ridge, the crustal rocks continue to cool and shrink over many millions of years, so that their depth is greatest nearest the continental margins where the crust is oldest. However, this deepening of the crust is largely compensated for by increases in the thickness of the overlying pelagic sediments. These pelagic sediments are predominantly soft muds (or oozes) rich in calcium carbonate (calcite), with fine-grained siliceous material from North America, Greenland and Iceland (Grousset and Chesselet, 1986) and small quantities of wind-borne (or aeolian) dust. At great depths, the hydrostatic pressure increases sufficiently for calcium carbonate to dissolve. When the rate at which it dissolves equals its rate of deposition a 'lysocline' develops. However, throughout most of Region V the depth is too shallow for a lysocline to develop and so its sediments are predominantly rich in calcium carbonate. The proportion of sediments that originate from terrestrial sources increases towards the continental margins.

Figure 2.5 **Shallow water hydrothermal vent on the João de Castro Bank in the Azores (R. Santos © *imag*DOP).**

Coring by the Ocean Drilling Program (ODP) has shown that the layers of pelagic deposition have remained almost undisturbed over geological timescales. It is the geological record preserved in these sediments that has provided most of the evidence on which our knowledge of the history of the oceans and their climates is based, and which now underpins the development of climate models. Throughout the Quaternary Period (the last 1.6 million years), the frequent oscillations between warm and cold climates have left a clear imprint on the sediments deposited. The alternating cold glacial and warmer interglacial periods have resulted in the deposition of bands of sediment containing contrasting types of calcareous pelagic microfossils; mostly coccoliths and foraminifers. In addition, the sediments deposited during the colder periods contain abundant quantities of ice-rafted debris. These cold periods culminated in dramatic collapses of the continental ice fields, which had bordered the North Atlantic, and resulted in the release of vast swarms of icebergs. These drifted over much of the North Atlantic, extending as far south as the coast of North-west Africa (Andrews, 1998), and as they melted they dropped debris, which formed sandy layers. These iceberg events known as ‘Heinrich events’ occurred every 6000 to 10 000 years, lasted several hundred years and preceded a complete reorganisation of the atmospheric and oceanic circulation as climatic conditions switched from cold to warm. The causes and mechanisms driving these dramatic oscillations in climate are still under discussion.

2.4.4 Continental margins

Since there is no subduction of ocean crust along the continental margins of Western Europe, its margins are tectonically passive and no deep trenches have formed. The foundations of the continental shelves are sedimentary and granitic (continental) rocks, which match those on the opposite side of the Atlantic from which they originally split. These basement rocks are covered with sediments eroded from the neighbouring land masses. At the outer edge of the continental shelf – the shelf-break – the gradient of the seafloor steepens abruptly to form the continental slope. The topography of these slopes was mostly moulded during the glacial eras, when sea levels were nearly 100 m lower than at present. The slopes are draped with a mix of pelagic and terrigenous sediments except where the gradients are too precipitous for deposits to accumulate or where strong currents scour the slope and keep it devoid of sediment. At the base of the continental slope is the continental rise, this is formed of rock debris from the slope and peters out over the abyssal plain. Since there are no trenches to act as traps, sediment slides and turbidity flows can move unimpeded out over the abyssal plain (Kenyon, 1987); some have travelled as far as the foothills of the Mid-Atlantic Ridge. During the Quaternary Period, there were major mass-wasting events, which tended to coincide with periods of sea level change as the climate oscillated between glacial and interglacial conditions. Some of these submarine slides have been massive, and have involved hundreds of cubic kilometres of material slipping off the slopes into deep water. These catastrophic events must have generated massive tsunamis and had extensive impacts on coastal habitats, deep-water sediments and benthic communities.

In the Southwest Approaches, the slope is dissected by a complex of canyons eroded by past turbidity and sediment flows, and currently by wintertime cascades of cold water spilling off the continental shelves. At the bottom ends of the canyons sedimentary fans have formed, from which systems of channels fringed by levees spread out, creating low relief far out over these otherwise monotonous abyssal plain environments (Kenyon *et al*., 1978). Over the abyssal plains the flows, and hence the deposition of the turbidites, have meandered following slight variations in the bottom topography.

Persistent along-slope currents deposit sediment drifts along the contours, which are known as contourites. Major drifts have been deposited along the right-hand flanks of the outflows from the Norwegian Sea as they round the Rockall Plateau, Hatton Bank and the Reykjanes Ridge (McCave and Tucholke, 1986; Lackschewitz *et al*., 1996). Deposition was greater during the glaciations when the volumes of these outflows were much greater; some sediment-bound contaminants are currently accumulating in these drifts (van Weering *et al*., 1998).

2.4.5 Seamounts

Seamounts originate as volcanoes, either along the mid-ocean ridge or in association with major fracture zones. In Region V the most important seamounts are associated with the ridge on either side of the Azores Fracture Zone. Current flow patterns over seamounts are complex because the shoaling topography accelerates the flow and generates eddies, and as a result there are significant, albeit localised, increases in vertical mixing. Interactions with tides can result in the formation of relatively stagnant anticyclonic cells of water, which may play an important biological role in retaining larvae in the vicinity of the features (Mullineaux and Mills, 1997). The localised vertical mixing caused by the eddies also stimulates primary production and attracts in mobile fauna such as fish (see Section 5.2.13), so they are important sites for oceanic fisheries (see Section 3.5.4). Seamounts also have larger-scale effects on the physical circulation, for example through dissipating eddies (see Section 2.7.3) (Shapiro *et al*., 1995).

2.5 Coastal margins

The only coastal margins in Region V are associated with the Azores Archipelago. The archipelago, which is situated about 1200 km west of Lisbon, consists of nine inhabited islands in three groups, lying astride the Azores Fracture Zone (see *Figure 3.1*). Its extreme ends are the islands of Corvo and Santa Maria, which are 615 km apart. The islands are mostly 3 to < 1 million years old (Azevedo *et al.*, 1991), but some are very young; the volcano of Capelinhos (Faial island) erupted just 40 years ago (Santos *et al.*, 1995). The islands rise steeply from a region of rugged submarine topography, and are associated with many shoals and seamounts. All are still volcanically active, particularly those closest to the ridge axis. The last major volcanic eruption was in 1958 and in 1998 an earthquake caused death and extensive damage to property in Faial.

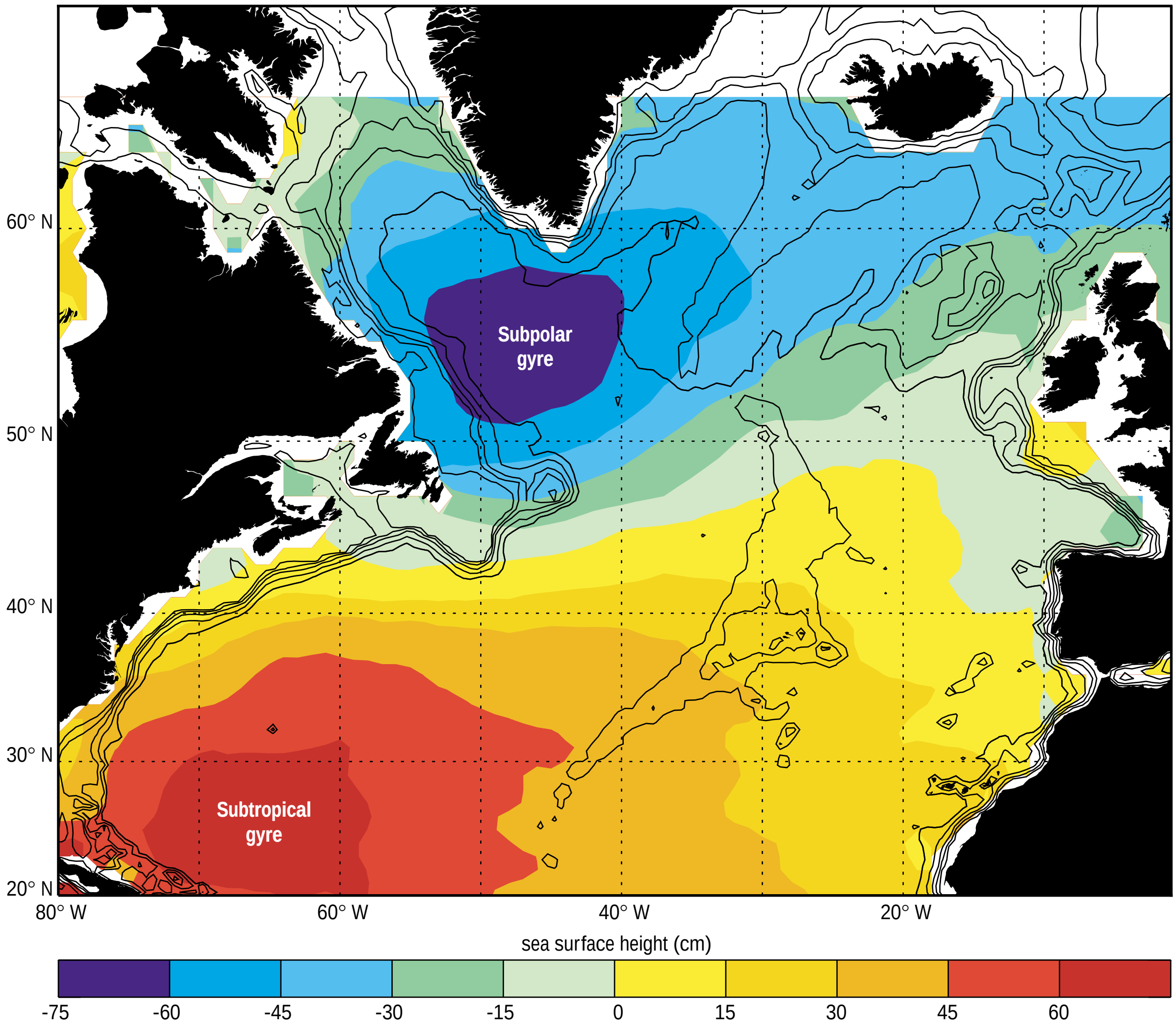
The total land area of the islands is 2333 km^2 and the highest point is 2351 m on Pico island. The islands lack substantial areas of estuaries and wetlands. Rainfall averages 500 – 1000 mm/yr, but exceeds 2000 mm/yr on higher ground. Even so, the volumes of freshwater run-off are only significant in terms of local ocean processes.

In the north-east of Region V there is an isolated rock pinnacle on top of the Rockall Bank and to the south, beyond the southern boundary of the OSPAR area, are Madeira and the Canary Islands, which both influence the region’s hydrography.

2.6 General hydrography

Ocean currents are primarily driven by surface winds and latitudinal differences in heat input and the balance

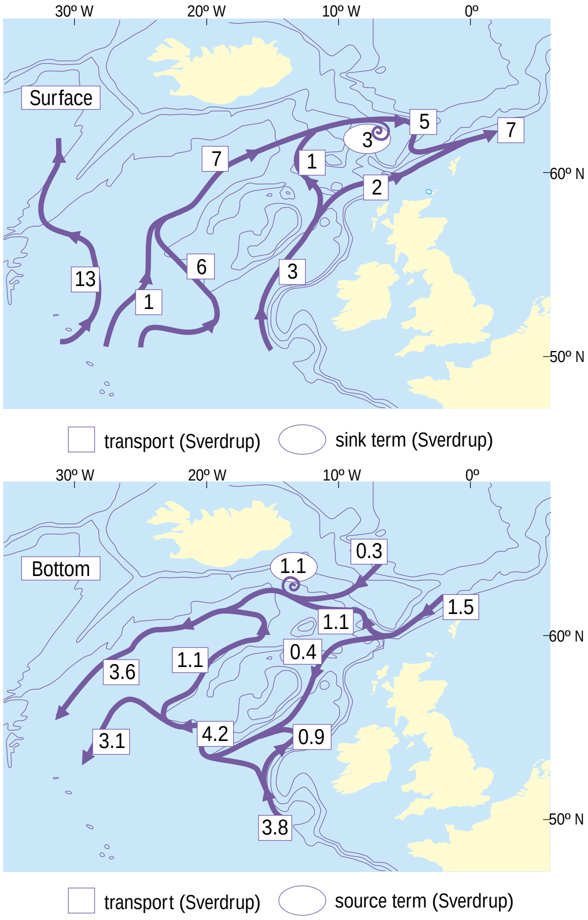
Figure 2.6 **Mean sea surface topography for 1992 to 1997 based on Topex/Poseidon altimeter data. Source: S. Esselborn, Institut für Meereskunde, Univ. Hamburg.**



between rainfall and evaporation. They are modified by the effects of the Earth's rotation (the Coriolis Effect), which in the northern hemisphere deflects their flow clockwise. There are two major circulation features in the North Atlantic; the subpolar and the subtropical gyres *(Figure 2.6)*, which are bounded by the region's major ocean currents. The NAC forms the southern boundary of the subpolar gyre and the AzC forms the northern boundary of the subtropical gyre. They are large-scale systems of major relevance. Both currents are broader, less restricted and less energetic than the currents in the North-west Atlantic (i.e. the Labrador Current and the Gulf Stream). Between the Grand Banks and the Charlie-Gibbs Fracture Zone the gyres interact (Rossby, 1996) through exchanges across adjacent boundaries of the NAC (Krauss, 1986). In the eastern North Atlantic, however, the gyres are separated by the Azorean buffer zone, where the exchanges occur through a much wider and more turbulent zone (Alves, 1996). It is within this buffer zone that most of the water in the upper layers of the region – a water mass known as North Atlantic Central Water (NACW) – is formed. The NAC transports considerable amounts of heat as it flows across the region and north-eastwards into the Arctic. There are compensatory counterflows of cold water from the Greenland and Norwegian Seas that spill over the shallow ridges between Iceland and Scotland. These water movements are illustrated in *Figure 2.7*. These cold dense overflows form a water mass (see Section 2.7.4) known as North Atlantic Deep Water (NADW). Contributions to NADW also come from Labrador Sea Water (LSW), which is produced in the Labrador Basin as a result of deep winter convection and mixing with overflow waters (Pickart, 1992). NADW can also be found throughout all the World's major ocean basins. It is the main component of the global thermohaline circulation known as the 'Ocean Conveyor', which plays an important role in global climate (see Section 2.1). Hence this water mass can be a conduit whereby changes generated in Region V can be transmitted to areas far removed from the North Atlantic. At great depth on the eastern side of Region V, there are inflows of remnants of Antarctic Bottom Water, identifiable by their high silicate content, and these can lead to long-term changes in the characteristics of the bottom waters of the region. It is important to remember that these currents play the dominant role in the distribution of dissolved and suspended contaminants throughout the region.

During the 1990s it was recognised that ocean circulation is far more dynamic than was previously thought and so highly sensitive to relatively minor decadal fluctuations in climate. Moreover, there are very strong feedback mechanisms whereby the oceans modulate the climate. Some of this forcing is external and seems to be coupled to the processes which also result in the El Niño phenomenon (Taylor *et al*., 1998), whereas some is internal to Region V and influences other oceanic regions.

Figure 2.7 **Estimated geostrophic transport in the surface and bottom layers to the north-east of Region V. Source: van Aken and Becker (1996).**



2.7 Water masses

2.7.1 Overview

Water masses are bodies of ocean water that have unique characteristics, which are set at the sea surface at the time and place of their formation. These characteristics include temperature, which is determined by atmospheric warming or cooling, and salinity, which is changed at the surface by dilution with rain or ice-melt water or is concentrated as a result of evaporation or ice formation. The concentrations of dissolved gases (e.g. oxygen and carbon dioxide) are determined by exchanges with the atmosphere, and their nutrient content is determined by deep mixing and regeneration. Water temperature and salinity together determine the density of a water mass, and it is the difference in density between different water masses that determines much of the motion within the ocean. If the density of a water mass is increased at the surface (as a result of cooling, ice formation or evaporation), it sinks into the ocean's interior, often sinking (subducting) along a front. It sinks to the depth at which its density matches that of the surrounding water (its density level) and then spreads out. But as it sinks and spreads it mixes with the ambient water masses, which results in the gradual modification of its original characteristics as it moves away from its site of origin. There are a variety of mixing processes spanning a wide range of time and space scales. Thus, at a given point the characteristics of a water mass carry imprints of its formation and subsequent mixing history, and these provide insights into the underlying processes of circulation and mixing (Curry *et al*., 1998).

Fluctuations in the volumes and characteristics of water masses, and in current speeds, generate variations in the transport of heat, salt and freshwater. These variations, particularly in poleward transport by the currents of the North Atlantic, have major impacts on the climate of Northern Europe. So monitoring fluctuations in the characteristics and volumes of the various water masses is providing unique insights into the way the atmosphere and ocean interact to regulate the climate. Changes in ocean transport, particularly of heat and salt, affect the atmospheric circulation on timescales directly relevant to climate.

The North Atlantic is the region where cold, fresh water masses coming from the polar seas, and the warm, salty waters originating from the subtropics and even the tropics are transformed by mixing and cooling. Although the temperature and salinity characteristics of these water masses are markedly different their densities are similar so when they meet there is vigorous intermixing (Rios *et al*., 1992). Many of the water masses found in the Atlantic have formed very recently, and so contain high concentrations of dissolved oxygen but low concentrations of nutrients (Levitus *et al*., 1993; Lozier *et al*., 1995). Throughout the deep waters of the North-east Atlantic, concentrations of dissolved oxygen are never low enough to limit aerobic biological activities and nutrient concentrations are never high enough for anthropogenic inputs to induce eutrophication.

Figure 2.8 illustrates the progressive modification of NACW as temperature and salinity above 1000 m decline northwards. Cold, high salinity water to the north of the Rockall and Hatton Plateau indicates Arctic Overflow Water. The low salinity water at 1600 – 1800 m is LSW that flows through the Charlie-Gibbs Fracture Zone at 52° 30' N. To the south of the Rockall and Hatton Plateau the salinity maximum at ~ 2600 m is a mixture of LSW and Arctic Overflow Water, and beneath that over the Porcupine Abyssal Plain is a deep water rich in silicate which contains a large component of Antarctic Bottom Water.

In *Figure 2.9* the band of high salinity water at shallow depths on the eastern flank of the Rockall Trough represents the northerly flow of the slope current. There is a marked front over the Reykjanes Ridge that marks the boundary between the relatively cold fresh waters of the Irminger Basin and the northward flow of water from the North Atlantic Current. The salinity minimum in both the Rockall Trough and the Icelandic Basin indicates the presence of LSW. Beneath this is a higher salinity colder vein of water. This is Overflow Water flowing southwards through Rockall Trough, around its southern end, and then northwards into the Icelandic Basin. This water carries a high load of suspended sediment, which it deposits in drifts around the flank of the plateau. In the Iceland Basin, the deepening of the isotherms to the east implies a northerly flow in the upper layers and a southerly flow in the deeper layers.

In general, water masses in the North Atlantic are distributed in a meridional pattern such that waters found at mid-depths in the south of the region outcrop to become the upper layers north of the Subpolar Front, whereas those occurring at mid-depths in the north become deep and eventually bottom waters in the south.

2.7.2 Thermocline and subthermocline water masses

Thermocline (upper layer) and subthermocline (intermediate) water masses extend from the surface to depths of about 1500 m in the north of Region V and to depths of about 2500 m in the south (Harvey and Arhan, 1988). They originate at the surface and their properties reflect seasonal and longer-term trends in atmospheric variability and mixing with waters from adjacent areas. In the north there are inflows of Subarctic Intermediate Water (SAIW) which originate as surface waters to the north of the Subpolar Front that have been cooled by the atmosphere. After convection and mixing they are advected mainly towards the south. Further south, SAIW tends to occupy the same depths as Mediterranean Water (MW) and LSW (Section 2.7.3) and forms horizontal fronts between these water masses across which there is active interchange and mixing.

NACW is characterised by a clear functional relationship between temperature and salinity and this is the water mass that occupies depths shallower than 700 m throughout most of Region V. There are two main regions where this water mass forms; one in the central eastern sector and the other in the south, and both lie within the gyre buffer zone of the Azores (see Section 2.6). A similar regime involving a sequence of atmospheric cooling, mixing and subduction leads to its formation, but in the southern formation region the atmosphere is warmer so the NACW produced there is lighter than the other variant. Both the NAC together with the associated

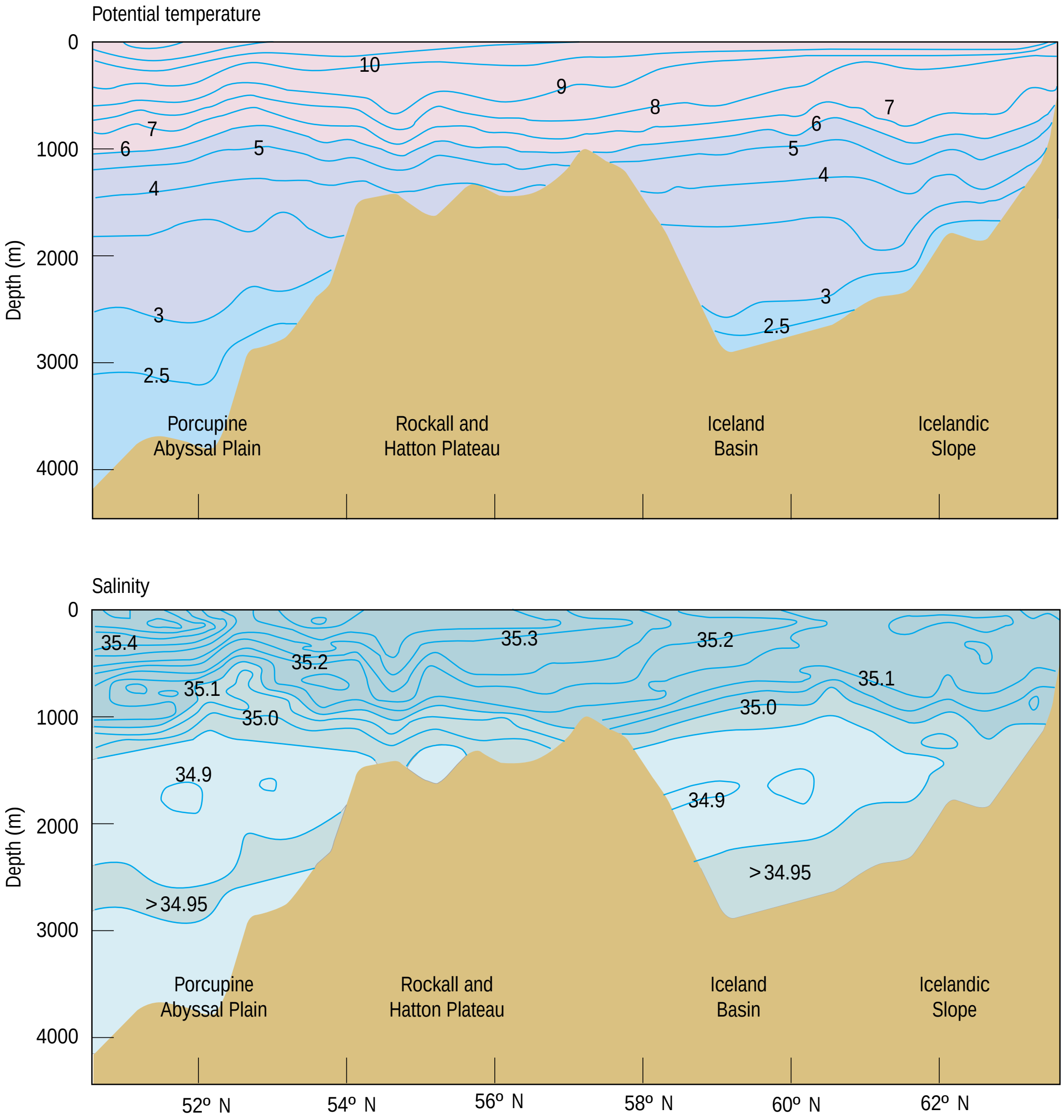
Subpolar Front and the AzC with the associated Subtropical Front play an important role in the lateral mixing of these thermocline and subthermocline waters. Any long-term change in atmospheric forcing or in the strength and effectiveness of the mixing generated by mesoscale features associated with these current systems will be reflected in the signatures of the subducted water masses. These differences will in turn be reflected in the potential energy content within the ocean interior that can produce water movements if released by some physical processes.

2.7.3 Mid-depth water masses

Labrador Sea Water

In the Labrador Sea severe cooling of the upper layers of the water during winter makes them unstable and storms result in extensive convection to considerable depths. The sinking of the cold surface water to depth is compensated for by deep water that is relatively warm and salty being moved to the surface. Variations in winter weather from year to year result in the generation of LSW with slightly

Figure 2.8 **North–south section showing potential temperature and salinity along 20° W in July 1988. Source: after van Aken and Becker (1996).**



different characteristics and varying volumes. Even so, its characteristic properties of temperature and salinity (about 3.4 ºC and 34.9 respectively) makes it the coldest, freshest and most highly oxygenated water mass at intermediate depths in the North Atlantic. It mainly circulates around the subpolar gyre, passing through the Newfoundland and Irminger Basins flowing either directly southwards, or north-eastwards entering the Icelandic and North European Basins. It spreads rapidly. By using CFCs as tracers, newly-formed LSW has been shown to reach the Irminger Sea in under a year, the Flemish Cap in about a year and the European continental slope within four to five years (Sy *et al*., 1997). Water is exported from the subpolar gyre mainly via the boundary currents, i.e. the deep western boundary current system below the Gulf Stream and the NAC and on both sides of the Mid-Atlantic Ridge.

Mediterranean Water

Within the Mediterranean, the losses of water through evaporation greatly exceed the inputs of freshwater from rainfall and river outflow. This excess loss is compensated for by strong inflows of surface Atlantic waters from the

Figure 2.9 **East–west section showing potential temperature and salinity along 58° N in April 1991. Source: after van Aken and Becker (1996).**

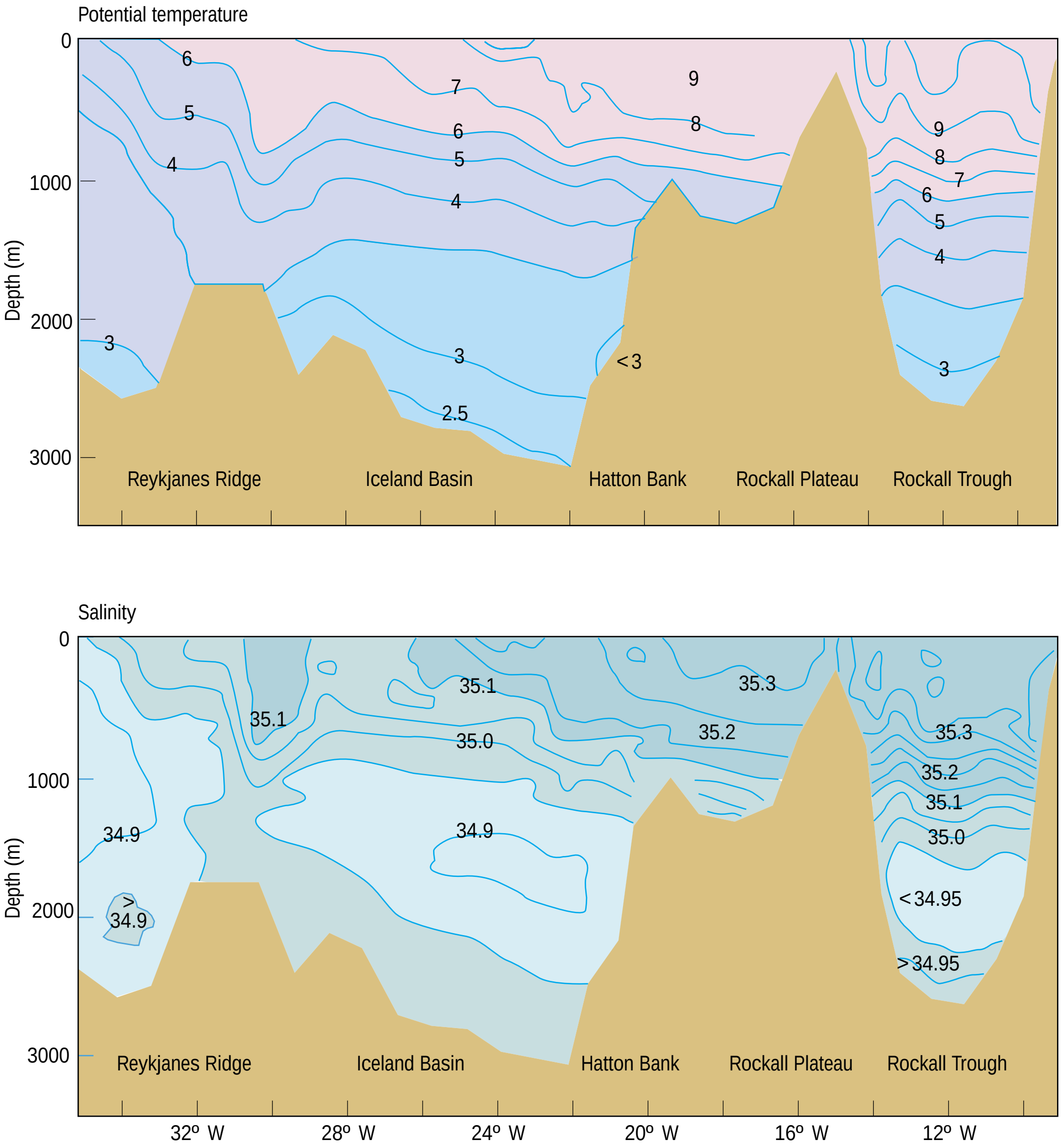
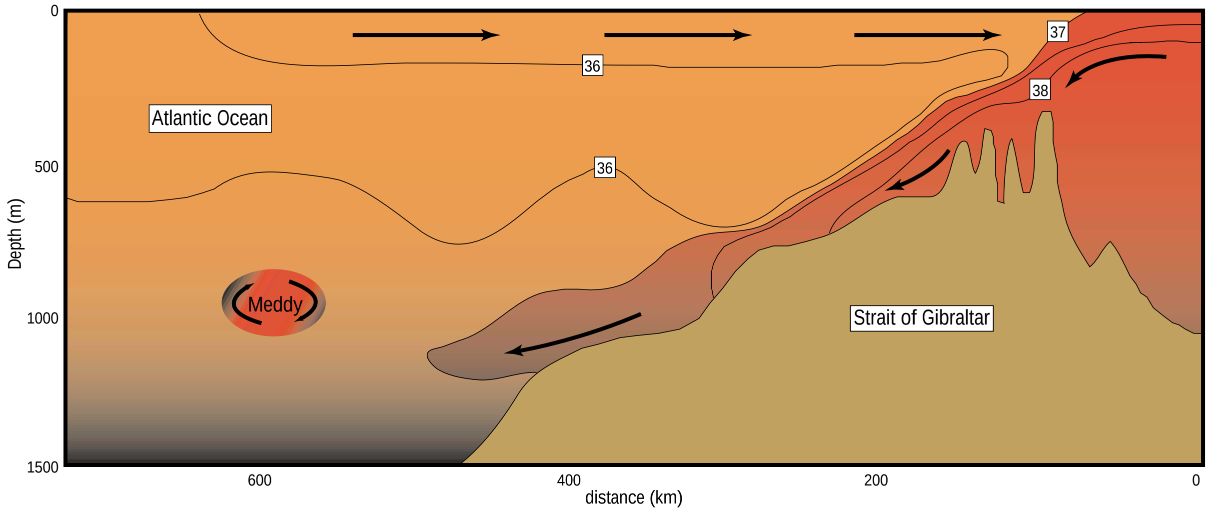


Figure 2.10 **Schematic representation of water flow through the Strait of Gibraltar and the formation of Meddies. Source: Richardson (1993).**



Gulf of Cadiz through the Strait of Gibraltar *(Figure 2.10)*. Beneath this variable flow into the Mediterranean, there is a westerly outflow from intermediate depths of the Alboran Sea. These exchanges are mainly controlled by the hydraulic properties of the Strait, sheer instabilities and intensive tidal mixing. Annual inflows are estimated at about 53 000 km^3 and the outflows at about 50 500 km^3 (Chou and Wollast, 1997). Once outside the Strait, the MW cascades down the northern slope of the Gulf of Cadiz entraining ambient water such that its core salinity is reduced from 38.4 to about 36.5 (Käse and Zenk, 1996). The original outflow of about 0.7 Sverdrup (Ochoa and Bray, 1991) increases three- to four-fold by the time the outflow waters reach their density equilibrium level and lift off the seafloor close to Cape St Vincent in Region IV. Thus in the slope region off the western Algarve coast there is an injection of heat and salt at depths of 800 – 1200 m into the North-east Atlantic and the import of chemical contaminants originating from Mediterranean sources (see Section 4.4.3).

Most of the outflow waters passing Cabo São Vincent turn north into Region IV where they spread into Region V in a complex pattern determined by Coriolis forcing and interactions with the local topography (Zenk and Armi, 1990). The Tejo Plateau, off Cabo da Roca and the scattered seamounts in the Iberian Peninsula play a significant role in determining the zonal alignment of the tongue of MW as it spreads through the North Atlantic (Käse and Zenk, 1987).

Some of this outflow water can be traced moving northwards parallel to the Iberian Peninsula and spreading towards higher latitudes. By the time it reaches the Rockall Trough its salinity maximum is no longer so pronounced, so that further to the north-west it competes with LSW coming from the western basins at slightly deeper depths (Paillet and Arhan, 1996).

Lenses of salty MW called ‘Meddies’ are probably responsible for a significant amount of the heat and salt fluxes in the MW tongue (see Section 2.8.3). Most Meddies move westward and diverge from the general northward pattern of spread of the rest of the outflow. Any Meddy that encounters a seamount tends to be dissipated and so acts as a point source of heat and salt (Shapiro *et al*., 1995).

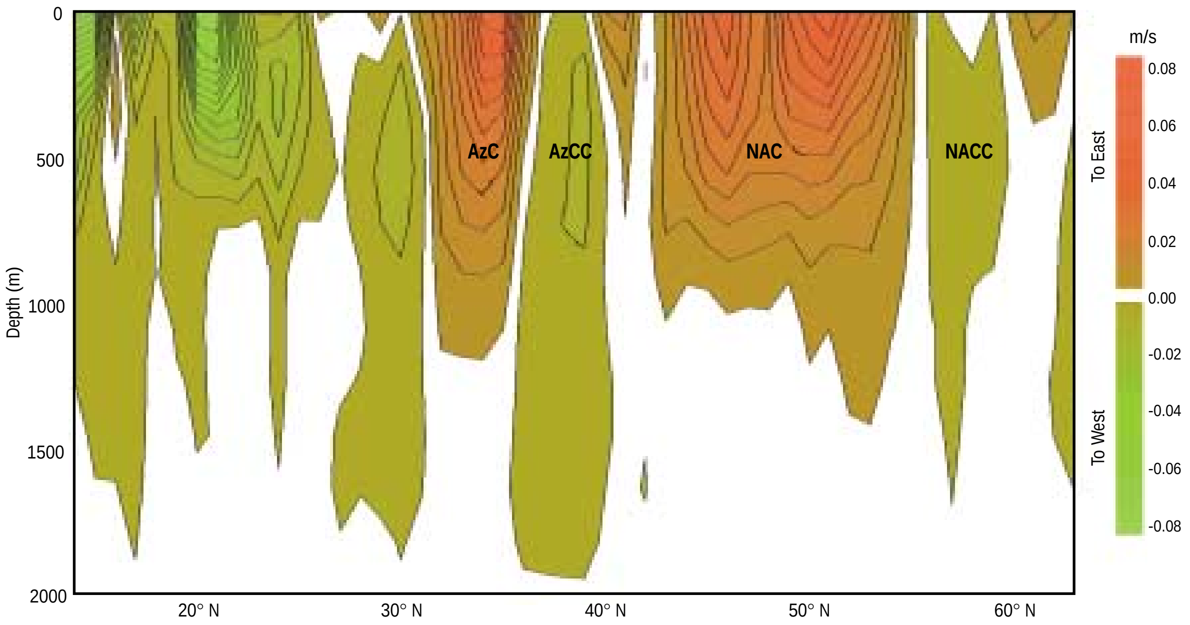
Recently, substantial changes have been detected in the physical characteristics of the Eastern Mediterranean Sea. The cause of these changes has been attributed to reduction in the flow of freshwater reaching the Eastern Mediterranean since the building of the Aswan Dam. These changes are now being transmitted to the Western Mediterranean and the likelihood is that within a decade the properties of Mediterranean Outflow Water will start to change and this will modify the circulation of the North-east Atlantic at intermediate depths (de Lange *et al*., 1999). This demonstrates how human impacts from outside the area may be transmitted into Region V.

2.7.4 Deep and bottom water masses

Arctic Overflow waters

Exchanges of heat between the North Atlantic and the Arctic strongly modify conditions in the polar ocean and drive the convective renewal of deep subsurface waters in the Labrador, Greenland and Icelandic Seas. Dense cold waters from these high latitude seas flow into the North Atlantic via channels through the shallow ridge, which separates Greenland, Iceland and Scotland. The volumes of these overflows vary seasonally and interannually, but are invariably present over the ridge. The mean inflow via the Denmark Strait is 2.9 Sverdrup and a further 2.2

Figure 2.11 **Mean quasi-geostrophic surface currents between 1948 and 1997. Source: Alves *et al*. (1998).**



Sverdrup enter mostly through the Faroe Bank Channel (van Aken and Becker, 1996). These subpolar waters make a major contribution to the characteristics and export of NADW and hence, to global thermohaline circulation.

Antarctic bottom water

Antarctic Bottom Water, formed in the Weddell Sea, flows up the western basin of the South Atlantic and through the Mid-Atlantic Ridge via deep fracture zones at equatorial latitudes. It flows northwards through the eastern basins and enters the Iberian Basin via Discovery Gap to the west of the Gorringe Bank (Saunders, 1987). This cold (<2 °C) water mass is rich in nutrients, notably in silicate. By the time it reaches Region V it has lost about a third of its original oxygen content (Mantyla and Reid, 1983). By mixing with both Arctic Overflow Waters and the overlying NACW it too contributes to the formation of NADW.

2.8 Circulation and volume transport

2.8.1 Main current systems

Region V is dominated by two major gyres (Krauss, 1996). In the south there is a clockwise flowing subtropical gyre that is predominantly wind-driven and which feeds water originating from the Gulf Stream into the region via the AzC. In the north there is an anticlockwise subpolar gyre which is predominantly buoyancy-driven. The Gulf Stream splits into three branches (Klein and Siedler, 1989), one of which recirculates within the Western Basin without crossing the Mid-Atlantic Ridge and entering the region. The second is the Azores/Front Current, which crosses the Mid-Atlantic Ridge south of the Azores and influences Region V across its southern boundary and hence the Azores Archipelago through the turbulent features it releases (Alves and de Verdière, 1999). The third branch flows predominantly north-eastwards and enters Region V from the south-west. To the north of 48º N its flow across 30º W is estimated at about 20 Sverdrup. At around 20º W it turns northwards (anticlockwise) and crosses 54º N (Ellett and Blindheim, 1992). Most of this flow enters the Iceland Basin to the west of the Hatton Bank contributing to the flow of North Atlantic water into the Norwegian Sea. As it crosses the Iceland-Faroes Ridge it intermingles with polar water from the East Iceland Current. But a relatively small component flows almost due east, supplements the flow of the European Slope Current and thence crosses the Wyville-Thompson Ridge into the Norwegian Sea.

The complex patterns of flow and the volume transports in the upper layers and at intermediate depths in the north-east sector of the region are illustrated in *Figure 2.7*. The waters that overflow the ridges between Iceland, the Faroe Islands and Scotland entrain large volumes of ambient water at intermediate depths and almost double in volume as they cascade down the slope of the ridges.

2.8.2 Upper layer circulation

The upper layer circulation in Region V is dominated by two eastward flowing currents, the NAC in the northern part of the region and the AzC that crosses the southern sector of the region (Alves *et al*., 1994; *Figure 2.11*). Both

Table 2.1 Seasonal mean flows (Sverdrup) for the Azores Current and the Azores Counter-Current. Source of data: Alves (1996).

	Winter	Spring	Summer	Autumn	Annual
Azores Current	8.9	19.7	12.1	11.7	13.1
Azores Counter-Current	-2.0	-3.0	-2.2	-0.8	-2.0

Eastward flow represented by positive values; westward flow represented by negative values.

appear to result from the splitting of the Gulf Stream to the east of Newfoundland. The flow of the NAC affects the sector between 40º N and 60º N, while the AzC affects the sector between 40º N to 25º N. Both these main flows have associated counter-currents on their northern flanks, the North Atlantic Counter-Current (NACC) and the Azores Counter-Current (AzCC) (Alves and de Verdière, 1999). The flow of the AzC has a single axis centred at around 34º N, whereas the NAC flow has a double axis crossing 30º W at 45º N and 50º N respectively. Across both the NAC/Subpolar Front system and the AzC/Subtropical Front system there is intense horizontal mixing. So that along the NAC system there is strong mixing between NACW and SAIW, while along the AzC system there is mixing between the two NACW waters (18 ºC and 13 ºC mode waters). *Table 2.1* summarises the annual mean downstream transports.

Both modelling and direct observations have demonstrated that the AzC generates persistent anticyclonic eddies along its northern flank (Alves and de Verdière, 1999). Models have demonstrated that the AzC may transport substances and small passive particles, including planktonic larvae, rapidly downstream and so impinge on Region V (Alves *et al*., 1998).

2.8.3 Eddies and eddy transport

Mesoscale eddies with dimensions of 20 – 200 km are dominant features in the oceans and transfer heat, salt and contaminants over long distances. In the northern hemisphere the cores of the cyclonic eddies have lowered sea levels and are filled with relatively cool sea water, whereas the cores of the anticyclonic eddies have elevated sea levels and are filled with relatively warm sea water. Mesoscale eddy activity in the Eastern Atlantic is about half that in the Western Atlantic, where rings are regularly spawned from the Gulf Stream. In Region V the majority of mesoscale features are generated in the Azores region, along the boundaries of the Slope Current (Pingree and Le Cann 1992a,b) or as ‘Meddies’ at intermediate depths (McDowell and Rossby, 1978). The influence of some of these eddies extends throughout the water column to the seafloor, where they contribute to the occasional periods of intense bottom currents (30 – 40 cm/s) referred to as ‘benthic storms’ (Klein, 1988) (see also Section 2.9.3).

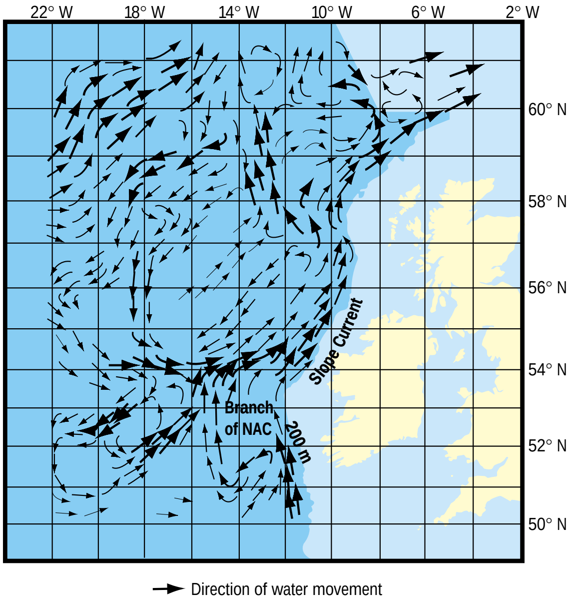
Meddies are exceptional examples of mesoscale eddies in that they occur at intermediate depths. Their formation is illustrated in *Figure 2.10*. They are lenses of nearly pure MW with diameters of < 100 km, which are generated in the sea area to the south of the Algarve (see Section 2.7.3). The mechanisms leading to their formation are still not fully understood, but interactions between the pulses of outflow from the Strait of Gibraltar and the local topography (especially the numerous canyons along the Portuguese Slope) together with baroclinic instabilities probably play a role. They are anticyclonic with maximum azimuthal speeds of ~ 0.3 m/s and can persist for over two years (Armi *et al*., 1989). They are contained within a ‘vorticity’ front, which effectively shields them from being eroded by rapid lateral mixing. Although their core speeds are usually restricted to the depths of the MW, they can show a dynamic signal at the surface (Stammer *et al*., 1991). In the Iberian Basin the majority of young Meddies drift south-westwards away from the Region V area at speeds of 2 – 6 km/d, but periods of steady movement can alternate with month-long periods of stagnation (Käse and Zenk, 1996). Although most Meddies never enter Region V, a few have been identified moving northwards and have been encountered as far north as 44° N.

Mesoscale structures contribute to ocean processes in two ways. Firstly, they are important mechanisms for the transfer of heat, salt and contaminants from one area to another, and may be particularly important in cross-slope exchanges. Secondly, because there is intermittent vertical mixing along the fronts that bound them, highly localised patches of enhanced primary production can develop, which tend to attract mobile pelagic fauna. Thus eddies contribute to the generation of the biological patchiness that is a ubiquitous feature of the near-surface layers. This heterogeneity is not only important in the dynamics of the interactions between primary and secondary production in the open ocean, but also serves to maintain ecological stability (Smith *et al*., 1996). It may also be transmitted down the water column by sedimentation and vertically migrating organisms and so contribute to the variability of samples collected in both deep water and shelf seas.

2.8.4 The Northwest European Slope Current

A significant feature in the hydrography of cross-shelf exchanges and ecology along the north-east boundary of Region V (and hence with Regions I, II and III) is the

Figure 2.12 **Water movements at 200 m based on model output from the DYNAMO Project. Source of data: A.L. New, SOC.**



Northwest European Slope Current (Pingree and Le Cann, 1989). This current generally flows polewards along the continental margin, which is counter to the residual currents on the shelf. However, its intensity is seasonal and its maximum poleward velocity of ~ 40 cm/s occurs in winter along the 1000 m contour. At 48° N its flow transports about 4 Sverdrup (Pingree and Le Cann, 1989) but declines northwards. But west of Ireland its flow, which by then has decreased to 1.5 Sverdrup, is supplemented by a branch of the NAC (see *Figure 2.12*) and its volume transport through the Faroe-Shetland Channel again approaches 4 Sverdrup (Huthnance and Gould, 1989). At mid-depths the current direction tends to be on-slope, whereas near the seabed it is down-slope, reaching speeds of 15 cm/s (van Weering *et al*., 1998). Slope currents are forced by density gradients and along-shore pressure gradients associated with coastal trapped waves, which have length scales longer than the width of the shelf (Huthnance, 1992). The Slope Current has a major impact on the biology of the shelf-break (see Section 5.2.13) and contributes to the formation and maintenance of the shelf-break front. It also plays a significant role in transporting dissolved and suspended material from the Atlantic northwards into the Norwegian Sea. There is a similar poleward-flowing current off Portugal in Region IV. There may be continuity between these flows but this is yet to be demonstrated.

2.9 **Waves and tides**

2.9.1 Surface waves

Waves and swell tend to be higher in the north than the south, and higher in winter than summer. Surface wave energy is generally at a maximum around the shelf-break. Decadal increases in measured wave heights documented by Bacon and Carter (1991) have been linked to increases in wintertime storminess and mean wind speeds (Bacon and Carter, 1993) related to the North Atlantic Oscillations (see Section 2.13).

2.9.2 Internal waves

Internal waves play an important role in vertical mixing particularly where the topography is shallow enough to interact with the upper ocean. Particularly along the upper slope and over seamounts, topographic features induce internal waves to break, thus enhancing vertical mixing. This is the process that results in primary production being elevated along the shelf-break front (Holligan *et al*., 1985; New and Pingree, 1990). In addition the physical dynamics at the shelf-break enhance both the vertical deposition and lateral advection of suspended sediments, and hence exchanges of natural and anthropogenic material between shelf seas and the deep ocean.

2.9.3 Tides

In the deep ocean, the tides are baroclinic and show less physical expression at the surface than the external tides experienced in inshore waters. They are basically internal waves with tidal periodicities (Ray and Woodworth, 1997), being semi-diurnal and generated by interactions between the oscillations generated by the gravitational effects of the moon (and to a lesser extent, the sun) and the underwater topography (Munk, 1997). However, vertical displacements can be extensive, for example internal waves with amplitudes > 200 m have been detected near shelf-breaks in the North Atlantic (Pingree and New, 1989). In the open ocean internal vertical displacements of 10 – 20 m are commonplace and can contribute to vertical mixing (Wunsch, 1975), particularly where the waves become unstable and break. Thus tides can play an important role in the development of the shelf-break front, along which biological productivity is enhanced. Usually there are few signs of these motions at the surface; an internal wave with a height of 10 m becomes a wave of only a few centimetres at the surface (Ray and Mitchum, 1997). It is claimed that ocean tides can now be predicted with confidence by using satellite altimetry to refine the outputs of tidal models (Kantha and Tierney, 1997).

During spring tides, when near-bottom currents become fast enough to resuspend sediments and detritus from the seabed, the tidal oscillations can contribute to the generation of benthic storms (see Section 2.8.3). Over slopes, these cycles of deposition and resuspension assist with the down-slope transport of material, particularly if they coincide with the passage of mesoscale eddies through a region. Time-lapse photographs of benthic environments have illustrated how deep-sea tidal oscillations influence the resuspension and deposition of sediments on the seabed, and also the behaviour of some fish and other benthic organisms (Lampitt *et al*., 1983).

2.10 Transport of solids

Deep ocean currents play a significant role in the erosion of sediments and the lateral transport of suspended particles. The erosive power of the flows through the channels in the Scotland–Iceland Ridge system results in the extreme coarseness or even absence of sedimentary deposits along the pathway of the cascading water. The high concentrations of suspended particulate material can be detected as nephels; layers of turbid water that strongly scatter light. Nephels can also originate in winter when water on neighbouring shelves cools faster than the oceanic water offshore, and so becomes unstable. Large boluses of water can suddenly slide off the shelf and cascade down the slope into deep water. These cascading boluses generally follow existing channels in the slope, eroding and scouring them and eventually depositing their sedimentary load in deep water. To the west of the Porcupine Bank internal tides can also generate currents, which locally can exceed 40 cm/s and hence erode the sediments. Thus nephels are generated locally within narrow depth zones at 400 – 600 m and flow downslope. As they move offshore, they leave the seafloor and interleave along isopycnals into the interior of the ocean. To the north of the Porcupine Bank, the currents generated by the tides are less focused by the topography and so nephels are only generated intermittently during spring tides (Dickson and McCave, 1986). Off the Goban Spur in the Southwest Approaches up to 50% of the organic matter reaching the benthic communities on the lower slope is carried laterally down-slope, rather than vertically by gravitational sedimentation (van Weering *et al*., 1998).

2.11 Focus areas

At the present state of knowledge no specific focus areas can be identified in Region V.

2.12 Meteorology

2.12.1 Pressure and wind

Region V is dominated by two major atmospheric pressure centres; the Icelandic low at the northern boundary and the Azores high at the southern boundary. So the climate of the area is dominated by strong westerly winds. Embedded within this belt of westerly winds are numerous cyclones, which develop along the zone of strongest temperature gradients, the Polar Front, and generally traverse Region V from south-west towards north-east. The mean position of the Polar Front varies seasonally. At mid-winter, it lies approximately from the south-west corner towards Ireland, but by mid-summer it has shifted northwards to lie from Labrador towards Iceland. The cyclonic activity in the atmosphere is much stronger in winter than in summer.

In the northern sector, mean wind speeds and storm frequencies can be expected to be at least as high as the values measured at coastal stations on Iceland, the Faroe Islands, Ireland and the Hebrides. Surface pressure maps indicate that the highest mean wind speeds and storm frequencies occur in the north-west of the region fairly close to Greenland. The frequency of these storms is not only considerably less in the south-eastern sector but also the storms themselves are much less violent in the summer months. In late summer and early autumn, hurricanes (or hurricanes that are transforming into mid-latitude cyclones) sometimes enter the region from the south-west.

The atmospheric pressure difference between the Azores high and the Icelandic low is an important characteristic of the weather throughout the OSPAR area and has a considerable influence on the oceanic circulation and climate. The strong westerly winds reach their maximum strength along a belt called the Atlantic jet stream, and this is a very important ‘engine’ for maintaining the flows of the Gulf Stream and the NAC. They also import atmospheric pollutants from sources across the Atlantic.

2.12.2 Temperature and precipitation

The northernmost sectors of Region V, as indicated above, are generally within the influence of the polar air mass. In winter, the temperatures of this air mass are generally around 0 – 5 ºC along the northern boundary. Much colder air from eastern Canada, Greenland and the ice-covered sea areas of the Arctic basin often flows out across the area but is rapidly warmed by heat from the Atlantic water. In summer, typical air temperatures are 7 – 11 ºC. In the southern sector the influence of the subtropical high, keeps air temperatures close to 15 ºC in winter and 22 ºC in summer.

The gradients in precipitation are generally opposite to the temperature gradients. Annual mean values range from around 400 mm in the south-eastern corner to 1200 – 1300 mm along the northern boundary. These values come from the Ocean Weather Ships where 'present weather' observations were used to estimate precipitation (Landsberg, 1984). Measurements at land stations are generally higher than those observed over the ocean nearby, because rain falls as the winds and clouds are forced upwards by the terrain. Hence the mean annual rainfalls at Ponta Delgada and Horta of 960 and 1030 mm respectively, are about double that falling over the ocean. Throughout Region V precipitation is greater in winter than in summer. This seasonality is most marked in the southern sector where, for example, the average rainfall in Dec – Feb is 320 mm, but only 80 mm in Jun – Aug.

2.13 **Climatic variability**

Climate is highly variable in the North Atlantic because of variations in the external forcing and internal instabilities. It has oscillated between warm and cool periods at decadal, centennial and millennial scales since the last Weichelian glaciation. Variations in the oceanic conditions of the North Atlantic and the overlying atmosphere control the climate of Western Europe, generally keeping its climate much milder than at similar latitudes elsewhere in the world.

Two major processes drive ocean circulation in Region V: firstly, the balance between the northwards outflow of surface water across the ridges between Scotland and Iceland into the Norwegian Sea and the deeper inflows, and secondly the formation and subsequent spread 18 ºC Mode Water in the Sargasso Sea. The strong inter-annual to decadal variability of these two processes appears to be inversely correlated. Dickson *et al*. (1996) linked this variability to the large-scale oscillations in atmospheric mass between the Icelandic Low and the Azores High – the so-called North Atlantic Oscillation. This oscillation is the dominant source of variability in atmospheric behaviour in the North Atlantic explaining 32% of the variance in monthly sea level pressure, it is also linked with variations in air temperatures, wind strength and direction and rainfall. The index of NAO variability is determined from the difference between atmospheric pressure measured at Stykkisholmur (or Akureyri) in Iceland and at Ponta Delgada in the Azores. The index is high when pressure is low over Iceland and high over the Azores, and is low when this difference is reduced or even, on occasions, reversed in sign ***(Figure 2.13)***. Oscillations in the NAO index undergo long-term cycles of variation with periodicities of 2.1, 8, 24 and 70 years. The index was particularly low during the 1880s and 1960s, and particularly high during the 1920s and 1990s. These oscillations have been linked to fluctuations in wind speed, heat fluxes, wave heights, storm tracks, patterns of evaporation and precipitation, and quantities of sea-ice in the Labrador Sea. For example, during the late 1950s, wintertime convective mixing in the Greenland Sea became progressively deeper, reaching a maximum of 3500 m in 1971. Since then the depth of mixing has steadily diminished with the result that since the 1980s there has been no renewal of water below 1600 m, and none below 1000 m since the 1990s (Dickson *et al*., 1996). Deep water in the Greenland Sea has become warmer and more saline since the early 1970s.

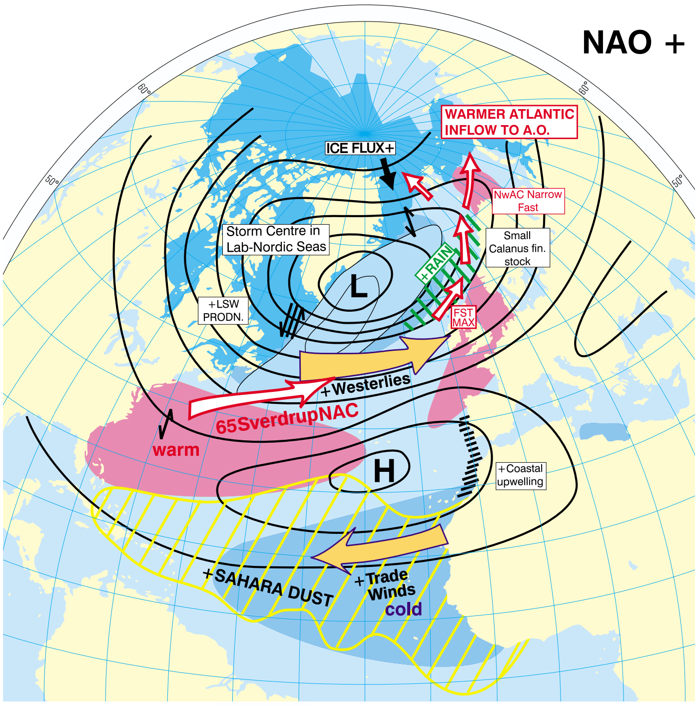
During the 1960s a major intrusion of fresher water was identified leaving the Greenland Sea, which became known as the 'Great Salinity Anomaly' (GSA). It took fourteen years to circulate around the North Atlantic subpolar gyre ***(Figure 2.14)*** and eventually re-entered the Norwegian Sea via the NAC in 1981/2 (Dickson *et al*., 1988). Since then, other high salinity anomalies have been reported from the Channel and the turnover of the deep water in the Labrador Sea has increased. Between 1966 and 1992 the total water column in the Labrador Sea lost on average 200 kg salt/m^2 and cooled by 0.46 ºC (equivalent respectively to adding about 6 m of freshwater per year and continuously loosing 8 W/m^2 for 26 years). A similar cycle of events seems to have occurred in the 1920s, so the conclusion was that these strong climatic variations in water mass characteristics in the North Atlantic were being generated by cyclic events and so did not represent progressive changes.

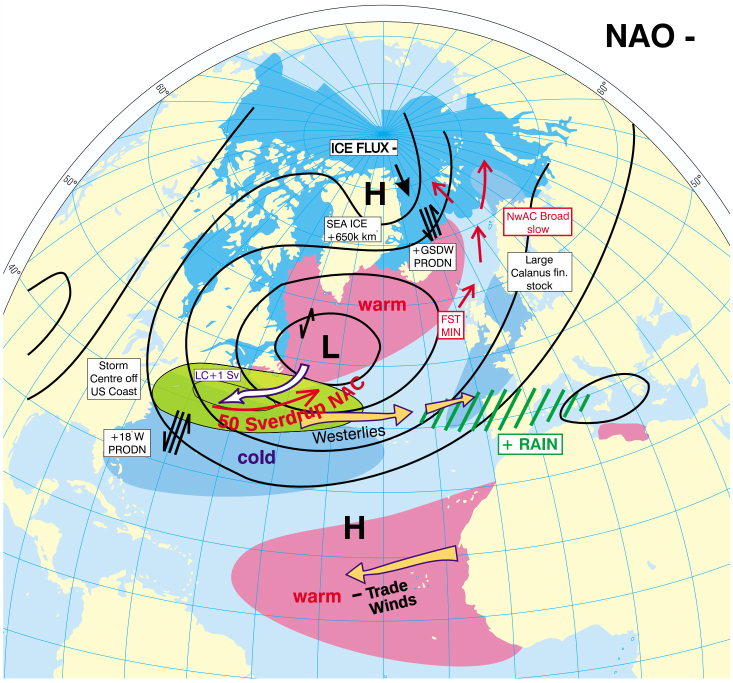
A second GSA appeared in the West Greenland Current in 1982 and again circulated around the subpolar gyre (Belkin *et al*., 1998) taking 6 – 7 yr to complete the circuit ***(Figure 2.14)***. A third has been circulating around the North-east Atlantic during the 1990s (Belkin *et al*., 1998). During the late 1980s the highest NAO index observed coincided with a time of exceptional winter warming of the land masses in the northern hemisphere. At the same time there were marked reductions in Arctic ice and permafrost and exceptional northerly advection of warm water and semi-tropical species into the seas off North-west Europe.

These anomalies appear to have had different origins. The GSA of the 1970s resulted from a boost in inputs of freshwater and sea-ice from the Arctic to the North Atlantic via the Fram Strait. This coincided with a marked increase in the extent of sea-ice in the Greenland Sea and the Iceland Sea. The two later GSAs formed locally in the Labrador Sea/Baffin Bay region and were the products of extreme winters, supplemented by abnormally high outflows of freshwater from the Canadian Archipelago driven by strong northerly winds. While the extent of sea-ice in the Labrador Sea increased at the time, there was no increase in the ice cover upstream in the Greenland Sea. Thus these salinity anomalies can be formed locally in the Labrador Sea or forced remotely.

Figure 2.13 **Conditions prevailing during the maximum and minimum phases of the North Atlantic Oscillation. Source: R.R. Dickson and I. Gooch, CEFAS.**

▨	upwelling
▨	distribution of Saharan dust
A.O.	Arctic Ocean
FST (MAX)	maximal Faroe – Shetland Transport
Lab	Labrador Sea
+ LSW Prodn.	maximal production of Labrador Sea Water
+ GSDW Prodn.	maximal production of Greenland Sea Deep Water
65 Sverdrup NAC	higher strength of North Atlantic Current
ICE FLUX +	positive change in volume flux of ice from the Arctic via the western Fram Strait

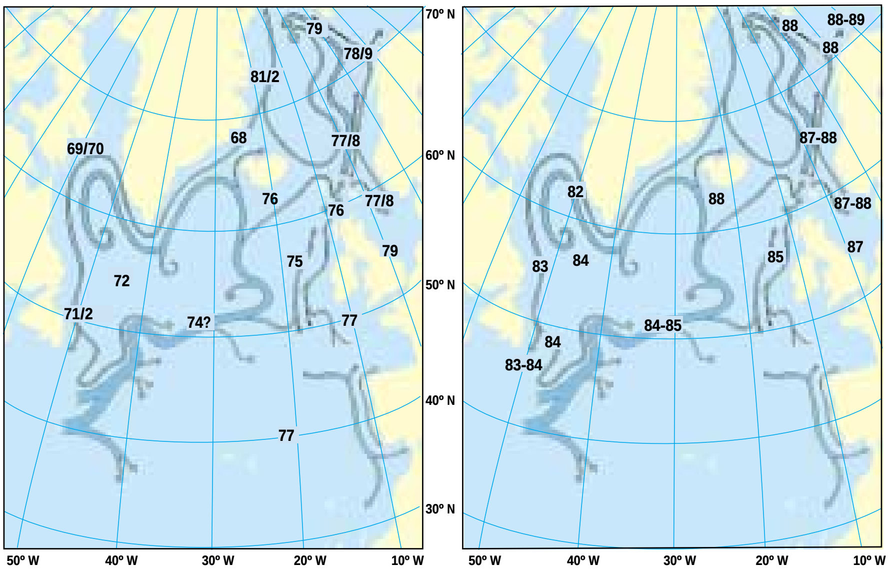




FST (MIN)	minimal Faroe – Shetland Transport
+ 18 °W PRODN	maximal production of 18° C Mode Water
LC+ 1Sverdrup	Labrador Current increased by 1 Sverdrup
50 Sverdrup NAC	lower strength of North Atlantic Current
ICE FLUX -	negative change in volume flux of ice from the Arctic via the western Fram Strait
SEA ICE +650k km^2	retraction of the median sea-ice border at the end of winter

🟦	relatively cold sea surface temperature
🟥	relatively warm sea surface temperature
🟩	rain
▨	changing distribution of increased rain
—	average isobars
↓↑	intense open ocean convection and strong heat flux
↯	capped open ocean convection and weak heat flux
⇨	general wind direction and intensity (weak/strong)
→	currents
Calanus fin.	*Calanus finmarchicus*
NwAC	Norwegian Atlantic Current (west of southern Norway)

Figure 2.14 **Propagation of two ‘Great Salinity Anomalies’ around the subpolar gyre in the 1970s and 1980s. Source: Belkin *et al*. (1998).**



These cyclical events are probably linked to the biological oscillations observed in the system, for example cycles in primary and secondary productivity, such as have been identified in Continuous Plankton Recorder (CPR) surveys, and variations in fish stocks and their recruitment. However, biological responses are notoriously non-linear and it has proved difficult unambiguously to link cycles in the physical environment with cycles in biological events. However, they have been linked to variations in zooplankton production and the distribution of fish (Fromentin and Planque, 1996; Friedland *et al*., 1993). In the longer-term, increases in freshwater transport combined with warmer atmospheric temperatures may result in the polar oceans being covered with a layer of more buoyant water. This would decrease, or even halt, much of the meridional circulation in the North Atlantic. In the early 1980s, phytoplankton assemblages to the north of 60º N suddenly became more polar in their characteristics (Reid *et al*., 1998). The hypothesis that this switch was linked to a weakening of the flow of the Gulf Stream following the diminution in deepwater formation has yet to be proved. Such changes imply that ocean circulation may respond unexpectedly rapidly to global warming, but what the longer-term implications may be for European seas remains unclear.

Thus it seems likely that changes to the global climate pattern will lead to quite rapid alterations in the physical characteristics of circulation in the North-east Atlantic. Substantial reductions in the degree of cooling of the upper ocean and ice formation in the Arctic may lead to reductions in the volumes of deep and intermediate water masses being formed. Reductions in the volumes of NADW seem likely to make the thermohaline circulation of the global ocean more sluggish, and so have far reaching impacts on the ecology of the oceans. In the North Atlantic, however, it seems probable that the volumes of water being transported polewards by the Gulf Stream and the NAC may be reduced. Its local effect on climate may be to make it cooler and to alter radically the distribution of rainfall. However, increases in cloud cover as a result of greater evaporation at low latitudes may also alter the amount of solar radiation reaching the ocean and hence make the eventual outcome in the region unpredictable. However, any change in the physical and biological functioning of the North-east Atlantic is likely to place strains on social and economic structures in all the OSPAR countries.

chapter 3

Human activities

3.1 Introduction

Region V is very different in character from the other OSPAR regions. It is predominantly deep-water and contains no extensive areas of shelf seas. Its only areas of land are the islands of the Azores Archipelago and the tiny rock outcrop on Rockall Bank. Hence it is remote from the influence of large riverine outflows and major discharges of contaminants from land-based sources. The region is currently used directly for shipping, cable routes, the extraction of hydrocarbons and fishing. Fishing is expanding into the deep water regions as fishing technologies improve, new stocks are discovered and as shallow water stocks are depleted or cease to be available to some fishermen because of quotas. There is also intensive fishing activity in the shallow waters surrounding the islands and seamounts of the Azores. Anthropogenic inputs have been much larger in the past. For example, during the Second World War numerous vessels were sunk in the region, and post-war large quantities of redundant munitions were dumped in deep water. The seabed is littered with large accumulations of clinker from the boilers of the old coal-fired vessels along the old shipping routes (Huggett and Kidd, 1983/4). Licensed disposal of industrial and radioactive waste continued until 1982. However, litter (including plastic, fishing floats, timber, polystyrene and tar balls) is still a common sight floating at the surface, particularly along convergent fronts. Industrial development is just beginning to impinge on the region with the beginning of the exploitation of hydrocarbon reserves along the continental slopes in the north-east. The only human population in the region is on the Azores.

Human impacts are generated within the region through the exploitation of resources, and from external sources via the inflows, i.e. ocean currents or the atmosphere. Similarly, some contaminants are exported from the region in the outflows. An example of an external impact that has just been identified is the reduction in the freshwater inputs into the Eastern Mediterranean from the construction of the Aswan Dam in Egypt, which has caused changes in the physical oceanography of the basin. These changes are currently being transmitted through the Strait of Sicily into the Western Mediterranean and are expected to change the characteristics of the Mediterranean outflow waters, and hence may perturb the thermohaline circulation of the North-east Atlantic (de Lange *et al*., 1999).

3.1.1 Boundaries

Much of Region V lies outside national Exclusive Economic Zones (EEZs) and so represents ‘Global Commons’. The exceptions are the substantial area (938 000 km^2) of the territorial seas and EEZ surrounding the Azores, designated as sub-area 3 of the Portuguese EEZ, and in the north-east where the outer fringes of the EEZs of France, Ireland, the UK and the Faroe Islands just impinge on the region. Region V also skirts the Icelandic EEZ in the north and the EEZ of Greenland in the north-west. There is a lack of formal agreement over the precise alignment of some of these boundaries, although several issues were resolved when the United Nations Convention on the Law of the Sea (UNCLOS) entered into force. For example, the outcrop on Rockall Bank is exemplified as a rock in the text of UNCLOS and so any claims based on it being an island are no longer valid. These legal boundaries are important in defining which country has the right to exploit particular resources and also carries the responsibility for managing the resources within the various zones.

3.2 Demography

The only population in the region occurs on the Azores Archipelago ***(Figure 3.1)***. The 1997 census data (from the Direcçåo Regional de Estatìstica e Planeamento dos Açores) indicate there are just over 241 000 residents in the Azores ***(Table 3.1)***, over half of whom live on the largest of the islands, São Miguel. However, during summer the influx of tourists doubles the population.

The islands’ population, which had been declining, increased during the latter half of the 1990s as economic conditions and the infrastructure improved with the help of EU funding; 73% of houses are now connected to electricity supplies, 61% to water and 69% to sewage treatment systems. In 1994–5 the population increased by 970 (0.4%).

Table 3.1 Population and surface areas of the inhabited islands of the Azores, 1997.

	Population	Surface area (km^2)	Density (inh/km^2)
Santa Maria	5 990	97	61.7
São Miguel	129 160	747	172.9
Terceira	56 540	402	140.6
Graciosa	5 010	61	82.1
São Jorge	10 280	246	41.8
Pico	14 990	448	33.5
Faial	14 770	173	85.4
Flores	4 430	142	31.2
Corvo	320	17	18.8
TOTAL	241 490	2 333	103.5

3.3 Conservation

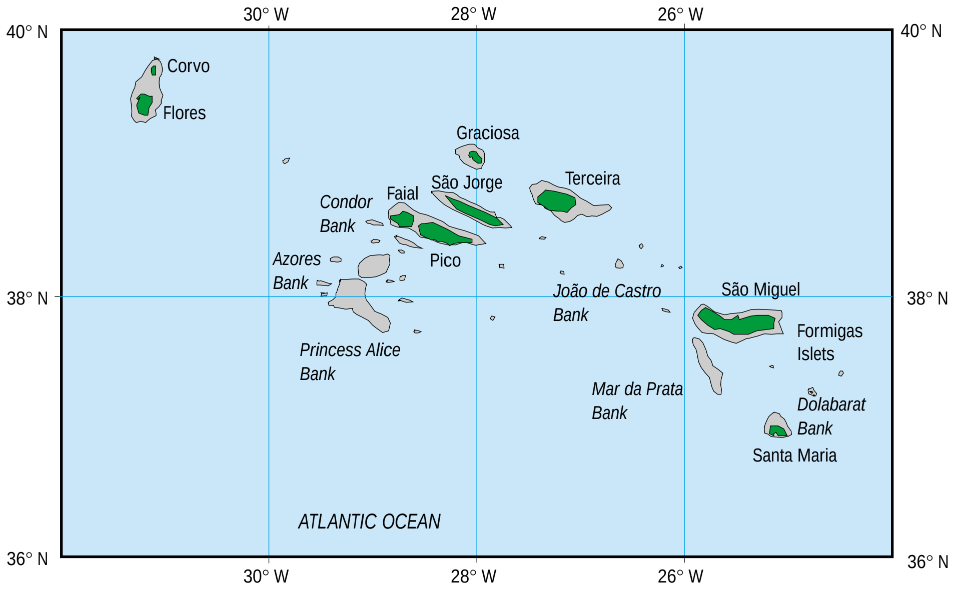
3.3.1 Ecological conservation

Habitats and species

All species of whales and dolphins, turtles and some bird species are protected to some extent under various international conventions. However, the conservation measures banning the exploitation of whales and dolphins under the International Whaling Convention have not been agreed to by all European countries. Nor are such measures effective in limiting by-catches of dolphins and small whales or turtles during fishing. Locally in the Azores, conservation legislation affords some protection to a range of species. There are no protected oceanic habitats in Region V, other than the Formigas Islets and the Dolabarat Bank, which lie within the EEZ of the Azores and are protected under national legislation.

There are nine protected marine areas in the Azores that are managed by the Environment Department, according to Portuguese law ***(Table 3.2)***. In addition there are fourteen Special Protected Areas designated under the EC Wild Birds Directive (79/409/EEC) to protect important breeding colonies of Bulwer’s shearwater (*Bulweria bulwerii*), Cory’s shearwater (*Calonectris diomedea*), Manx shearwater (*Puffinus puffinus*), little shearwater (*Puffinus assimilis baroli*), Madeiran storm petrel (*Oceanodroma castro*), common tern (*Sterna hirundo*) and roseate terns (*Sterna dougallii*). To comply with the EC Habitats Directive (92/43/EEC) a list of seventeen sites important for European conservation has been prepared, nineteen of which are either coastal or marine, and under this Directive all whales and turtles are fully protected.

Figure 3.1 **Islands and banks of the Azores Archipelago. Source: Santos *et al*. (1995).**



Biodiversity

Biodiversity of most oceanic ecosystems is poorly understood. Nearly all phyla have representatives in the bottom-living communities (the benthos), which is almost twice as many as are found in terrestrial and pelagic communities (Ormond *et al*., 1997). Large plants, however, only occur in shallow coastal waters, whereas the microflora is highly diverse. This lack of large plants may be one reason why the rich variety in animal phyla is not reflected in a correspondingly rich variety of species. Pelagic communities are locally rich in species, but because the species are very widely distributed, the global inventory of known oceanic species is very much smaller than that of terrestrial and even shelf-sea ecosystems (Ormond *et al*., 1997). Since the scales of the distributional patterns are much coarser, the classical species/area relationships established for island faunas (Huston, 1994) do not appear to apply in open ocean pelagic ecosystems.

There is a steep north/south gradient in the numbers of species, which is stepped at 40º N. Species richness reaches a maximum at depths of about 1 km, both in the

Table 3.2 Designated marine protected areas in the Azores.

Site	Conservation value	Usage
Santa Maria		
Baía da Maia	representative littoral habitats	recreational
Baía da São Lourenco	representative littoral habitats	recreational
Baía da Anjos	representative littoral habitats	recreational
Baía da Praia	representative littoral habitats	recreational
Formigas Islets	littoral and sublittoral rocky habitats	some fishing allowed
São Miguel		
Ilhéu de Vila Franca	volcanic crater; nesting site for Cory's shearwater	recreational
São Jorge		
Ilhéu do Topo	botanical and ornithological	
Lagoa do Santo Cristo	protection of clam (*Ruditapes decussatus*)	coastal lagoon
Faial		
Monte da Guia	volcanic crater	protected landscape

water and on the seabed. Estimates of the global numbers of species in benthic ecosystems range from half a million (Gage and May, 1993), to ten million (Grassle and Maciolek, 1992) or even hundreds of millions (Bouchet and Lambshead, 1995). Recent investigations of sediment communities inhabiting the continental slope to the west of Scotland, carried out as part of Environmental Impact Assessments (EIAs) prior to the development of deep-water hydrocarbon reserves, have shown that locally species richness is extremely high. However, extrapolating these data to estimate the size of benthic faunas globally is very misleading. Inventories of the known species of the large organisms are surprisingly small considering the wide geographic areas they occupy (for data on fish see Section 5.2.8). Knowledge of the faunas of the smaller species (macrofauna and meiofauna) will, for the foreseeable future, remain too sparse to derive believable estimates of the numbers of benthic species in Region V (and the global ocean). Thus management measures to conserve the biodiversity of Region V will have to remain precautionary.

3.3.2 Archaeological conservation

Ever since their discovery and colonisation in the Fifteenth Century, the Azores have been an important staging post for ocean travel. During the era of sail, the islands provided facilities to effect repairs and to obtain fresh water and food, and so numerous Portuguese, Spanish, English and French vessels foundered there. In all at least 517 wrecks *(Table 3.3)* have been registered and are protected against ‘treasure’ hunters.

Table 3.3 Registered wrecks around various islands of the Azores.

Formigas Islets	1
Santa Maria	9
Graciosa	14
Corvo	15
Pico	25
Flores	32
São Jorge	43
Faial	83
São Miguel	138
Terceira	157
TOTAL	517

3.4 **Tourism and recreation**

3.4.1 Tourism

Tourism has been growing steadily in the Azores since 1980, with lodging capacity increasing by 83.5%. The strongest growth, averaging 7.9% per annum, was from 1988 to 1995. Most tourists come from the Portuguese mainland, but large contingents come from Germany and the UK, attracted by the clean environment and opportunities for outdoor pursuits.

Figure 3.2 **Whalewatching near the Azores (F. Cardigos © *imag*DOP).**

Some tourist activities are controlled. Recreational fishing, using rod and line and spear-fishing, exploits a variety of inshore fishes, few of which are caught commercially, but the popularity of underwater diving and spear-gun fishing has necessitated the introduction of regulations limiting the daily catch to five fish per person. Whalewatching has expanded rapidly in recent years, and is now regulated in order to protect both visitors and whales *(Figure 3.2)*.

3.4.2 Cruise industry

Worldwide there are over 240 ocean-going cruise ships with a total gross tonnage of over 5 million t and a passenger carrying capacity of about 160 000 (Seatrade Cruise Review, 1997). About half these vessels operate at times in the North-east Atlantic, although most cruise destinations are outside Region V. The number of ships and their passenger carrying capacity have been expanding rapidly. In spring 1997, 27 new cruise ships were on order, increasing the tonnage by 1.88 million and the passenger capacity by nearly 30%. Two of the latest vessels to have been built have gross tonnages of 130 000 t and carry about 3000 passengers (and similar numbers of crew). The operation of such large vessels must place considerable strain on local port facilities.

3.4.3 Ocean yachting

Ocean yachting is a small but growing recreational activity. In 1995, 1783 boats carrying 6718 people visited the Azores *(Figure 3.3)*. This growing activity poses local environmental problems such as the risk of introducing non-indigenous species and of pollution from antifouling

Figure 3.3 **Horta on Faial and its yacht harbour (R. Patzner © *imag*DOP).**

paints, particularly those containing TBT (see Section 4.5.1).

3.5 Fishing

There are four broad categories of fishing in Region V:

a. fisheries for large pelagic tuna and tuna-like fish. These occur mainly in the southern sector. ICCAT has responsibility for the international management of these fisheries;

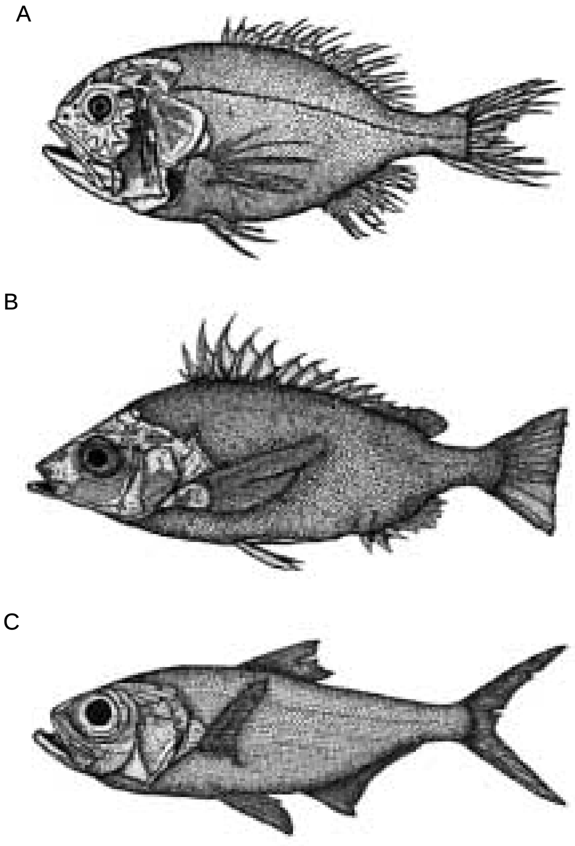
b. longline and trawl fisheries in deep waters on the continental slopes *(Figure 3.4)*. These target species such as ling (*Molva molva*), tusk (*Brosme brosme*), argentine (*Argentina sphyraena*), grenadiers (*Macrourus berglax* and *Coryphaenoides rupestris*) and various species of deep-water shark;

c. fisheries for demersal and pelagic stocks (other than tunas and related species). These have developed recently and are rapidly expanding; and

d. fisheries using traditional longline, handline and gillnet methods around the Azores and adjacent seamounts.

For several reasons, only general and non-specific statements can be made on the basis of reported catch data. There is little correspondence between Region V and the areas adopted for reporting catches to ICES and ICCAT. This makes it difficult to use catch data to develop a coherent management strategy. All these fisheries are multi-species. Hence not only are they difficult to manage sustainably, but they also result in considerable quantities of by-catch. Many of the data on landings are of questionable value, one of the reasons being the uncertainties of many of the species' identifications. Moreover, with few monitoring programmes and only sporadic participation by many fleets, reported catches are highly suspect for many target and minor species. Nor do the data on landings reflect the overall impacts on the non-target stocks or the extent of damage inflicted on some deep-sea habitats. Fishing effort in the deeper waters tends to be unpredictable, since it waxes and wanes according to the fluctuations experienced by fishermen as their access to other stocks is limited by regulation or overfishing.

Figure 3.4 **Deep-living fishes exploited commercially over seamounts and continental slopes. A: orange roughy (*Hoplostethus atlanticus*); B: armourhead (*Pseudopentaceros wheeleri*); C: alfonsin (*Beryx splendens*). Source: Rogers (1994).**



3.5.1 Fisheries for large pelagic species

The management areas adopted by ICCAT match neither the OSPAR regions or the ICES statistical areas, nor the ranges of these highly migratory fish. Hence none of the derived data on stock sizes and landings are specific to Region V. The species caught in Region V are listed in *Table 3.4*. The problems of regulating the stocks of species such as Atlantic bluefin tuna (*Thunnus thynnus*) and bigeye tuna (*T. obesus*) to ensure there is no overexploitation remain unresolved. Fishing boats from many nations, including many from non-OSPAR countries, operate in the region. For example in 1996, 282 Japanese longliners operated in the Atlantic Ocean, some fishing as

Table 3.4 Deep-living species fished commercially or regularly occurring as by-catch in commercial fisheries.

		ICES Fishing Areas targeted (or by-catch)			ICES Fishing Areas targeted (or by-catch)
	Teleosts				
+	Baird's smooth-head				
	Atlantic wolf-fish			longfin hake	
+	black scabbardfish	(V), VI, VII, IX, XII		forkbeard	(VIII)
+	argentine/great silver smelt	II, III, (IV), (V), (VI), (VII)	+	greater forkbeard	(V), VIII, (IX)
+	golden-eye perch	(VIII), X, XII		saithe or colley	
+	red bream/alfonsino	X	+	wreckfish	(VIII), X, XII
+	tusk	IV, V	+	Greenland halibut	II, IV, V, XIV
+	rabbitfish	(V), (VI), (VII)	+	redfish	
+	conger eel	(IX), X	+	roughnose grenadier	
+	round-nose grenadier	II, (III), (V), VI, VII, XII, (XIV)			
+	big-eye/deep-water cardinal fish	(V), (VI), (VII), XII		Elasmobranchs	
	witch			gulper shark	(IX)
+	blue-mouth	(V), (VIII), (IX), X		leaf-scale gulper shark	VI, VII, VIII, (IX)
	Atlantic halibut			black dogfish	
	American plaice			Portuguese dogfish	
+	orange roughy	V, VI, VII, XII		longnose velvet dogfish	VI, VII, VIII
+	silver roughy			kitefin shark	X
+	silver scabbardfish			birdbeak dogfish	
+	megrim	VIII		deepsea cat shark	
+	anglerfish or monkfish	IV, V, VIII		great lantern shark	
	eelpouts			velvet belly	
+	rough-head grenadier	II, (IV), (V), (XIV)		black-mouthed dogfish	(IX)
	capelin			Greenland shark	
	haddock			knifetooth dogfish	
+	hake	VIII		six-gill shark	
+	blue whiting			skates	
	lemon sole				
+	ling	IV, V, (VIII)		Decapods	
+	blue ling	V, VI, (VIII)	+	deepwater red crab	V
+	mora	(V), (VI), (VII), VIII		deep-sea shrimp	II, III
+	red/blackspot sea bream	(VIII), IX, X	+	giant red shrimp	IX

+ the most important deep-water species according to ICES (1998).

far north as 60º N (ICCAT, 1997), and caught > 50 000 t; 65% being bigeye tuna. A variety of fishing methods are used; longlining, purse-seining, baitboats (with and without artificial floating objects), harpoons, driftnets and gillnets *(Figure 3.5)*. ICCAT evaluations indicate that stocks of most species are currently being exploited in excess of their replacement potential.

For example, Atlantic bluefin tuna is being caught in an area stretching from the Gulf of Mexico to Newfoundland in the western Atlantic, and from the Canary Islands to the south of Iceland in the eastern Atlantic, as well as throughout the Mediterranean Sea. The vessels taking part in the fishery range from local recreational and artisanal boats to large vessels with the ability to operate in any ocean. Annual catches in the Atlantic are around 40 000 million t, exceeding the rate estimated to be sustainable by over 25%. In 1974, an ICCAT Committee recommended that the fishing mortality of bluefin tuna throughout the Atlantic and the Mediterranean should not increase. Although this recommendation came into force in 1975, it has been neither respected nor enforced in the subsequent twenty-five years.

The impacts of overfishing are being exacerbated by the general disregard of size restrictions on the fish that may be landed. In 1980, a minimum size limit of 3.2 kg was adopted for both bigeye and yellowfin tunas (*Thunnus albacares*). In 1994, the proportion of undersized small yellowfin tuna landed from the Atlantic fell to a low of 31.4%, but reverted to 49.7% in 1995, which is close to the 20-year mean of 48%. The problem arises because the young and full-sized tuna form mixed-species schools near the surface, often associated with

Figure 3.5 **Fishing for tuna off the Azores (I. Morató © *imag*DOP).**

drifting objects, whale-sharks (*Rhincodon typus)* or seamounts. So vessels targeting legal-sized fish inevitably take a heavy by-catch of undersized fish. Large quantities of undersized bigeye tuna continue to be captured and landed, mostly by the equatorial surface fleets; in 1996 the proportion of undersized fish landed increased to 70%.

The northern stock of albacore (*Thunnus alalunga*) is exploited by surface and longline techniques. Spanish fishermen troll at the surface in the Bay of Biscay and adjacent waters, and Spanish and Portuguese baitboats operate there and near the Azores. The albacore are now exploited at their maximum sustainable level and the fishery is taking considerable by-catches of otherwise protected species (see Section 5.3.2).

In 1996, the reported landings of blue marlin (*Makaira nigricans*), 1870 million t, were the second highest landings for more than 30 years. Reported landings alone exceed the replacement yield and so the status of the stock is likely to decline. Similarly, landings of swordfish (*Xiphias gladius*), a species that ranges widely throughout Region V and is taken mainly as a by-catch during longlining, were consistently around 1600 million t during the 1990s. Such a rate is unsustainable and can be expected to deplete the stocks. In addition, fisheries targeting swordfish take extensive amounts of by-catch; only 10% of the fish landed belong to the target species (see Section 5.3.2).

3.5.2 Continental slope fisheries

Deep-living demersal species targeted commercially or regularly taken as by-catch are listed in *Table 3.4*. Several of these species have considerable longevity and take many years to reach maturity. For example, the deepwater redfish (*Sebastes mentella*) lives 70 – 75 yr (Campana *et al.*, 1990) and the orange roughy lives for > 100 yr (Fenton *et al.*, 1991) and in the Atlantic takes 30 – 35 yr to reach maturity. Analysis of the age structure of an argentine stock fished experimentally off Ireland showed that 40% were > 20 yr old (McCormick, 1994). Such stocks can sustain only very low exploitation rates, yet these deep-sea fisheries are expanding very rapidly. Biological and assessment information is sparse and ageing techniques have been validated for only three of the 340 deep-living species of bony fishes (teleosts) recorded in the North Atlantic (Haedrich and Merrett, 1988), and for only one of the 40 species of shark (Bergstad, 1994).

Species richness of deep-sea fish assemblages increases with depth to depths of 1000 m. So as one species is fished out, the temptation is to target another species, thus maintaining the fishing pressure on the original target species. For example, to the west of Ireland and France the fishery for hake (*Merluccius merluccius*) and/or red sea bream (*Pagellus bogaraveo*) has shifted to the exploitation of some of the deep-living sharks (*Deania calceus, Somniosus rostratus, Centrophorus granulosus, Centroscymnus coelolepis*). Only the livers of these sharks have significant economic value, so the liver is removed (20 – 30% of weight) and the rest discarded. Because the oil (70 – 80% of the liver's weight) is extracted, converting the landings to meaningful fishery statistics is a major problem (Iglesias and Paz, 1995).

3.5.3 Demersal and pelagic fisheries

Knowledge of the biology of most target species is inadequate, but all the indications are that most, if not all, stocks can only sustain low rates of exploitation. These fishes tend to be long-lived, slow to mature and to have low fecundities. Hence they do not have the resilience to recover rapidly from overexploitation. In the north, the primary fishery is trawling for redfish (*Sebastes marinus*) and deepwater redfish. Redfish stocks include a genetically distinct component, *S. marinus ëgiantí,* and deepwater redfish stocks include separate deep-sea and oceanic stocks. Thirteen national fleets participate in this fishery, the major ones being from Russia, Germany, Iceland and Norway. Redfish catches in Region V peaked in 1994 and 1995, at 94 000 t and 127 000 t respectively, when the areas and the depths being exploited were extended. The most recent assessments of deep-sea redfish, although being highly uncertain, indicate that the decline in biomass throughout the 1990s is nearly equivalent to the total biomass of fish that has been removed. This implies that the accumulated stock of old fish is overexploited rather than harvested sustainably. As the redfish stocks have declined, other species are now being targeted. Along the Mid-Atlantic Ridge these include the golden-eye perch (*Beryx splendens*), orange roughy, black scabbardfish (*Aphanopus carbo*) and wreckfish (*Polyprion americanus*). Catch per unit effort (CPUE), normally a useful management index, is not an informative measure of the status of these stocks. These fisheries have been expanding rapidly, but only in very few have by-catch and discard rates been studied. In those that have, the weights of discards often equal the weights of fish landed. Generally these fisheries are environmentally damaging and unsustainable.

3.5.4 Azorean and seamount fisheries

These fisheries target a great variety of species, including red sea bream, wreckfish, conger eel (*Conger conger*), forkbeards (*Phycis blennoides* and *P. phycis*), blue-mouth (*Helicolenus dactylopterus*), golden-eye perch, alfonsine (*Beryx decadactylus*), kitefin shark (*Dalatias licha*) and gulper shark (*Centrophorus granulosus*), using a variety of methods. Landings in recent years have been < 5000 t/yr, and so exploratory surveys are being carried out to evaluate other stocks. There are three categories of fishing (Santos *et al*., 1995). One targets young horse mackerel (*Trachurus picturatus*) and chub mackerel (*Scomber japonicus*) using seine nets, dipnets and liftnets from small boats < 12.5 m. Secondly, there is a seasonal pole and line fishery for tuna during March to October, and a bottom longline and handline multi-species fishery. Thirdly there is a demersal fishery, which probably has the greatest impact on the marine communities, in which the most important species are red sea bream, blue-mouth, forkbeards and conger eel. These fisheries are all interrelated; for example, mackerel and juveniles of the red sea bream are used as bait for the tuna longlining and so do not get reported in the landing statistics.

Landings of these species increased after the replacement of the traditional open-decked boats with more efficient close-decked boats. However, the CPUE for red sea bream has declined by 50%; possibly because large, and unreported, numbers of juveniles are being taken for bait. As fishing activity moves progressively offshore, at least 50 other species of fish are now taken regularly.

The exploitation of a number of invertebrates in inshore waters is now regulated, but there are two problems. Firstly, how to enforce regulations in artisanal fisheries, and secondly, what catch rates can most of these invertebrates sustain.

3.6 **Aquaculture**

Aquaculture is presently restricted to inshore waters. There have been two experimental aquaculture projects in the Azores. The first was to farm red sea bream and was unsuccessful. The second, currently being promoted by the Regional Government, is to produce live *Haliotis discus hannai* for human consumption.

3.7 **Coastal protection and land reclamation**

3.7.1 Coastal protection

The steep coastlines of the Azores are composed of volcanic rocks and so are resistant to erosion and unsuitable for land reclamation. Further expansion of the cruise industry may necessitate the further development of port facilities.

3.7.2 Energy

At present no energy is being extracted directly from the ocean. The region is unsuitable for Ocean Thermal Energy Conversion (OTEC), which to be effective requires there to be a temperature difference of 20 ºC between the water at the surface and at a depth of 1000 m. The outflow water from the Strait of Gibraltar *(Figure 2.10)* keeps the deep-water temperatures abnormally high. Maximum wave energy occurs in the vicinity of the shelf-break, but the technology for extracting energy from waves in shallow water, let alone the open ocean, remains undeveloped. A small experimental wave energy generator is now being constructed on the island of Pico on the Azores. Open ocean culturing of macroalgae to provide biomass has been discussed, but no commercial technology has been developed.

Small wind farms now operate on the islands of Santa Maria, São Jorge and Graciosa. The sixteen generators produce between 5.1 and 8.8% of the power demand on each of these islands. These installations are to be extended and new ones constructed on other islands. There is also extraction of geothermal power on the Azores.

3.8 **Sand and gravel extraction**

Some sand is extracted from the inshore waters of the Azores, around the islands of Santa Maria, São Miguel and Terceira, mostly by dredging. Licences have been approved for the annual extraction of 140 000 m^3. However, since the Azores are volcanic the exploitable reserves are limited. Similarly, no potential seabed mineral resources have yet been identified within the area. However, metal-rich crusts are being deposited on the Mid-Atlantic Ridge in association with hydrothermal vent activity (see Section 2.4.2), so it is feasible that in the future commercially viable deposits may be discovered.

3.9 **Dredging, dumping and discharges**

Dredging is only conducted in the inshore waters of the Azores. In the past ocean dumping of sewage sludge, industrial residues, radioactive wastes and redundant munitions was conducted at a range of licensed deep-

Table 3.5 Permits issued for the disposal of wastes into the North Atlantic in 1978–86. Source of data: London Dumping Convention circulars.

		Waste type	t
1976	Denmark	industrial liquids	22 400
	UK	industrial liquids	95
		industrial solids	2 035
		industrial sludges	365
1977	Denmark	industrial liquids	31 000
	Netherlands	industrial solids	3 000
		munitions	73
	Canada	radioactive tracer	0.002
	UK	industrial solids	2 670
		industrial sludges	70
1978	Denmark	industrial liquids	31 000
	France	dredged spoils	14 600 000
	Ireland	caustic liquids	1 100
	UK	ammunition	20
		pipes	150
		seal carcasses	3 000
		industrial sludges	170
		industrial solids	2 235
1979	Denmark	industrial liquids	34 000
	France	dredged spoils	1 430 000
	Netherlands	radioactivity	3 431
	UK	industrial sludges	770
		industrial solids	95
		radioactivity	2 300
1980	Denmark	industrial liquids	34 000
	France	dredged spoils	4 380 000
	Germany	sewage sludge	172 000
	UK	arsenic sulphide	70
		contaminated iron oxide	70
		antimony chloride residues	45
1981	Denmark	industrial liquids	34 000
	Germany	sewage sludge	607 000
1982	Germany	sewage sludge	31 000
	UK	arsenic sulphide	180
		antimony chloride	45
		contaminated iron oxide	140
		aqueous waste containing organohalogens	8 800
1983	Denmark	pharmaceutical	34
	UK	concrete in steel drums	200
		arsenic sulphide	50
1984	UK	industrial sludges	50
		inert ammunition	20
	Spain	sand contaminated with cyanide	30
1985	UK	arsenic sulphide*	
1986	UK	industrial sludges	50

It is not known whether these licences were fully taken up in every case.

* 51 m^3.

water sites *(Table 3.5)*. Discharges from surface vessels and oil platforms are currently making a relatively small contribution (*c*. 13%; IWCO, 1998) to the overall input of contaminants.

3.9.1 Industrial waste

In the past, licences were issued permitting the disposal of industrial materials at a number of designated dump sites, most of these were inshore but there were a few in Region V *(Figure 3.6)*. The issuing of a licence did not necessarily mean that the waste was actually dumped. Disposal was usually by directly discharging material at the sea surface, either by pumping slurries or by dropping the waste packaged in sealed containers. The wastes disposed of were generally those which at the time were difficult and expensive to reprocess or detoxify. Records of the licences granted are to be found in the OSPAR annual reports, but precise information on the exact quantities and types of substances disposed of, is often incomplete.

3.9.2 Radioactive waste

In the early years, sea disposal of radioactive wastes was uncoordinated and a number of shallow sites were used for the disposal of relatively small amounts of wastes. After 1967, disposal was coordinated by the Nuclear Energy Agency (NEA/OECD). By 1985 twenty-one countries were party to the NEA (Belgium, Canada, Denmark, Finland, France, the Federal Republic of

Figure 3.6 **Location of sites licensed for the dumping of industrial wastes until 1986.**

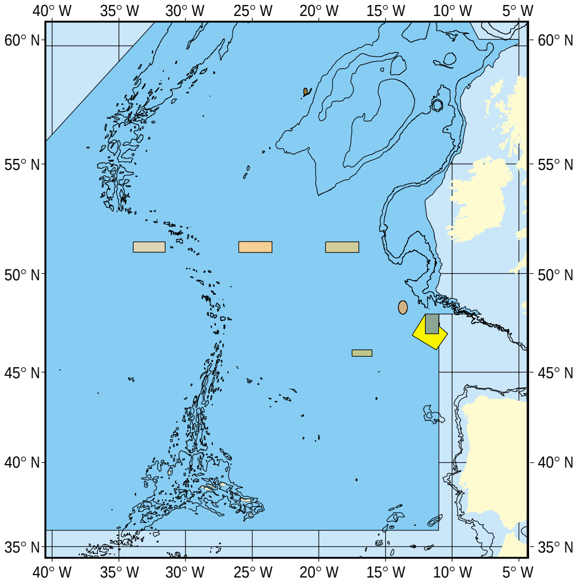
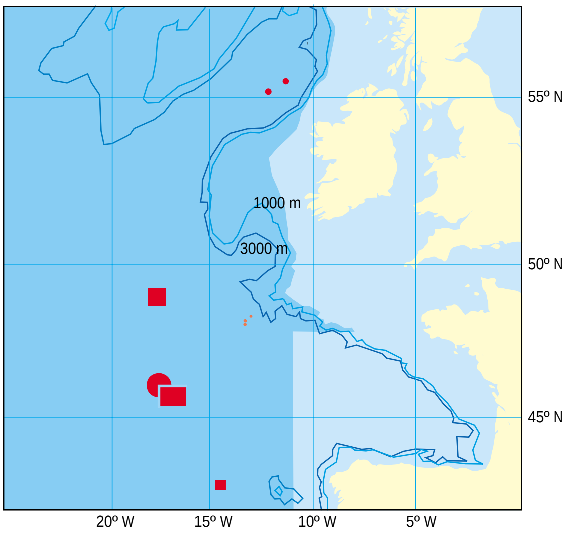


Figure 3.7 **Location of sites used for the disposal of radioactive wastes until 1983.**



Germany, Greece, Iceland, Ireland, Italy, Japan, Luxembourg, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, the UK and the USA). The dumping of nuclear waste was regulated under the provisions of the London Dumping Convention (details and site selection criteria are to be found in OECD (1985)). Four main sites were used in Region V *(Figure 3.7)*:

a. in 1967 a 50 km square centred on 42º 30’ N, 14º 30’ W;
b. in 1969 a 50 nm square centred on 49º 05’ N, 17º 05’ W;
c. in 1971–6 a circle of radius 35 nm centred on 46º 15’ N, 17º 25’ W; and
d. in 1977–82, the ‘NEA site’, a rectangle bounded by 45º 50’ N and 46º 10’ N and 16º 00’ W and 17º 30’ W. This site, with an area of 4250 km^2, is in the foothills of the Mid-Atlantic Ridge and its nearest points are 741 and 627 km from the Irish and Spanish coasts respectively.

The wastes dumped mostly comprised low-level materials from nuclear plant operations, fuel fabrication and reprocessing, radionuclide use in medicine, research and industry, and decontamination of redundant plant and equipment. The α-active wastes were mostly from nuclear fuel processing and the production and use of specific radionuclides (e.g. ^{241}Am used in smoke detectors, ^{226}Ra in medicine). The β- and γ-activity wastes came from the production of ^{241}Pu in fuel reprocessing, fission products produced in routine nuclear power plant operations (e.g. ^{90}Sr and ^{137}Cs), activation products (e.g. ^{55}Fe, ^{58}Co and ^{60}Co), the production of specific nuclides (e.g. ^{14}C and ^{125}I), the products of decontamination, and tritium (generated during production and use of labelled compounds for medical, research and industrial applications). Plutonium and americium accounted for > 96% of the α-activity dumped, and tritium and plutonium-241 for > 87% of the β-activity dumped. The remainder of the β/γ activity was mostly ^{90}Sr, ^{137}Cs and ^{60}Co. There has been leakage from drums of material that were dumped *(Figure 3.8)*. However, the results achieved under the Coordinated Research and Environmental Surveillance Programme of the NEA (OECD, 1990) concluded that the radiological impacts on human and oceanic populations emanating from these dump sites remain, and are likely to remain, exceedingly small compared to the natural background levels. These conclusions have recently been validated by some *in situ* labelling experiments conducted on the grenadier *Coryphaenoides armatus* and the deep-sea amphipod *Eurythenes armatus* (Charmasson, 1998).

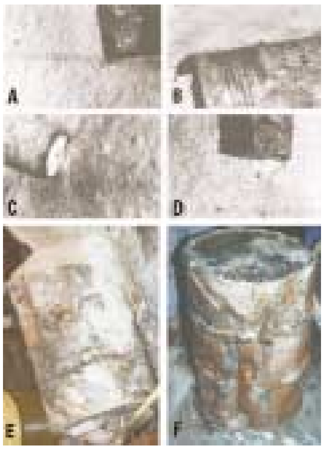
Loss during transportation is another mechanism whereby radionuclides may reach the deep ocean. For example in November 1997, a section of the container ship Carla sank at 40º 03’ N, 22º 50’ W. Three of the containers contained radioactive sources of 65, 65 and 200 TBq ^{137}Cs respectively, and now lie at a depth of about 3000 m. They had been sealed according to the international procedures for the transportation of radioactive materials, and so the risk of serious environmental contamination is considered to be small.

3.9.3 Munitions

At the end of the Second World War considerable quantities of arms and munitions were dumped at sea, which included considerable quantities of chemical warfare materials. The latter consisted mainly of tear gases, nerve gases and other agents. The majority was dumped in areas which at the time were considered deep enough to be safe because they were not being, nor expected to be, exploited for fishing. Most were dumped in the Baltic and the Skagerrak, but 69 000 grenades containing the nerve gas tabun (hydrocyanic acid mixed with 20% chlorobenzene) were subsequently retrieved embedded in concrete and sunk in the Bay of Biscay (NATO, 1995). Tests on three grenades showed that their toxic contents had largely decomposed. Between 1946 and 1949, twelve redundant vessels loaded with confiscated German munitions, including chemical munitions, were scuttled at depths ranging from 500 to 4200 m in the Southwest Approaches. A further twelve were scuttled in the Rockall Trough between 1945 and 1957 (ACOPS, 1988), at depths ranging from 800 to 2500 m *(Figure 3.9)*. No reports on monitoring of these vessels have been published.

Quantities of munitions lost during military actions in the war (shells and bombs which failed to explode, and

Figure 3.8 **Drums photographed *in situ* at the NEA radioactive waste dump site showing benthic organisms in close association (a–d). Source: M. Sibuet, IFREMER. Two corroded and leaking drums recovered from the dump site in 1991 (e–f). Source: M. Vobach, German Federal Fisheries Research Centre.**



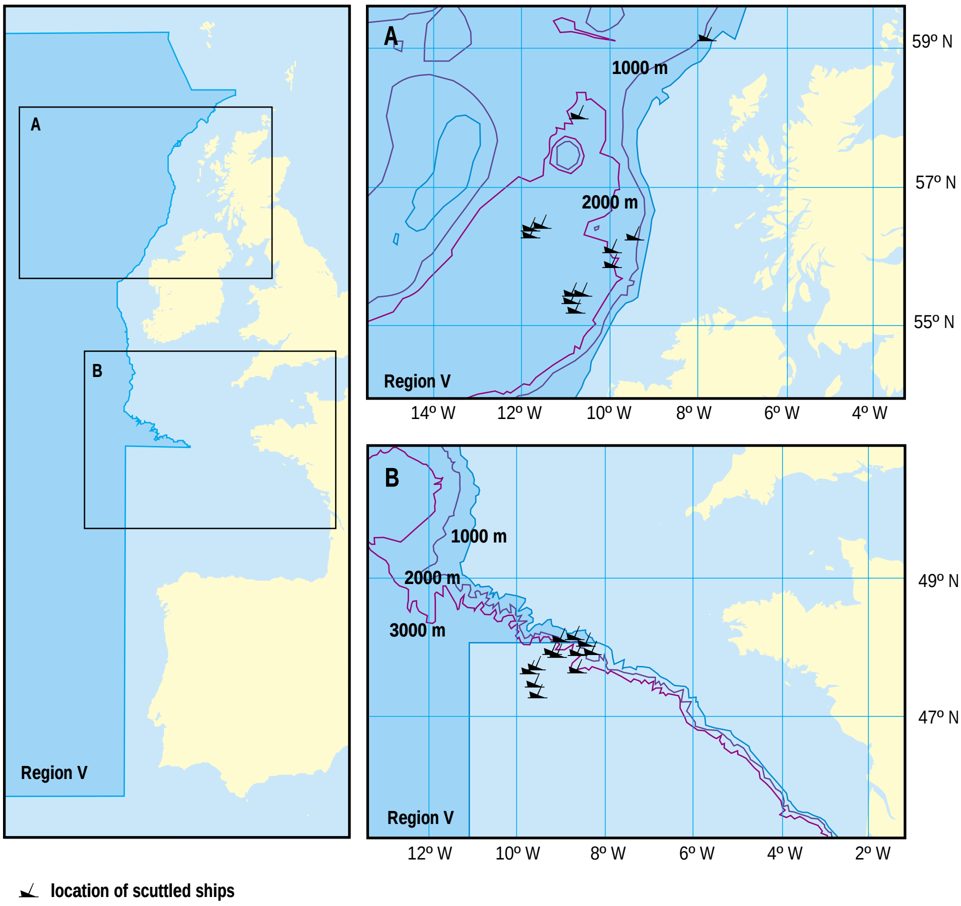
in cargoes and magazines of sunken military and merchant ships) far exceeded those ultimately disposed of in deep water.

Disposal of redundant munitions by various Western European countries has continued intermittently, mostly in coastal seas. The most recent incident was in 1994 when Portugal scuttled a redundant ship loaded with > 2000 t of unstable ammunitions 215 nm from the Portuguese coast at the edge of their EEZ in > 4000 m of water (OSPAR, 1995).

3.9.4 Carbon dioxide

The oceans have taken up about 30 – 40% of the carbon dioxide emitted since the onset of the industrial revolution. This has resulted in the pool of dissolved inorganic carbon in the deep ocean having increased from 38 to 38.1 x 10^{12} t since the start of the industrial revolution (Siegenthaler and Sarmiento, 1993) and the pH of the upper ocean has probably been reduced by about 0.1 units. The impacts are discussed in Section 4.10.

Figure 3.9 **Locations at which redundant vessels loaded with munitions, including chemical warfare weapons, were scuttled between 1945 and 1957.**



3.10 Oil and gas industry

Offshore exploration for hydrocarbons is at an early stage of development in Region V. Areas have been licensed for exploration in the north-east of the region in the EEZs of the UK and Ireland, in the Rockall Trough, the margins of the Rockall and Porcupine Banks and in the Southwest Approaches. Exploration and development do have some impacts. The use of seismics in exploration (and scientific research) is thought to affect certain biota, especially whales (see Section 5.3.3), and operational activities inevitably result in some discharges into the marine environment. The high economic cost of offshore exploitation and the relatively low returns are stalling development of some of these deep-water reserves. In a global context, the deep offshore reserves in the North Atlantic are small compared to those of the Middle East and Azerbaijan, but nationally they are of considerable economic importance.

3.11 Shipping and other commercial activities

3.11.1 Shipping

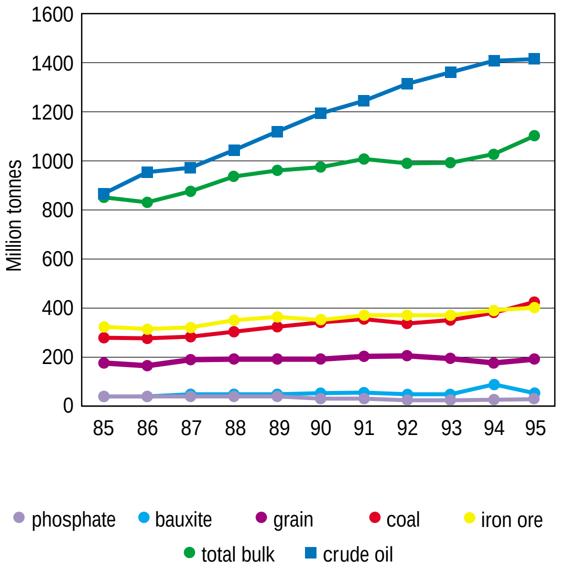
Ocean transportation continues to grow as world trade expands *(Figure 3.10)*. Large bulk carriers continue to convey increasing quantities of raw materials in a relatively efficient and environmentally friendly manner. However, the increasing size of the vessels does mean that accidents when they do occur have greater impacts, although the majority of sinkings occur in inshore waters. The transportation of crude oil increased 5% per annum in 1985–95, resulting in a total increase of 61% in the tonnage carried and 86% in the tonne-miles. Of the total 1415 million t of crude oil transported by sea about 374 million t (26.4%) were either destined for, or came from North-western Europe. Seaborne trade in iron ore, coal, grain, bauxite and alumina, and phosphates also increased by an average of 2.6% per annum over the same period. Of the 402 million t of iron ore carried, about 125 million t (31.3%) passed through the OSPAR area. There was an increase of 59% in coal shipments as a result of strong demands for thermal coal (see Section 4.10), which in the context of the carbon dioxide problem is of concern.

MARPOL-regulated operational discharges from tank cleaning at sea and other legal operational discharges continue to introduce small quantities of contaminants into the region, but there is no evidence, nor does it seem at all likely, that these present any significant environmental risk. Ships under ballast exchange ballast waters in open ocean areas as a way of reducing the risks of introducing non-indigenous species to inshore environments. There are no known examples of such introductions occurring in any open ocean environments. The risk of non-indigenous species becoming established in the shallow waters around the Azores is considered to be small because the islands are not currently being used by bulk carriers.

Litter discarded from vessels at sea continues to be a chronic, albeit relatively small, problem in Region V. The litter ranges from plastic bags, containers and polystyrene fragments, to baulks of timber and pieces of rope. Tar balls, presumably from tank cleaning, are still abundant at the surface and tend to accumulate along fronts. Lost and discarded fishing gear, floats, nets and lines are also frequently encountered, particularly close to fishing grounds. On-board incineration of combustible refuse from shipping and the availability of waste facilities in many ports has lead to a marked reduction in the quantities of litter in the open ocean. However, less scrupulous ship operators may still be illegally discharging at sea either through ignorance or in order to avoid paying the charges levied by port operators for waste and refuse disposal.

Together with the increase in bulk transport has been the growth of container traffic carrying manufactured goods, and this is likely to continue, for example forecasts are that by 2020 the port of Rotterdam will be handling 20 million containers annually. The maximum size of container carriers continues to increase; currently the largest vessels are capable of carrying 7000 containers. Losses of containers in bad weather are quite frequent, and not all containers have their contents well documented. Even so, recovery of dangerous cargoes from deep water is often impossible (see Section 3.9.3).

Figure 3.10 **Growth in world transportation of bulk commodities by sea from 1985 to 1995. Source of data: Fearnresearch (1996).**



However, accidents in the open ocean are less frequent and the subsequent ecological impacts smaller than those resulting from similar accidents nearer shore.

3.11.2 Communications

Despite the enormous expansion of satellite use for communications, transocean cables are still in high demand because of the need for security. Computer networks and communications are expanding exponentially, and technically cables are better (and cheaper) for such links. The development of fibre-optic technology has enabled much more efficient use of cables. Consequently, there is an expansion of cable laying activities in the North Atlantic *(Figure 3.11)*. Cables have a minimum impact on the environment, but do restrict deep trawling and some scientific activities.

3.12 Coastal industries

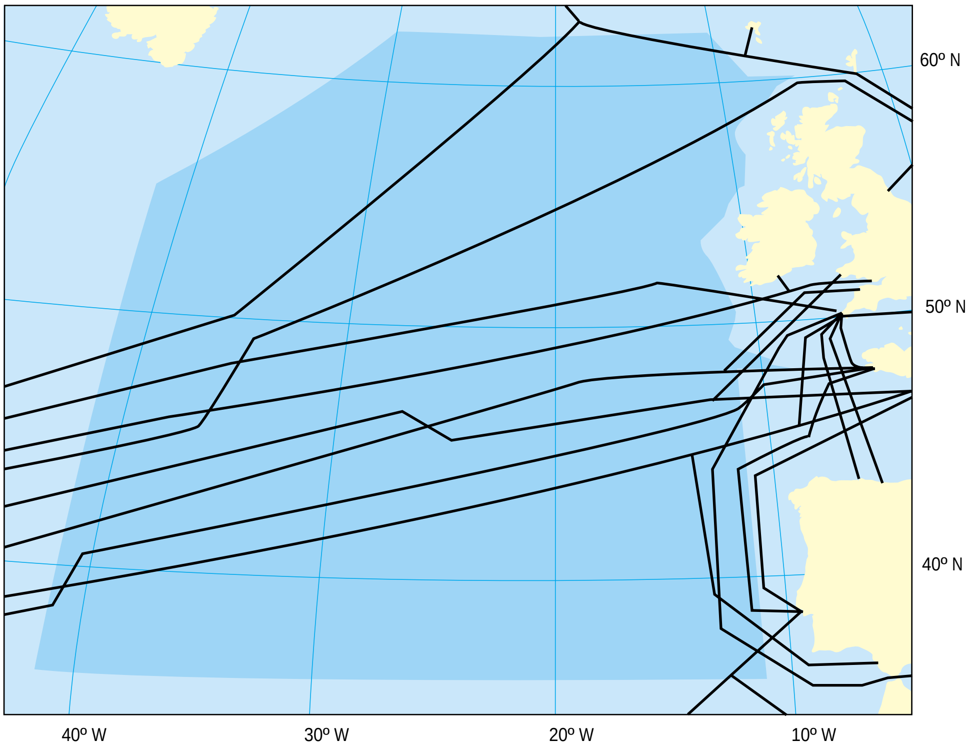
There are a few coastal industries in the Azores but their impact, even locally, is quite trivial and unlikely to grow to any serious proportions.

3.13 Military activities

Wars and their associated military activities have left a legacy throughout the region. During the Second World War some 20 million t of shipping were sunk in the Atlantic. Post-war, military authorities faced with the problem of how to deal with dangerous munitions scuttled numerous redundant vessels loaded with such materials (see Section 3.9.4). Throughout the Cold War, there was intense military activity, including naval exercises and patrolling, aimed at monitoring the movements of Soviet submarines passing through the channels in the ridges between Scotland, the Faroe Islands and Iceland. There were constant overflights by military aircraft from both sides probing air defences, and a nuclear strike force was constantly maintained airborne as a deterrent. Inevitably there were accidents and the seabed is now littered with artefacts resulting from these activities. This litter ranges from sunken vessels, some having been nuclear powered or armed with nuclear devices, to munitions and pyrotechnics used in exercises, to hydrophone arrays (still operational) deployed along the western margins of the European continental margin.

Despite the ending of the Cold War, some military activity continues. This is needed to maintain a body of

Figure 3.11 **Routes of deep sea fibre-optic cables across Region V. Source: France Télécom.**



trained personnel and adequate weaponry, necessary to protect national interests and to support international peacekeeping, particularly to deal with regional conflicts. These missions often require a rapid response capability; hence the continuing need for bases in mid-ocean, such as on the Azores, to act as staging posts for the transportation of personnel and equipment to centres of conflict.

Many national military forces are developing a responsible ethos of environmental compliance alongside their primary mission. The updating of hydrographic and bathymetric surveys and the maintenance of satellite navigation networks, which are vital for the safety of marine operations, are conducted by agencies that are predominantly funded by navies, so not all the information reaches the public domain.

3.14 Land-based activities

Land-based activities have a relatively small impact on Region V, except as sources of atmospheric contaminant inputs. Fluxes entering the oceans via the atmosphere are generally poorly quantified, but become increasingly important with distance from land. For many persistent organic contaminants, some heavy metals and nitrogenous compounds entering oligotrophic ocean regions, the atmospheric inputs are non-trivial (see Chapter 4).

3.15 Agriculture

Agricultural activities in the Azores have little impact on Region V. However, agricultural activities in Europe and America constitute sources of atmospheric inputs to the deep ocean, particularly for nitrogenous compounds and biocides.

3.16 Regulatory measures and future developments

There are four Conventions, three of these global, that offer some protection specifically to deep-sea environments (Sand, 1992):

a. the Convention for the Protection of the Marine Environment of the North East Atlantic, 1992 (OSPAR Convention);
b. the UN Convention on the Law of the Sea, 1982 (UNCLOS);
c. the Convention on the Prevention of Marine Pollution by Dumping of Wastes and other Matter, 1972 (London Convention or LC); and
d. the Convention for the Prevention of Pollution from Ships, as modified by the protocol of 1978 relating thereto (MARPOL 1973/78).

The OSPAR Convention stipulates that Contracting Parties shall take all possible steps to prevent and eliminate pollution and shall take the necessary measures to protect the maritime area against the adverse effects of human activities so as to safeguard human health and to conserve marine ecosystems and, when practicable, restore marine areas which have been adversely affected. The Convention addresses the prevention and elimination of pollution from land-based and offshore sources. It prohibits incineration and dumping at sea, the latter with certain exceptions (e.g. dredged material). It also provides for the assessment of the quality of the marine environment and the protection and conservation of the ecosystems and biological diversity of the maritime area.

UNCLOS has been ratified by 122 States (December 1997). It has amongst its objectives the promotion of ‘peaceful uses of the seas and oceans, the equitable and efficient utilisation of their resources, the conservation of their living resources, and the study, protection and preservation of the marine environment’. It confirms the sovereign rights that States have to exploit their natural resources, but balances this against the duty to protect the marine environment. It provides States with the international basis upon which they must pursue the protection and sustainable development of resources in marine and coastal environments, both within their own EEZs and on the high seas (see parts V, VI, VII, IX and IX). Any activities by a State must cause no significant adverse changes in either the living or non-living components of the marine and atmospheric environment. Moreover these activities must not cause significant adverse effects on ecosystem diversity, productivity and the stability of biological communities. Nor should any activity cause unreasonable loss of scientific or economic value of marine resources relative to the benefits otherwise being derived from the activity in question.

In September 1997, the London Convention had been ratified by just 77 States. In 1996 it adopted a protocol which specifically states that ‘the disposal (or storage) of wastes or other matter directly arising from, or related to exploration, exploitation and associated offshore processing of seabed mineral resources is not covered by the provisions of the Convention’ (IMO, 1997). However, disposal of industrial wastes is now banned under the Convention. MARPOL specifically deals with discharges from ships and platforms (but not via pipelines) and has currently been ratified by 102 States.

There is a multiplicity of organisations involved in the management of fish stocks in the Northeast Atlantic – the Northeast Atlantic Fisheries Commission, the North

Atlantic Salmon Conservation Organization, ICCAT, ICES and the European Community with its Common Fisheries Policy. The UN Conference on Straddling Fish Stocks and Highly Migratory Fish Stocks is addressing the ways in which States are required to cooperate to conserve and promote the optimum utilisation of these stocks. Turtles and seabirds are afforded some measure of protection under international agreements. The situation in respect of whales is particularly confused. Under the International Convention for the Regulation of Whaling (ICRW) and UNCLOS, States are free to take living resources from the High Seas as long as their exploitation is carried out in a sustainable manner. The International Whaling Commission (IWC), with considerable international support, is trying to impose a moratorium on all whaling. However, not all OSPAR countries support this moratorium, and they point out that there are contradictions between the provisions of ICRW and the actions of IWC. The North Atlantic Marine Mammal Commission (NAMMCO) is a regional organisation which has been established by those countries that consider that sustainable exploitation of whales is justified.

The adoption of Annex V to the OSPAR Convention is a relatively recent development in providing protection for biodiversity and specified species and habitats, but it is yet to be seen how this Annex will be implemented in offshore waters. National Portuguese legislation has been introduced to implement the EC Habitat Directive (92/43/EEC) in the coastal and EEZ waters around the Azores, otherwise EC Directives do not apply to Region V. The provisions of the Conventions on Sustainable Development and Biodiversity should be applicable to Region V, but so far the focus has mainly been on terrestrial and inshore habitats and species.

chapter 4

Chemistry

4.1 Introduction

Region V has not been regularly monitored for contaminant levels in the water, sediments or biota, and only a few of the old dump sites have been monitored intermittently. So virtually all the information has been derived from the scientific literature. Sea water contains nearly all the known elements and a wide variety of organic compounds, some dissolved and some associated with suspended particles. The chemistry of naturally occurring compounds is complex, so it is often difficult to determine their origins. Some substances are highly conservative with long turnover times in marine environments while others, mostly those that are involved in biological processes, have rapid turnover times, and are extremely variable in time and space.

Many of the anthropogenic substances now being manufactured by industry, do not occur naturally in the environment. These synthetic compounds are often specifically selected for manufacture because they are both persistent and highly toxic to biota. The introduction of such substances into the marine environment seldom has predictable results, especially those (e.g. PCBs) that readily dissolve in lipids (i.e. are lipophilic). These tend to accumulate within body tissues and tissue concentrations tend to increase along food chains (i.e. they are biomagnified). Some of these compounds are highly specific in their toxicity (e.g. the effects of TBTs on molluscs), but by removing specific groups of organisms they disturb food webs and disrupt ecosystem structure. Recent evidence indicates that a wide variety of these substances can also disrupt the functioning of hormonal systems (endocrine disruption). Others, while not directly affecting biota or ocean ecosystems, can have far-reaching impacts mediated through changes they induce in environmental chemistry external to the oceans (e.g. the effects of CFCs on the atmosphere). *Table 4.1* summarises the toxicological effects of a selection of these substances.

4.2 Inputs

Analyses of ice cores and lake sediments have shown that inputs of many heavy metals to the atmosphere and aquatic environment *(Table 4.2)* have trebled or even quadrupled during the Twentieth Century (Nriagu, 1990, 1992). These increases are reflected in increases in the metal loads of some biota. Inputs to the oceans from the atmosphere show strong regional variations with inputs into the N. Atlantic > N. Indian > N. Pacific > S. Atlantic > S. Indian > S. Pacific. Some of the anthropogenic fluxes now entering the oceans from the atmosphere exceed those from natural sources, for example lead. Mean lead concentrations in the wind-mixed layer of the North Atlantic are about 26 times higher than in the South Pacific (Johnston *et al*., 1996). However, lead inputs have been falling since most motor fuel became lead-free. Organisms and ecosystems have a limited ability to cope with increases in the concentration of those toxic substances that occur naturally in the environment. However, there are few reliable data providing insight into the long-term trends in the chemical composition of either water or biota in Region V.

Contaminants are introduced into the marine environment as a result of a wide variety of human activities. It is often difficult to distinguish the relative proportions of anthropogenic versus natural inputs, especially when the natural processes resulting in the inputs are also perturbed by human activity (e.g. chemical weathering and forest fires). *Table 4.3* summarises one attempt to make such a comparison (Duce *et al*., 1991). Anthropogenic inputs reach the sea either directly, via dumping and discharges, or indirectly via rivers and the atmosphere. Many that enter via riverine discharges become bound to estuarine sediments, hence estuaries tend to have become semi-permanent repositories for a large proportion of the heavy metals discharged into rivers since the industrial revolution, such that only about 10% of the discharges eventually reach the deep ocean. Consequently, riverine and land-based discharges quantitatively dominate inputs into shelf seas, but offshore inputs from the atmosphere and *in situ* discharges from shipping and mineral extraction are more important. Models of atmospheric inputs from OSPAR countries

Table 4.1 A summary of the toxicological effects of a range of contaminants occurring in Region V.

Mercury	Nerve toxin, particularly damaging to developing young. Reduces plant growth. Damages gills and disrupts gut absorption and chemoreception in fish. Strongly bioaccumulative.
Cadmium	Affects growth and larval development. Upsets ionic control and calcium metabolism in fish. Accumulates in kidneys and liver of higher animals and disrupts calcium and vitamin D metabolism.
Lead	Damages central nervous system, particularly when the brain is growing. Accumulates in the gills, liver and kidneys of fish and reduces larval survival.
Polychlorinated biphenyls	Highly accumulative. Effects depend on chemical structure; co-planar forms are most toxic. Generally immunosuppresive, some are carcinogens and/or homorne disruptors.
Dioxins and furans	Carcinogenic. Immunosuppressive. Disrupt reproduction. Generally more toxic then co-planar PCBs.
Hexachlorobenzenes	Inhibit haem sysnthesis and cause porphyria.
Brominated flame retardants	Toxicixty not understood.
DDT	Hormone disruptor. Affects liver enzymes. Causes eggshell thinning in birds.
Toxaphenes	Affect nervous system, particularly in fish which become hyperactive and loose balance control.
Chlordane	Neurotoxic. Carcinogenic. Disrupts immune and reproductive system.
Dieldrin	Carcinogenic.
Mirex	Affects reproduction and induces cancers in laboratory animals.
Tributyltin	Hormone disruptor, particularly in gastropod molluscs.
Polycyclic aromatic hydrocarbons	Wide range of substances, some are carcinogenic and/or mutagenic.

Table 4.2 Comparison of natural and anthropogenic inputs (t x 10^3/yr) of heavy metals at the global level. Source of data: Nriagu (1990, 1992).

	Cadmium	Mercury	Lead	Copper	Zinc	Arsenic	Chromium	Nickel
Natural emissions to atmosphere	1.4	2.2	12	28	45	12	43	29
Anthropogenic emissions to atmosphere	7.6	3.6	332	35	132	19	31	52
Inputs to aquatic systems*	9.1	6.5	138	112	237	42	143	114
Flux resulting from weathering†	4.5	0.9	180	375	540	90	810	255
Riverine inputs to oceans	0.07	0.03	0.29	4	5.6	1.6	5.8	4.6
Atmospheric inputs to oceans	3.2	1.7	88	34	136	5.8	-	25

* includes atmospheric inputs; † weathering is estimated from soil concentrations and suspended sediment loads in rivers.

suggest that the littoral countries are the major sources (van Pul *et al*., 1998). However, if the model inputs are scaled according to population size, then the atmospheric deposition per capita is higher for some of the countries with relatively low industrial activities such as Iceland. This suggests the models still require improvement. Moreover, deposition occurs mostly downwind of the source. So substantial aeolian inputs of contaminants (e.g. iron, lead, zinc and many organochlorine compounds) to Region V originate from the North American continent, either carried all the way by wind or by the major ocean currents after having been deposited in the western Atlantic. Contaminants released into the atmosphere over Europe are mostly blown north-eastwards and so are deposited over land. Other sources, such as the plumes of iron-rich Sahel dust, only affect Region V under exceptional weather conditions (Reiff *et al*., 1986).

At the global scale, atmospheric inputs are quantitatively similar to the riverine inputs (Duce *et al*., 1991). Fluxes and deposition rates to the North Atlantic and North Pacific are 5 - to 10-fold higher than to oceans in the southern hemisphere.

Total inputs of nitrogenous compounds are similar in both the northern and southern hemispheres, but those from anthropogenic sources, such as nitrogen oxides, are far higher in the northern hemisphere. Similarly inputs of synthetic organic compounds that are predominantly dispersed in the atmosphere, such as hexachlorocyclohexane (HCH), PCBs, DDT and hexachlorobenzene (HCB), are substantially higher in the northern hemisphere than the southern.

Atmospheric deposition is either dry (as gas or on particles) or wet (in solution or in suspension in rain, hail and snow). Highly soluble gases (e.g. sulphur dioxide) are readily removed by rain so their inputs are higher nearer to their sources. Direct gaseous transfer rates increase with increasing wind speeds (Liss and Merlivat, 1986), particularly when breaking waves inject bubbles into the water. Inputs of less soluble contaminants (e.g. organochlorine compounds and mercury) enter the ocean predominantly via dry deposition. A number of metals (including lead, cadmium, zinc, copper, nickel, arsenic, mercury and tin) are described as 'Anomalously Enriched Elements' (AEEs). They are predominantly associated with particles < 1 µm in size that are the products of combustion. The proportions of AEEs in these particles are well in excess of those expected from the natural weathering of minerals and in sea salt *(Figure 4.1)*. The larger dust particles (> 1 µm) have chemical compositions (of aluminium, iron, silicon and phosphorus) that indicate they are derived from the erosion of continental rocks and soils.

Table 4.3 Estimated natural and anthropogenic emissions (t x 10^3/yr) of selected heavy metals. Source of data: Duce *et al*. (1991).

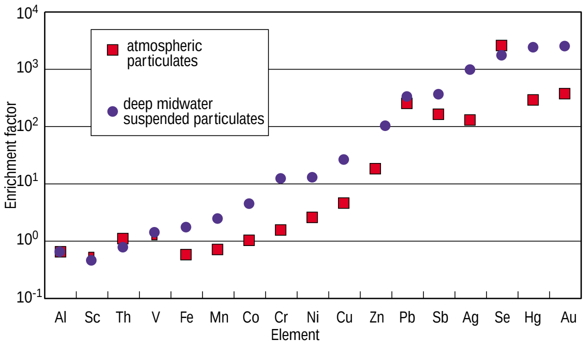
	Natural		Anthropogenic	
	mean	range	mean	range
Cadmium	1.3	0.15 – 2.6	7.6	3.1 – 12
Lead	12	1 – 23	332	289 – 376
Copper	28	2.3 – 54	35	20 – 51
Zinc	45	4 – 86	132	70 – 104
Arsenic	12	0.9 – 23	18	12 – 26
Nickel	30	3 – 57	56	24 – 87

4.3 Background/reference values and fluxes

4.3.1 Baseline values

There are few reliable data on the concentrations of trace elements and organic substances in oceanic Atlantic waters. So the OSPAR assessment criteria (OSPAR, 1997a,b) can not be applied to Region V. Furthermore, the development of sophisticated sampling and analytical techniques during the 1990s demonstrated that, inadvertently, all the earlier analyses had been seriously contaminated, resulting in a substantial lowering of the baseline concentrations for all heavy

Figure 4.1 **Mean enrichment factors for particulates from the North Atlantic. Source of data: Buat-Ménard and Chesselet (1979).**



The enrichment factors are relative to mean abundance in crustal rocks.

metals. Intercalibration exercises have also shown that individual analysts even from the best laboratories derive values with small, but often significant, differences in concentration (Topping, 1997). It is also doubtful whether a few point measurements from such a vast area (and volume) can be considered representative. *Table 4.4* summarises ranges in concentration for some metals in the water column of the North Atlantic and *Figure 4.2* compares concentration profiles in the North Atlantic and North Pacific. Many metals occur in lower concentrations in surface waters because they are taken up during biological activity and then exported into deep water where they are regenerated. Thus the 'older' deep waters of the North Pacific are richer in these metals (Bruland and Franks, 1983). Hence interpretation of concentration profiles requires an understanding of the variety of biogeochemical processes regulating the sources, fluxes and sinks of contaminants, as well as ocean circulation patterns.

4.3.2 Material fluxes

There are three main processes whereby substances are exported from the surface to the deep ocean *(Figure 4.3)*:

a. the solubility pump (or advection);
b. the biological pump, which has two components: the passive (sedimentation) and active transport of the products of primary production; and
c. the sediment pump.

Figure 4.2 **Dissolved metal profiles (mM/kg) for the North Atlantic and North Pacific. Source: Bruland and Franks (1983).**

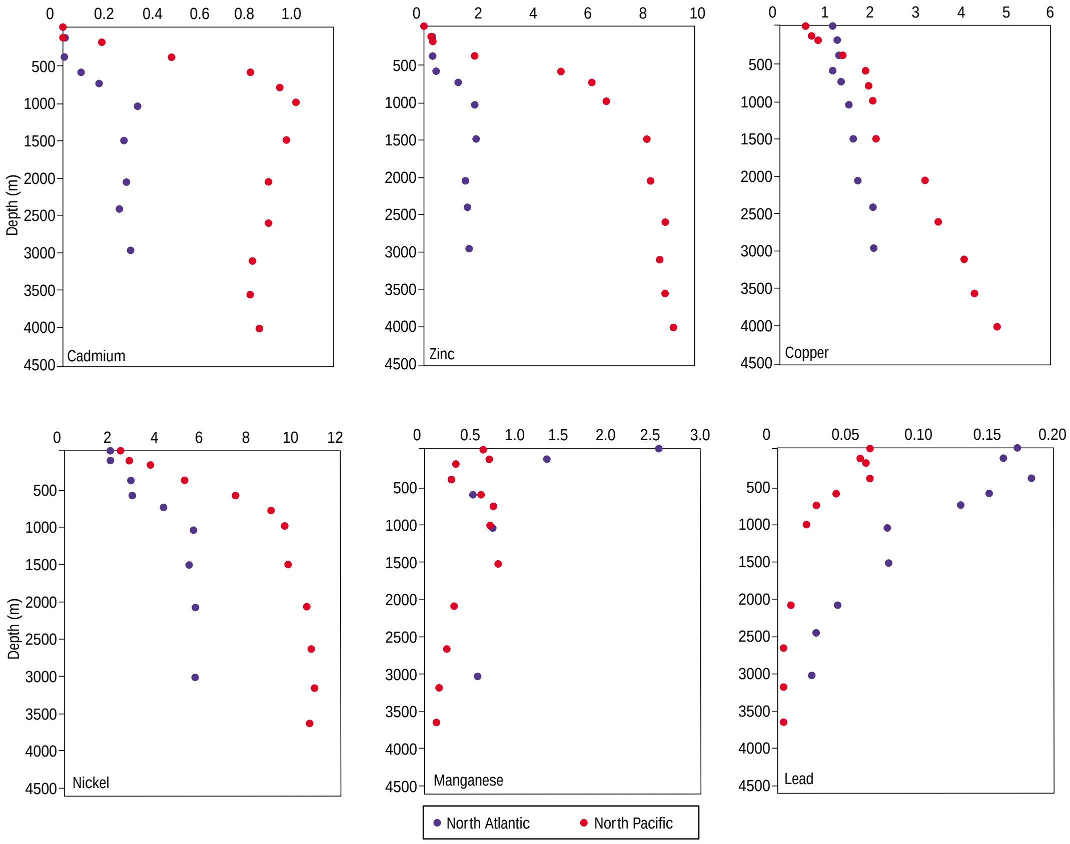


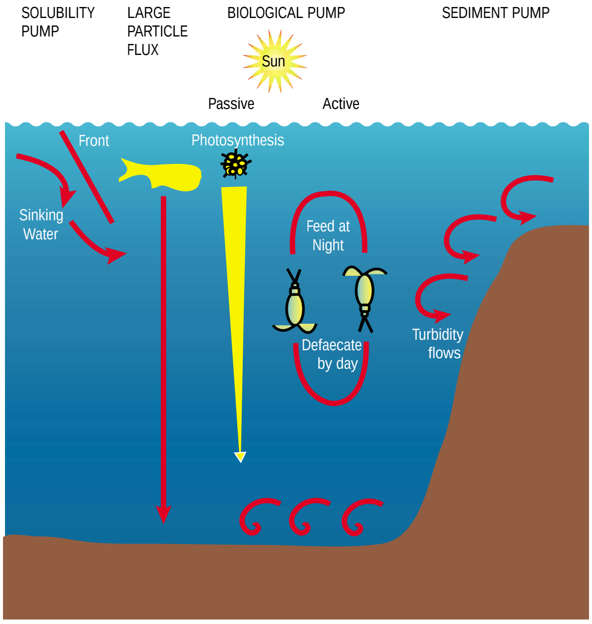
Table 4.4 Range in heavy metal concentrations (ng/l) observed in the North Atlantic. Source of data: Schmidt and Gerwinski (1992).

Cadmium	5 – 25
Chromium (VI)	90 – 120
Copper	50 – 100
Iron	25 – 150
Lead	5 – 20
Manganese	10 – 25
Mercury	0.1 – 0.4
Nickel	160 – 250
Selenium (IV)	2 – 20
Uranium	3000 – 3500
Vanadium	1250 – 1450
Zinc	200 – 300

There are also fluxes across the sediment/water interface. Fluxes to the sediments result from:

a. the slow deposition and accumulation of fine particulate material of pelagic or aeolian origin;
b. rapid fluxes of small quantities of large items (e.g. dead large animals, material rafted by ice or floating objects); and
c. lateral transport (mostly near the continental margins but also in some of the deep currents that result in the deposition of turbidites and sediment drifts (see Section 2.4.4)).

Figure 4.3 **Schematic diagram of the various 'pumps' whereby material is exported to the deep ocean.**



Chemical and microbial breakdown of organic and inorganic material occurs both at the sediment interface and within the sediment and results in the release of soluble compounds back into the water column. Mineral particles also undergo slow (or diagenetic) changes within the sediment that can result in chemical fluxes back into the overlying water, the most dramatic example being the plumes of metal ions and dissolved gases that are emitted as a result of hydrothermal circulation (see *Figure 2.4*). The high pressures and temperatures deep within the crustal rocks result in some elements being released into the circulating vent waters, whereas others (e.g. potassium) are removed.

The solubility pump

Surface water that sinks below the thermocline into the interior of the ocean, carries with it dissolved organic and inorganic compounds. At convergent fronts, the sinking surface water mixes within the water column and so does not reach the bottom. But in the Weddell Sea (and until recently in the East Greenland Sea) it penetrates all the way to the bottom. Chemicals, both natural and anthropogenic (e.g. CFCs) are used to track these waters as they sink. For example in Region V, Antarctic Bottom Water, which originates in the Southern Ocean, is identified by its high concentration of dissolved silicate. Some radioactive contaminants have been used as tracers, notably tritium from nuclear weapon testing and ^{137}Cs from the Chernobyl accident. CFCs are currently proving to be the most useful and informative tracers. They are an inert and highly conservative group of compounds comprising chains of carbon atoms of various lengths. Over the years the proportions of the different chain-length compounds that have been manufactured have changed, and these provide time markers as to when the water was last at the surface, as well as estimates of the volumes of water being advected.

The biological pump

About 10 – 15% of the organic matter produced by photosynthesis in the upper ocean sinks under gravity through the thermocline into the ocean's interior. During the spring bloom at 47º N, 20º W, the vertical particle flux measured in sediment traps at 150 m was 9.8 mmol C/m^2/d, i.e. about 11% of the primary production (Lochte *et al*., 1993). Most of this organic flux is oxidised within the water column and only 10% reaches the seabed (i.e. 1 – 3% of primary production). The size of the phytoplankton cells fixing the carbon near the surface influences the proportion that is exported by sedimentation. Most organic material produced by picoplankton (phytoplankton cells $<$ 2 µm in size) is recycled above the thermocline. However, the total surface area of these tiny cells together with those of the bacteria are about an order of magnitude larger than all other particles in the water. Hence the dynamics of contaminants that become adsorbed onto organic surfaces is largely determined by the fate of these tiny cells within the water column (see Section 5.2.6).

Export of organic matter results largely from the production of large phytoplankton cells, particularly diatoms. As the nutrients become exhausted in the wind-mixed layer above the thermocline, the diatoms aggregate into large flocs (known as marine snow), which sink rapidly. Sinking rates of particles are proportional to their size, the larger the aggregates the faster they sink. There is less time for a rapidly sinking particle to have its contents remineralised by bacteria, or to be intercepted and consumed by mid-water animals. Within four to six weeks of the onset of the bloom large quantities of detrital material settle onto the seabed (see Section 5.2.5).

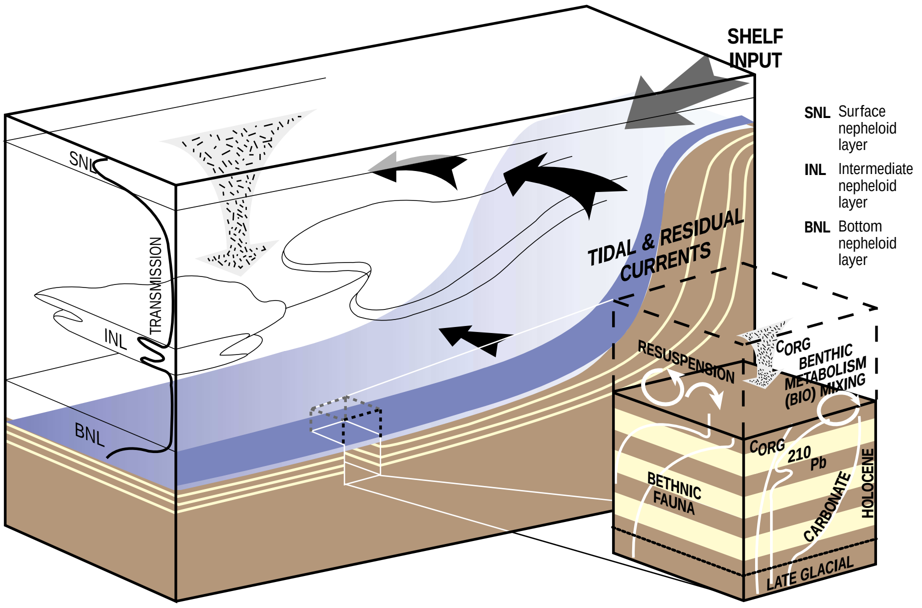
Organic matter is also exported from the euphotic zone by vertically migrating animals (Angel, 1985; Zhang and Dam, 1997). There are three categories of vertical migration – diel, ontogenetic and seasonal – but only diel migrations contribute significantly to downward transport. At dusk many pelagic animals, large and small (up to 50% of the biomass), migrate up from deep water into the euphotic zone. They arrive with empty guts and spend the night feeding. At dawn they swim back down through the thermocline into deep water with full guts. So whatever they excrete or defecate (or if they get eaten or die in deep water) contributes to the material exported from the euphotic zone. At times this export can amount to at least a third of that removed by sedimentation (Zhang and Dam, 1997), but there are considerable regional (and seasonal) variations in the intensity of these migrations (Hays, 1996).

Another mode of biological export is through the rapid sinking of dead large animals, such as whales and discards from fishing vessels. These reach the bottom virtually intact, but are rapidly consumed by a feeding guild of scavengers dominated by amphipods (see *Figure 5.12*). In terms of the gross fluxes this export will be very small, but ecologically it may be very important.

The sediment pump

Along continental slopes, suspended sediments derived from the shelf are transported both along-shore and offshore (van Weering *et al*., 1998). Tides, internal waves and to a lesser extent storms, generate local near-bed currents that resuspend sediments and transport them as bed load (see Section 2.10). As water picks up higher loads of suspended material it becomes denser and tends to slide down slope. The surface nepheloid layer is generated mainly by biological activity, the intermediate nepheloid layer by tidal currents and internal waves and the bottom nepheloid layer by resuspension processes at the seabed *(Figure 4.4)*. These sediment exports with their associated contaminant loads are intermittent and so difficult to quantify.

Figure 4.4 **Elements of the sediment pump across a shelf-slope-abyssal plain transect to the south-west of Ireland. The inset shows the processes controlling sedimentation, particle composition, carbon dynamics, oxygen content and benthic biomass in the benthic boundary layer and surface layers of the sediment. Source: van Weering *et al*. (1998).**



Summary of fluxes

Fluxes of particulate material are essentially downward as a result of gravitational sedimentation, vertical migrations and down-slope transport. Once on the seafloor, benthic storms associated with mesoscale eddies and tidal oscillations can result in intermittent resuspension events in the benthic boundary layer.

4.4 **Heavy metals**

4.4.1 Introduction

Traces of many metals, even some that are generally considered to be toxic, are essential for normal biological activity. For example, copper is a co-metal in haemocyanin and vanadium occurs in the respiratory pigment of salps (Rainbow, 1990). Traces of zinc (Sunda and Huntsman, 1992), copper (Manahan and Smith, 1973) and cadmium (Lee *et al*., 1995) are also essential for optimal phytoplankton growth. Organisms can control their active take-up of these metals, halting their uptake once their needs are satisfied. However, the sites at which the active take-up occurs can be blocked (poisoned) by chemically similar metals such as silver, lead and mercury (Rainbow, 1990). Cadmium, which is required in trace quantities, also blocks the uptake of other metals once a very low threshold concentration is exceeded. Uptake from the surrounding water may be direct across the gills or the body wall, or from food in the guts. After uptake compounds are regulated by excretion, stored in the form of detoxified by-products or merely tolerated. Storage can be as metallothioneins, lysosomes and granules (Rainbow, 1990). Mesopelagic decapod crustaceans, for example, store copper detoxified as copperthionein in their hepatopancreas and the quantities stored increase with age. Such species are useful as indicator species but they also contribute to biomagnification – the tendency for some metals to accumulate along food chains (Rainbow, 1989). Physiological responses to the inputs of different toxins vary widely, but sublethal effects only appear once an individual’s ability to cope with the uptake begins to be exceeded. Not all organisms have the ability to regulate metals such as copper, so for them sublethal effects occur at relatively low concentrations whereas others, such as those that are found around hydrothermal vents, can tolerate extremely high localised concentrations.

Most studies on toxicity have been carried out on shallow-living species, which are simple to maintain in the laboratory. But these are likely to be more tolerant physiologically than deep water species, which are not normally exposed to such wide fluctuations in concentration. Responses to toxic metals also include induction of tolerance/resistance, inhibition of growth, abnormal development (especially in larvae), impairment of reproduction and alterations in the hatching rate of eggs (Langston, 1990). Exposure to toxins depends on an organism’s ecology, for example, burrowing animals are more exposed to sediment pore waters than to the overlying sea water, similarly mucus-web feeding animals may be particularly vulnerable because of the high affinity of their mucus for certain elements. Data on metal levels in marine vertebrates have been summarised by Thompson (1990).

4.4.2 Cadmium

Cadmium behaves like a nutrient in sea water. Its concentrations in the water column are depleted near the surface as a result of biological activity and increase with depth through regeneration ***(Figure 4.2)***. Carnivorous crustaceans tend to accumulate, rather than to excrete, non-essential cadmium (Rainbow, 1989). Those from uncontaminated oceanic waters typically contain 1 – 2 µg/g, but slow-growing species from mesopelagic depths have been found to contain up to 43 µg/g (Rainbow, 1990). Detritivorous species tend to accumulate other naturally occurring trace metals such as polonium (Cherry and Heyraud, 1981). Cadmium concentrations in fish are generally low; muscle contents seldom exceed 0.2 µg/g ww, but the content of liver and kidney is higher ***(Table 4.5)***. There are considerable variations between individuals, for example, concentrations reported for black marlin (*Makaira indica*) range from 0.2 to 83.0 µg/g. The higher concentrations may result from pollution but may equally well result from an individual’s preference for a particular diet rich in carnivorous crustaceans. In seabirds and marine mammals, cadmium concentrations tend to be low in muscle and again higher in liver and kidney, they also tend to increase with age. Species that feed on euphausiids and cephalopods tend to have higher cadmium contents than those that feed on fish (cf. narwhale (*Monodon monoceros*), Muir *et al*., 1992) versus pilot whales (*Globicephala* spp.), *Table 4.6*), and coastal-dwelling species generally have higher contents than oceanic species (e.g. Law *et al*., 1991). Pilot whales appear to have a high tolerance, their liver concentrations can be as much as 50 µg/g ww and their daily intake, estimated to be 3 – 4 µg Cd/kg body weight, would result in severe health problems in humans (Law *et al*., 1991).

4.4.3 Mercury

Mercury is a non-essential metal that occurs in the marine environment in both inorganic and organic forms. Anthropogenic inputs from power generation, waste incineration, cement production and smelting, are now two- to four-times the natural fluxes from volcanoes, crustal degassing and weathering (Lamborg *et al*., 1999). The

Table 4.5 Trace elements in deep-water fishes from the North-east Atlantic.

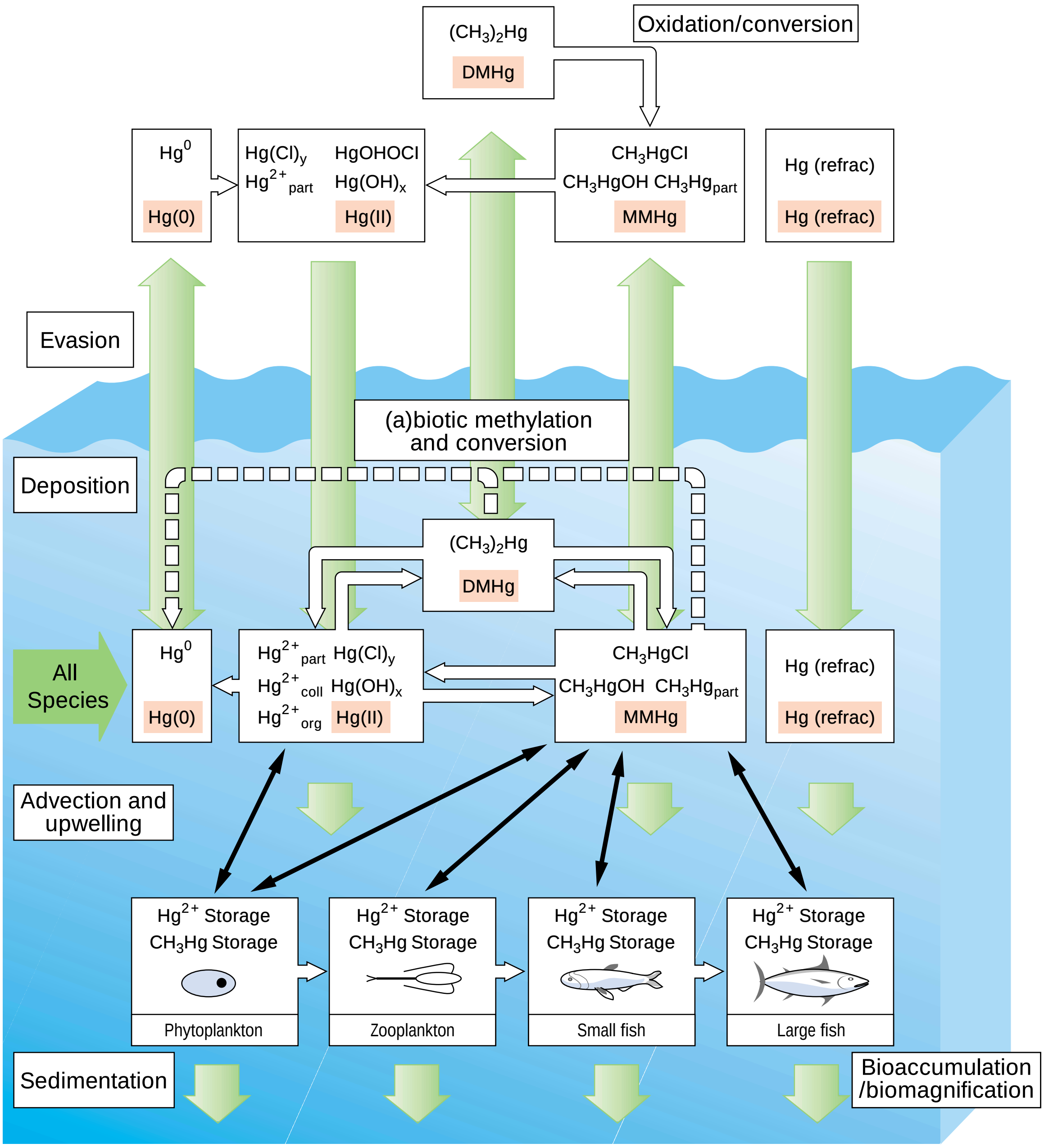
		Cadmium (ng/g)	Mercury (ng/g)	Lead (ng/g)	Copper (µg/g)	Zinc (µg/g)
smooth grenadier*	muscle	4	150	5	0.21	3.91
		2 – 10	35 – 532	n.d. – 24	0.17 – 0.37	3.06 – 5.79
	liver	292	75	48	1.92	16.18
		143 – 841	15 – 221	14 – 128	0.90 – 7.49	10.52 – 35.08
large eyed lepidion*	muscle	5	77	2	0.17	2.62
		3 – 13	38 – 398	n.d. – 11	0.13 – 0.24	2.16 – 3.56
	liver	268	50	33	3.07	15.05
		146 – 863	16 – 276	1 – 84	1.53 – 8.54	9.29 – 47.08
round ray*	muscle	12	129	27	0.33	5.53
		8 – 27	44 – 410	n.d. – 44	0.22 – 0.83	4.57 – 6.15
	liver	509	83	26	1.98	17.97
		228 – 4399	24 – 288	n.d. – 128	1.12 – 15.90	9.67 – 32.67
round-nose grenadier†	muscle	2	70	0.00	0.08	2.2
		n.d. – 110	20 – 280	n.d. – 60	0.03 – 0.54	1.7 – 2.9
Coryphaenoides mediterraneus†	muscle	20	70	720	0.48	5.0
		n.d. – 70	20 – 340	70 – 2400	n.d. – 0.89	2.6 – 8.5
rough-head grenadier†	muscle	10	340	10	0.01	3.2
		n.d. – 210	150 – 880	3 – 40	n.d. – 0.24	2.8 – 3.9
orange roughy†	muscle	10	420	10	0.09	2.7
		n.d. – 90	110 – 860	n.d. – 660	0.04 – 0.19	2.0 – 3.4
spearsnouted grenadier†	muscle	20	170	570	0.40	6.7
		10 – 410	120 – 500	310 – 970	0.33 – 0.70	5.0 – 10.6
Nematomurus armatus†	muscle	10	380	170	0.3	4.4
		10 – 130	190 – 650	70 – 440	0.2 – 0.6	4.2 – 4.9

* Mormede and Davies (1998); † Cronin *et al*. (1998); n.d. not detected.

mercury cycle in the oceans is highly complex *(Figure 4.5)* and there are dynamic exchanges between the oceans and the atmosphere. Most inputs to the oceans arrive from the atmosphere (Fitzgerald and Mason, 1996) and deposition occurs as much as 1000 – 2000 km downwind of a source. Over the Atlantic the mercury levels in the atmosphere have been increasing annually by 1.46% (Slemr and Langer, 1992), and isotopic studies in the Pacific indicate that surface water concentrations are already eight to twenty times higher than natural levels (Mason *et al*., 1994). Mercury that is deposited from the atmosphere may be reduced to elemental mercury, methylated, or scavenged by particles; its behaviour is largely determined by biological and biochemical processes (Lindqvist, 1991). Methyl mercury is the form that is most readily absorbed and toxic. In the deep water of OSPAR Region IV (the Bay of Biscay and Iberian Coast), the highest mercury concentrations occur at subthermocline depths (Cossa *et al*., 1992) and a similar pattern can be expected to occur in Region V. This concentration maximum includes both monomethylmercury (MMHg) and dimethylmercury (DMHg) as a result of regeneration from particles, but the subsequent behaviour of these two forms is different. MMHg is scavenged by particles and exported by sedimentation into deep water. Whereas DMHg is vented back into the atmosphere where it is decomposed (Cossa *et al*., 1997). The Atlantic inflow into the Mediterranean transports about 61 – 107 (mean 84.3) kmol/yr, whereas the Mediterranean outflow transports 92 – 134 (mean 112.6) kmol/yr (Cossa *et al*., 1997).

The subthermocline maximum in MMHg and DMHg may account for mercury concentrations in mesopelagic fish being quadruple those of epipelagic species (Monteiro *et al*., 1996). Larger, longer-lived pelagic fish species, such as tuna and swordfish, accumulate very high concentrations *(Table 4.7)*, which in some specimens may exceed those normally considered to be acceptable for human consumption (5 µg/g ww). In fish muscle the mercury occurs predominantly as MMHg *(Table 4.7)*. In the Azores, which are remote from large anthropogenic sources, most mercury comes from volcanic activity. Andersen and Depledge (1997) found concentrations to be higher in older and larger specimens of crabs, barnacles and shallow-living fish. In comparison, concentrations in deep-sea species in the north-east of the region closer to anthropogenic sources are quite low *(Table 4.7)*.

Figure 4.5 **Biogeochemical cycling of mercury in the upper ocean. Source: after Lamborg *et al*. (1999).**



Forms of mercury

Hg(0)	elemental mercury
Hg(II)	ionic mercury
DMHg	dimethylmercury
MMHg	monomethylmercury
Hg (refrac)	mercury in a non-reactive or refractory form

Table 4.6 Contaminant concentrations in squid and cetaceans from the North Atlantic.

	Cadmium	Mercury	Lead	Copper	Zinc	Silver	Selenium	Source
Squid								
Loligo forbesii	0.59	-	-	-	-	-	-	A
long-fin squid	0.1 – 0.25	0.02 – 0.13	0.35 – 1.0	6.5 – 77	6.8 – 31	-	-	B
short-fin squid	0.07 – 0.88	<0.02 – 0.4	<0.1 – 1.8	0.5 – 14	7.2 – 19	-	-	B
Cetaceans								
sperm whale								
southern North Sea*	30	34	0.11	2.3	34	-	11	C
long-fin pilot whale								
Faroe Islands	59	66	-	6.3	82	-	-	D
Faroe Islands	-	1.05 – 112	-	-	-	0.013 – 0.33	1.59 – 28.5	E

* stranded in Belgium but originating from the North Atlantic. A: Caurent and Amiard-Triquet (1995); B: Hall *et al*. (1978); C: Law *et al*. (1997); D: Caurant *et al*. (1994); E: Becker *et al*. (1995).

Table 4.7 Total mercury and methyl mercury concentrations in invertebrates and fish from around the Azores. Source of data: Andersen and Depledge (1997).

	Total mercury (µg/g)		Methyl mercury (%)
	mean	range	
Invertebrates			
crab (*Cancer pagurus*)			
gill	0.86	0.44 – 1.44	47.5
midgut	1.27	0.54 – 1.23	52.2
muscle	0.73	0.41 – 1.37	90.7
gonad	0.34	0.28 – 0.37	80.8
barnacle (*Megabalanus tintinnabulum*)	0.07	0.04 – 0.19	55.0
limpet (*Patella* sp.)	0.04	0.02 – 0.14	23.0
Fish			
albacore	0.37	0.22 – 1.13	92.1
skipjack	0.19	0.09 – 0.34	94.1
white sea bream	0.30	0.03 – 0.71	90.9
scabbard fish	0.28	0.12 – 0.59	80.1
forkbeard	0.10	0.02 – 0.41	85.8
blue-mouth	0.26	0.12 – 0.70	85.9
red mullet	0.12	0.04 – 0.21	88.9
horse mackerel	0.04	0.02 – 0.14	82.7
thick-lipped grey mullet	0.20	0.02 – 0.90	91.1
red sea bream	0.26	0.08 – 0.56	90.4
conger	0.25	0.15 – 0.41	83.7
spotted moray eel	0.05	-	75.0
common seabream	0.47	-	86.5
swordfish	4.91	-	-
blue-mouth	1.10	-	-

Mercury levels are low in marine mammals, but tend to be higher in fish-eaters. In striped dolphin (*Stenella coeruleoalba*) the mercury burden increases towards the equator (André *et al*., 1991), because mercury is more available biologically in oceanic upwelling regions. A similar pattern is reported for short-fin pilot whales (*Globicephala macrorhyncha*). Selenium and mercury both accumulate with age in whales (Becker *et al*., 1995) and the proportion of methyl mercury decreases as the overall mercury load increases. Mercury concentrations vary between and within species, partly as a result of variations in diet. Thus pilot whales (feeding predominantly on shallow-living squid and

Table 4.8 Mercury concentrations in the food (pg/g) and feathers (µg/g) of seabirds from the Azores. Source of data: Monteiro *et al*. (1998).

		Food	Feathers	Biomagnification
Mesopelagic feeders				
Bulwer's shearwater		318 ± 47	22.3 ± 0.4	225
Madeiran storm petrel	summer	243 ± 37	11.1 ± 0.3	146
	winter	432 ± 94	17.4 ± 0.4	129
Epipelagic feeders				
Cory's shearwater		131 ± 17	5.4 ± 0.1	132
little shearwater		72 ± 33	3.1 ± 0.1	138
common tern		54	2.1 ± 0.1	125

fish) contain more mercury than sperm whales (*Physeter macrocephalus*) (feeding on deeper-living squid). Although the data provided in *Table 4.6* were obtained from animals outside Region V, they had probably spent some of their time within the region. Pilot whales from the Faroe Islands show a high correlation between their selenium and mercury contents and their mercury levels increase with age (Caurant *et al*., 1994). The local human population in the Faroe Islands has an abnormally high exposure to both cadmium and mercury because of their traditional consumption of pilot whale meat.

In seabirds mercury levels also vary between and within species, generally concentrations in liver > in kidney > in muscle. Seabirds demonstrate high levels of bioaccumulation and the mercury content of their feathers provides a reliable measure of body burden. Pelts collected in previous centuries illustrate the historical build-up of mercury in the environment (Thompson *et al*., 1993). Seabirds are ideal subjects for monitoring mercury in different components of the marine environment (Monterio *et al*., 1998); they are relatively accessible and their feathers can be sampled without causing undue harm. The various species show marked differences in their mercury loads depending on whether they feed on epipelagic or mesopelagic prey *(Table 4.8)*.

4.4.4 Lead

Profiles of lead in sea water indicate that the major inputs are from the atmosphere *(Figure 4.2)*. Aerosols over the North Atlantic have a lead content of 1.4 – 17.7 µg/m^3 (Véron *et al*., 1992), compared to < 0.06 – 1.5 µg/m^3 in those from over the South Atlantic (between 35º S and 45º S). Stable isotope ratios demonstrate that most lead has been coming from vehicle exhausts. The ^{206}Pb/^{207}Pb ratios characterise the sources. The ratios in contemporary emissions are 1.19 – 1.21 for the US, 1.11 – 1.16 for Western Europe, 1.115 – 1.135 for Scandinavia and 1.16 – 1.185 for Eastern Europe (Véron *et al*., 1999). Between 1979 and 1984 the lead contents of aerosol over the western Atlantic halved following the decline in use of leaded fuels in the US (Fowler, 1990). Even so, in 1985 at 52.7º N, 35.5º W the aerosol concentrations doubled when winds blew from North America (Véron and Church, 1997), illustrating how sources of atmospheric contaminants may lie outside the OSPAR area. About 10 – 30% of the aeolian lead inputs are scavenged onto particles and exported to the sediments, the remainder being carried in by the currents. About half the lead in the subsurface waters of the North-east Atlantic was initially deposited in the North-west Atlantic and then carried in by the flow of the subtropical gyre (Véron *et al*., 1999). Lead concentrations in the upper 2000 m are 20 – 76 pM, compared with 17 – 32 pM at depths > 2000 m. The higher concentrations in the upper waters reflect the predominance of the industrial inputs. *Table 4.9* summarises data for three sites in Region V (Véron *et al*., 1999).

The Azores, midway between North America and Europe, have aerosols with the lowest lead content. The actions taken to reduce the use of leaded fuel in motor vehicles have been highly successful in reducing lead inputs, and illustrate how legislative and fiscal action can be effective in maintaining environmental quality.

Lead concentrations in fish are generally low and below detection levels. When detectable, concentrations are higher in liver and kidney than in other tissues. Concentrations in seabirds and seals rarely exceed 1 µg/g ww, but concentrations in bone tend to be higher, and individuals from heavily polluted coastal environments have much higher lead burdens. Data for deep-sea fish, oceanic squid and cetaceans are summarised in *Tables 4.5* and *4.6*.

4.4.5 Copper

Concentration profiles for copper in sea water show a strong biological influence *(Figure 4.2)*. Copper occurs in high concentrations in hydrothermal vent fluids. It is an essential element needed in trace quantities by vertebrates, crustaceans and fish, but is toxic at high concentrations. It is well regulated physiologically by most organisms. Concentrations in fish muscle are around

Table 4.9 Lead concentrations (pM) and stable isotope ratios in sea water profiles in summer 1993 at three locations in Region V. Source of data: Véron *et al*. (1999).

	Depth (m)	Lead concentration	^{206}Pb/^{207}Pb ratio (± error)
52.7º N, 35.0º W	65	57	1.200 ± 0.001
	600	61	1.186 ± 0.001
	1000	70	1.186 ± 0.001
	2200	38	1.181 ± 0.002
	3300	n.d.	1.202 ± 0.003
56.0º N, 25.5º W	550	57	1.179 ± 0.001
	1740	76	1.192 ± 0.001
	2920	17	1.187 ± 0.001
58.5º N, 28.2º W	20	47	1.187 ± 0.001
	175	59	1.187 ± 0.005
	1180	76	1.192 ± 0.001
	1940	75	1.192 ± 0.001

0.1 – 0.8 µg/g ww *(Table 4.5)*. In seabirds concentrations vary little either between species or geographically. Concentrations tend to be highest in liver tissue with mean values of around 6 µg/g ww. In seals concentrations of copper are highest in liver, but do not appear to increase with age, nor are the concentrations higher in polluted regions such as the Wadden Sea. There is usually a reduction in the copper burden of whales as body length and body weight increase, although Caurant *et al*. (1994) reported concentrations of copper increasing with age in pilot whales.

4.5 Persistent organic compounds

Since the petrochemical and chlorine industries first developed in the 1920s, emissions of persistent organic contaminants to the environment have steadily increased. Today, the majority of the 63 000 industrially synthesised chemicals in common use are organic. About 1000 new synthetic chemicals are introduced each year (Shane, 1994). However, about 3000 compounds account for 90% of the quantities manufactured. In Europe around 4500 of the substances in general use are known to be toxic and environmentally damaging (Edwards, 1992). The various types of biocide, manufactured specifically because of their toxicity and persistence, are of particular concern. The majority of persistent organic compounds enter the oceans from the atmosphere, but there are some direct inputs (e.g. TBTs from some antifouling paints). Many bioaccumulate becoming increasingly concentrated in top predators *(Table 4.10)*.

4.5.1 Tributyltin

There are no reports of TBT toxicity in open ocean organisms, although local effects have been detected around the Azores. Effects of TBT toxicity were first noted in France in the late 1970s, when oyster spat-falls declined sharply and the shapes of adult shells became abnormal. Since then ‘imposex’ effects have been identified in 188 species belonging to 63 genera of molluscs (Bettin *et al*., 1996). The induction of ‘maleness’ in molluscs may result from TBT altering the activity of an enzyme (cytochrome P450 mono-oxygenase) which interferes with the metabolism of testosterone (Oberdörster *et al*., 1998).

Table 4.10 Concentrations (µg/g ww) of mercury and organochlorines in blubber samples from adult pilot whales killed at two sites in the Faroe Islands in 1986. Source of data: Simmonds *et al*. (1994).

	Nordragota	Leynar
no. samples.	39	23
Mercury	n.d. – 0.63	0.23
		0.08 – 0.54
%HEL	88.2	87.0
	66.7 – 107.2	77.9 – 92.8
γ-HCH (lindane)	0.38	0.30
	n.d. – 0.92	n.d. – 0.6
E.EPOX	0.23	0.28
	n.d. – 1.23	n.d. – 0.99
DDE	11.87	15.9
	1.16 – 36.47	1.23 – 33.83
Dieldrin	1.90	2.12
	0.47 – 5.15	0.54 – 5.27
PCB	16.95	28.68
	n.d. – 47.68	8.42 – 64.19

n.d. not detectable. Detection limits as follows: 0.005 µg γ-HCH/g, 0.01 µg DDE/g, 0.01 µg dieldrin/g, 0.05 µg PCBs/g.

4.5.2 Polychlorinated biphenyls

Polychlorinated biphenyls were first introduced in the 1920s and used for many industrial purposes, including transformer oils, window sealants, and hydraulic, drilling and heat-exchange fluids. Over the years other organochlorines have been introduced as herbicides (Agent Orange), pesticides (DDT, aldrin, chlordane, lindane, toxaphene and dieldrin) and fire retardants (Mirex and brominated diphenyls). These synthetic chemicals have provided considerable short-term gains in industrial applications and in the control of insect pests and vectors of disease. However others, such as dioxins and furans, have no commercial applications and are by-products of industrial processes, particularly those involving combustion; these are highly toxic substances even in minute quantities. Their danger to human and environmental health was first recognised in the 1960s, but the full seriousness of their toxicity only emerged after dioxins were released during the Seveso accident in 1976. A voluntary ban on the supply of PCBs was introduced in the US and UK in 1986, but this did not cover the use of existing equipment containing PCBs. Even so, much of the equipment containing PCBs has been phased out by the offshore industry. Before these restrictions were introduced, about 2 million tonnes of PCBs had been manufactured (de Voogt and Brinkmann, 1989), about 30% of which is now in the environment. About 4% has been degraded or incinerated and the remainder is either still in use or in some form of storage. Many appliances containing PCBs remained in use after the ban (OECD, 1987); so the amounts in the environment may still be increasing. There is a substantial disparity between the quantities of PCBs reaching the northern and southern hemispheres, with the North Atlantic receiving a proportionally larger input *(Table 4.11)*. These semi-volatile compounds are carried in the atmosphere to high latitudes where they ‘condense’ out (Wania and Mackay, 1993). Atmospheric inputs to the OSPAR area are estimated to be about 20 t/yr; Region V receives inputs via the prevailing winds from the American continent.

PCBs are the most abundant of the chlorinated aromatic contaminants in the marine ecosystem. Being both lipophilic and resistant to degradation, they bioaccumulate (Fowler, 1990). Marine mammals have a low ability to metabolise PCBs and some species carry very high loads *(Table 4.10)*. In mammals PCBs induce pathological changes in reproductive organs and cycles, which tends to depress their reproductive potential. They also depress the immune system, which is thought to have contributed to the severity of the 1988 epizootic plague in seals in North-west Europe (e.g. Harwood and Reijinders, 1988). Baleen whales, which feed on zooplankton and have relatively low metabolic rates, carry relatively small organochlorine loads. Sperm whales, which feed on deep-water squid have intermediate loads, whereas the predatory dolphins, which feed closer to the surface, carry higher loads. Species that stay in waters where contamination is low, carry smaller burdens than those, like pilot whales, that migrate regularly into more polluted areas. Females are less contaminated than males because they transfer some of their PCB load to the developing foetus during pregnancy.

Analyses of blubber from long-fin pilot whales (*Globiocephala melaena*) caught in the Faroe Islands *(Table 4.10)*, and from some other whale species from the North-east Atlantic *(Table 4.12)*, show concentrations with a wide range of variability that are difficult to interpret.

4.5.3 Polycyclic aromatic hydrocarbons

Polycyclic aromatic hydrocarbons are aromatic compounds with two to eight rings produced during combustion, and some occur in crude oil. Some are released during forest and bush fires, but most come from condensation of hydrocarbon fragments during the burning of fossil fuels. Anthropogenic inputs are now reported to be globally well in excess of natural inputs (Lipiatou *et al*., 1997). The low molecular weight PAHs occur in the vapour phase in the atmosphere. They dissolve in sea water and are degraded microbially, both in the water and at the water/sediment interface. In contrast, high molecular weight PAHs are mostly associated with particles, both in sea water and in the atmosphere. Atmospheric concentrations of PAHs peak during winter when their emissions are at their highest, and atmospheric mixing heights are reduced. Their concentrations are also higher in the plumes spreading downwind of industrial centres. In aerosols, concentrations occur in the order – benzofluoranthenes > fluoranthenes = chrysene > pyrene > benzo[*e*]pyrene = phenanthrene. Some PAHs are metabolised into reactive and toxic intermediaries; benzo[*a*]pyrene, for example, is converted into compounds that bind directly with DNA and are powerful carcinogens. The high variability in the concentrations of these compounds and their complex structures makes their monitoring a difficult problem (Topping, 1997).

A variety of PAHs have been identified in sea water *(Tables 4.13* and *4.14)*, most of which are associated with particles. Concentrations of PAHs such as naphthalene, anthracene, pyrene, chrysene + triphenylene, fluoranthene, acenaphthene, phenanthrene and

Table 4.11 Estimated total deposition and mean fluxes of organochlorines into the North Atlantic, the South Atlantic and the Global Ocean. Source of data: Duce *et al*. (1991).

	North Atlantic		South Atlantic		Global Ocean	
	total deposition (t/yr)	mean flux (µg/m^2/yr)	total deposition (t/yr)	mean flux (µg/m^2/yr)	total deposition (t/yr)	mean flux (µg/m^2/yr)
ΣHCH	850	16	97	1.9	4800	13
HCB	17	0.31	10	0.2	77	0.23
Dieldrin	17	0.3	2	0.04	43	0.11
ΣDDT	16	0.28	14	0.27	170	0.44
Chlordane	8.7	0.16	1	0.02	22	0.06
ΣPCB	100	1.8	14	0.27	240	0.64

Table 4.12 Concentrations of DDT derivatives and PCBs in the blubber of whales and dolphins from the North-east Atlantic. Source of data: Borrell (1993).

	Location		Lipid (g/kg)	*p,p'*-DDE	*p,p'*-TDE	*o,p'*-DDT	*p,p'*-DDT	∑*p,p'*-DDT
fin whale	Iceland	male	775	0.49	0.18	0.43	0.19	0.85
		female	690	0.34	0.12	0.31	0.15	0.61
sei whale	Iceland	male	572	0.21	0.09	0.18	0.1	0.4
		female	678	0.05	0.03	0.05	0.03	0.11
sperm whale	Iceland	male	403	4.16	1.1	2.43	2.54	7.8
long-fin pilot	Faroe	male	772	20.23	4.5	8.44	6.66	31.39
whale	Islands	female	770	7.97	1.89	3.6	3.53	13.4
white-sided	Faroe	male	803	15.63	3.33	9.19	3.49	22.46
dolphin	Islands	female	837	10.32	2.33	5.71	2.33	14.97
harbour	Faroe	male	865	3	1.31	0.98	1.26	5.57
porpoise	Islands	female	940	2.12	0.94	0.66	0.72	3.78

chrysene-triphenylene are several times higher in the North Sea than in the open North Atlantic, and from their distributions oil installations are clearly the source. So as offshore development gets underway in the open Atlantic, similar increases in environmental PAH concentrations are likely. The Mediterranean acts as a net source of PAHs; about 33 t are lost via the flow of Atlantic water into the Mediterranean, but 53 t are introduced via the Mediterranean outflow (Lipiatou *et al*., 1997).

4.5.4 Other persistent organic compounds

High latitude condensation has also been suggested as the mechanism whereby large amounts of lindane (γ-HCH) are reaching the Arctic (Oehme, 1991). Jansson *et al*. (1993) identified 31 halogenated compounds that need to be monitored around Sweden (see also AMAP, 1997). These compounds will all be reaching Region V via the outflows of water from the Norwegian Sea. Amongst these compounds is toxaphene, a complex mixture of camphenes used as a pesticide. Although its use is banned in most European countries, it still occurs in detectable quantities in the Baltic. Its most likely source is as one of the pesticides applied to the cotton fields in the Caribbean (Johnston *et al*., 1996). This exemplifies how bans on the local regional use of some of these persistent organic contaminants will not necessarily eliminate them from the North Atlantic, if they continue to be used in other countries (Voldner and Li, 1995). Another factor is the time it takes for some of these highly persistent chemicals to be removed from marine environments, for example DDT and HCH derivatives are still detectable in the North Atlantic despite their use being curtailed for several years.

Dioxins are a group of about 210 structurally-related compounds (chlorinated dioxins and dibenzofurans) that are by-products of industrial processes involving chlorine (i.e. the production and use of chlorine gas, bleaching and disinfecting water, use of organochlorine compounds, incineration and the burning of PVC). Dioxins first appear in lake sediment cores dating from the 1920s. Even in trace quantities dioxins are extremely toxic, so their monitoring is a major technical challenge.

4.6 **Multiple chemical inputs**

The main sources of multiple chemical inputs are mariculture and the offshore hydrocarbon industry. At present these have little impact in Region V, but an expanding hydrocarbon industry should be monitored.

4.6.1 Endocrine disruption

One of the latest developments in ecotoxicology is the recognition of endocrine disruption by anthropogenic contaminants (Stone, 1994). The impact of DDT and its

PCB	% DDE/$\Sigma p,p'$-DDT	%$\Sigma p,p'$-DDT/PCB
1.26	56.2	66.8
0.94	55.8	64.2
0.46	48.8	80.1
0.18	43.2	56
10.51	53.4	75
48.81	61.3	64
26.27	53.1	42.9
42.68	64.8	49.2
25.34	58.6	46.6
13.39	54.5	42.6
8.83	56	43

derivatives was recognised in the 1960s and was the first indication of how anthropogenic inputs, especially of synthetic organic compounds, had the potential to interfere with normal physiological activity. The induction of imposex in dogwhelks (*Nucella lapillus*) by TBT used in marine antifouling paints focused attention on the physiological effects induced by many synthetic organic compounds and the products of petrol combustion (including PAHs and their metabolites, PCBs, dioxins, phthalates and the breakdown products of organochlorines such as alkyl phenols). Some of these substances have oestrogenic effects, which are often synergistically magnified by the presence of other contaminants (Henderson, 1996).

Colborn *et al*. (1993) published a list of chemicals known to disrupt reproductive and other endocrine functions *(Table 4.15)*. In terms of effects, many of these compounds may be enhanced if they occur in combinations. Research is currently concentrated on their impacts on human health, but their impacts on wild populations also needs to be studied. One mechanism whereby some of these compounds act, is by binding with the cytosolic aryl hydrocarbon receptor protein (Ah), which underpins a substantial number of biochemical pathways (Hansen and Shane, 1994), including hormone metabolism (Seegal *et al*., 1991). Geisy *et al*. (1994) identified twenty-two groups of halogenated compounds whose toxicological action may be mediated through their effects on the Ah receptor system.

Table 4.13 PAH concentrations (ng/l) in the North-east Atlantic at 37º N between 15º W and 17º W. Source of data: OSPAR.

	Mean	Range
Naphthalene	0.17	0.1 – 0.26
C1-naphthalenes	0.2	0.11 – 0.29
C2-naphthalenes	0.22	0.13 – 0.31
Acenaphthene	0.03	0.02 – 0.05
Acenaphthylene	0	0.0 – 0.0
Anthracene	0	0.0 – 0.0
Fluorene	0.04	0.02 – 0.05
Phenanthrene	0.14	0.08 – 0.21
C1-phenanthrenes	0.07	0.05 – 0.09
Dibenzothiophene	0.02	0.01 – 0.03
C1-dibenzothiophenes	0.03	0.02 – 0.04
Dibenzothiophene	0.05	0.04 – 0.05
Pyrene	0.03	0.02 – 0.03
Benz[*a*]anthracene	0	0.0 – 0.0
Chrysene-Triphenylene	0.01	0.01 – 0.01
Benzo[*b*]fluoranthene	0	0.0 – 0.0
Benzo[*k*]fluoranthene	0	0.0 – 0.0
Benzo[*e*]pyrene	0	0.0 – 0.0
Benzo[*a*]pyrene	0	0.0 – 0.0
Perylene	< 0.001	< 0.001 – < 0.001
Di-benz[*a,c*]anthracene	< 0.001	< 0.001 – < 0.001
Indeno[1,2,3-*cd*]perylene	0	0.0 – 0.0
Benzo[*ghi*]perylene	0.01	0.0 – 0.01
Coronene	0.01	0.0 – 0.01

Table 4.14 Dissolved and particulate PAH concentrations (pg/l) in the North Atlantic. Source of data: Lipiatou *et al*. (1997).

	Dissolved	Particulate
Phenanthrene	400	1.8
Fluoranthrene	110	1.9
Pyrene	74	1.3
Benz[*a*]anthracene	6	0.5
Chrysene + Triphenylene	2	1.8
Benzofluoranthenes	7.5	2.5
Benzo[*e*]pyrene	1.6	0.5
Benzo[*a*]pyrene	1.5	0.5
Benzo[*ghi*]perylene	0.4	0.5
Indeno[1,2,3-*cd*]pyrene	0.4	0.5
Total PAHs	620	12

4.7 Hydrocarbons

There are natural seepages of hydrocarbons into the Atlantic, as well as emissions from vessels and now the expanding hydrocarbon industry. The recent rounds of licensing areas for hydrocarbon exploration in UK and Irish waters included deep water areas around Rockall, Porcupine Bank and the Southwest Approaches. Exploitation of resources to the west of the Shetland Islands has become possible as a result of technical developments allowing operations to continue in all but the most extreme weather and sea conditions. At present the decline in oil prices and the high costs of operating offshore are slowing the rates at which these offshore reserves are being developed. However, these delays will probably be temporary and ultimately the reserves will be exploited. Concerns have been expressed about the likely impacts of these developments on the ecosystems of the continental slopes. These slope waters are frequented by small numbers of endangered marine mammals (e.g. blue whales (*Balaenoptera musculus*) and humpback whales (*Megaptera novaeangliae*)) and the shelf-break front is an important seasonal feeding ground for oceanic seabirds. It is probable that whales are sensitive to seismic activity and that there will be some interference with fishing activities. Even so, experience in the North Sea suggests that with careful and sensitive environmental management the impacts can be kept from having a serious and persistent impact on the general ecology of the area.

Operations, especially the discharging of drilling fluids, will cause increases in the local turbidity of the water. Concerns have focused on the deep-water corals *Lophelia pertusa* and *Madrepora* spp. These corals are associated with carbonate mounds (or bioherms, see *Figure 6.1*) and even form reef-like structures in some Norwegian fjords. They occur scattered along much of the North Atlantic margin wherever there are rocky substrates, strong current regimes and water temperatures of 4 – 8 ºC at depths of 30 – 1000 m. These coralline zones are inhabited by over 800 species, although none appear to be specifically associated with the coral. Such species richness is high but not unusual in benthic communities within the geographical and bathymetric range of these corals.

Most major oil spills that occur during transportation take place in shallow waters, as a result of groundings or collisions, where they cause major pollution. Over deep water their impact is less serious and their clean-up is usually left to natural weathering processes. The more volatile (and toxic) components rapidly distil off, and where the wind and wave regimes are highly dynamic the slicks are broken up, accelerating microbial degradation, particularly if the surface waters are rich in nutrients. Floating tar balls, especially those which have been weathered, are a resource for some of the fauna associated with the air/water interface. Goose barnacles such as *Dosima fascicularis* and *Lepas pectinata* (Minchin, 1996) settle on them and ocean striders (*Halobates* spp.) lay their eggs on them.

4.8 Radionuclides

Traces of radionuclides occur naturally in the oceans, generated by cosmic radiation, inputs from the weathering of continental rocks and volcanic activity, and atmospheric inputs resulting from the ^{238}U decay series *(Table 4.16)*. Nuclear weapons tests have added 4 – 5 t

Table 4.15 Chemicals in common use known to have endocrine-disrupting effects. Source: Colborn *et al*. (1993).

Herbicides			
2,4-D	Alachlor	Atrazine	Nitrofen
2,4,5-T	Amitrole	Metribuzine	Trifluralin
Fungicides			
Benomyl	Mancozeb	Tributyltin	Ziram
Hexachlorobenzene	Metiram-complex	Zineb	
Insecticides			
α-HCH	DDT (metabolites)	Methomyl	Parathion
Carbaryl	Endosulfan	Methoxychlor	synthetic pyrethroids
Chlorodane	Heptochlor	Mirex	Toxaphene
Docofol	Lindane	Oxychlordane	Transnonachlor
Dieldrin			
Nematocides			
Aldicarb	DBCP		
Industrial chemicals			
Cadmium	Mercury	Pentachlorophenols	Phthalates
Dioxin	Polybrominated biphenyls	Penta- to Nonylphenols	Styrenes
Lead	Polychlorinated biphenyls		

Table 4.16 Background concentrations of radioisotopes in sea water (Bq/m^3).

Origin	Isotope	Concentration
Primordial	^{40}K	12 000
	^{87}Rb	110
	^{234}U	46
	^{226}Ra	40
	^{210}Pb	3.5
	^{235}U	3
	^{210}Po	2.2
Cosmogenic	^{14}C	6
	^{3}H	100

of plutonium to the environment and discharges from Sellafield and La Hague have been estimated to have added a further 300 and 1.5 kg respectively (NATO, 1995), although UK authorities estimate the Sellafield output to have been 182 kg. The total inventory of ^{239,240}Pu in the world's oceans is reported to be around 16 x 10^{15} Bq (Baxter *et al*., 1995). The Chernobyl accident in 1986 released large quantities of ^{131}I, ^{137}Cs and ^{134}Cs, together with other radionuclides, although only ^{137}Cs and ^{134}Cs reached the Atlantic Ocean in detectable concentrations via the Baltic Sea outflow. Current anthropogenic sources are mostly land-based discharges from reprocessing plants, but there are also inputs as a result of accidents during transportation and leakage from the old dump sites and wrecks of nuclear-powered vessels (see Section 3.9.3). Apart from the inputs from the reprocessing of wastes, there is no evidence that any of these inputs have significantly increased the exposure of human populations to radiation. Similarly no damage to marine ecosystems has been demonstrated.

According to a detailed report by the OECD (1985) the main radioactive waste dump site in the North-east Atlantic poses a negligible risk in terms of human impact. Numerous investigations have been performed in the dump site area and in reference areas where no waste has been dumped (OECD, 1990). At the time, the only radioactive contamination detected in organisms within the water column had originated from atmospheric tests of nuclear weapons (Feldt *et al*., 1981). Later investigations of both the water column (Nies, 1988, 1989) and of the pelagic and benthic fauna (Feldt *et al*., 1985, 1989) came to similar conclusions. However, in a more recent study by Baxter *et al*. (1995) biota at the waste dump site in the North-east Atlantic were found to be slightly contaminated with plutonium. They concluded that part of this plutonium could have originated from the containers, thus not only from the fallout. Since the survey indicated extremely low concentrations, the measurements are of considerable uncertainty. The only ecological studies carried out have been some photographic surveys which found no evidence of impact other than the drums being used as settlement sites by deep-sea anemones (Sibuet *et al*., 1985; Sibuet and Coic, 1989). Models of the spread of isotopes indicate that beyond the immediate vicinity of the disposal site (the near-field) the radiological dose rates to marine organisms generally remain within the range of the natural background dose rates, and hence can be expected to be having no effect at the population level. The modelled radiological dose rates did approach the upper limit of the natural background dose rates in molluscs.

Since the introduction of the moratorium on radioactive waste disposal in 1983 (*Table 4.17* summarises radiaoctive wastes dumped in the North-east Atlantic between 1969 and 1982), there has been some monitoring of plutonium and ^{137}Cs concentrations in water, sediments and fish (Kanisch, 1993). The ratios of the plutonium isotopes give an indication of the source. Because plutonium is almost entirely man-made, virtually all the inputs are anthropogenic and originate from the atmospheric testing of nuclear weapons, satellite power sources (^{238}Pu) or from nuclear fuel reprocessing (Buesseler, 1986). Weapons testing was mostly conducted in the northern hemisphere, so inventories of ^{239,240}Pu fall-out vary with latitude, e.g. inventories are almost an order of magnitude higher at 40º N than on the equator or at the poles. Additionally, in the North-east Atlantic, 592 x 10^{12} Bq of ^{239,240}Pu have been released from the Sellafield nuclear reprocessing plant, most of which is still within the Irish Sea (i.e. within Region III). Buesseler (1986) found that at the time inventories of plutonium declined with depth, so that in the 1980s only about 24% of fallout had reached the sediments. ^{240}Pu/^{239}Pu ratios decrease with increasing depth being

Table 4.17 Radioactive wastes dumped in the North-east Atlantic under NEA/ENEA supervision, 1969–82. Source of data: OECD (1985).

	Gross tonnage	α-emitters	Radioactivity (TBq)	
			ex-tritium	tritium
1969	244	-	12.62	-
1971	375	0.07	12.95	-
1972	508	0.22	14.8	7.1
1974	508	0.59	142.12	67.41
1975	202	0.89	26.83	15.73
1976	349	0.56	9.36	17.5
1977	450	0.7	24.57	13.54
1978	733	1	150.66	14.43
1979	409	0.003	5.14	-
1980	301	0.06	27.64	1876.31
1981	404	0.57	72.89	1324.86
1982	847	0.29	147.09	499.43
TOTAL			646.67	3836.31

about 0.18 on the shelf (typical of stratospheric fallout linked to particles < 1 µm which accounts for > 80% of the worldwide fallout) and falling to 0.1 at 5000 m (typical of the fallout resulting from near-ground testing). Early tests gave $^{240}Pu/^{239}Pu$ ratios of > 0.3. Tests by the USSR, which resulted in about 75% of all fallout, resulted in $^{240}Pu/^{239}Pu$ ratios of 0.18. Buesseler (1986) reported ratios of 0.16 and 0.15 in the North-east Atlantic. Pentreath (1988) suggested that $^{238}Pu/^{239,240}Pu$ ratios of 0.04 are characteristic of global fallout so ratios that are higher imply the source is not nuclear weapon testing. Buesseler (1986) found that the annual net diffusive flux of plutonium out of the sediments is occurring at extremely slow rates, 0.2 – 24 x 10^{-5} dpm $^{239,240}Pu/cm^2$. However, at millennial time scales such slow remobilization rates may become significant.

There has been some monitoring in the vicinity of sunken nuclear-powered and armed naval vessels. Only one such loss occurred in Region V; a soviet November Class submarine sank 480 km north-west of Spain in 4700 m of water in April 1970. Just outside Region V, 650 km south-west of the Azores, the US submarine Scorpion sank in 3100 m of water in May 1968 (NATO, 1995). At the latter site traces of ^{60}Co, produced by activation of steel near the reactor and released by corrosion, have been detected in nearby sediments. Generally, radiological monitoring has shown that the leakage of radioisotopes from these wrecks and others (such as the Komsomolets at 73º 43’ N, 13º 17’ E, south of Bear Island) has been very limited and has been spreading very slowly. No monitoring of seabed communities, other than measuring contaminant levels, has been conducted in the vicinity of any of these wrecks; so whether or not there has been any environmental impact has not been determined. There have been other substantial inputs of anthropogenic radioactivity into the marine environment, notably the major release of caesium which followed the Chernobyl accident, and releases from nuclear reprocessing plants that have been progressively reduced.

4.9 Nutrients and oxygen

4.9.1 Nutrients

Concentrations of nutrients, namely nitrate, phosphate and silicate, in the oceanic waters of Region V are generally lower than in other oceans (Levitus *et al*., 1993; Lozier *et al*., 1995). The water masses that flow into the region contain relatively low concentrations of nutrients. Also, because the deep waters are relatively ‘young’ (i.e. they have been at the surface relatively recently), they contain relatively small concentrations of nutrients regenerated from the remineralisation of sedimentary particles. Thus, despite the comparatively great depths to which winter cooling overturns and vertically mixes the water column in the North-east Atlantic, particularly in the area to the west of the Bay of Biscay, overall productivity is not as high as in the North Pacific. Neither eutrophication nor the development of ‘red-tide’ blooms of harmful algae are likely to be induced in these open ocean waters.

Riverine inputs of nutrients are mostly removed by biological activity in estuaries and inshore waters, so further offshore the aeolian inputs assume greater importance (Duce *et al*., 1991). These diminish downwind, but are still estimated to be providing up to 17% of the nitrogen available in the upper ocean in the subtropical waters to the south of Region V. Some examples of estimated atmospheric inputs of nitrogenous substances to areas associated with Region V are shown in *Table 4.18*. The main anthropogenic inputs of nitrogen are NO_x from industrial combustion and car exhausts, HNO_3 also from car exhausts, industrial fixation of nitrogen in the manufacture of fertilisers and ammonia emissions from intensive stock farming and the extensive growth of leguminous plants. Globally these anthropogenic sources of nitrogen now exceed natural sources (Vitousek, 1994). Background levels of dissolved inorganic nitrogen (DIN) are probably similar to those observed in the Southern Ocean i.e. ~ 6 µmol $N/m^2/d$.

4.9.2 Oxygen

Dissolved oxygen concentrations in the water column of the wider Atlantic region never fall low enough to limit the distribution of aerobic organisms (Mantyla and Reid, 1983). The lowest levels encountered, > 4 ml/l, occur at the oxygen minimum which is located close to the density surface $\sigma_1 = 31.85$ and occurs where the water is oldest at the base of the permanent thermocline, i.e. at depths of about 900 m (Lozier *et al*., 1995). Similarly the upper layers of most sediments of pelagic origin are well ventilated and hence contain sufficient oxygen to support aerobic respiration by benthic species. Within all sediments there is a depth at which conditions switch from being oxidising to reducing. This shift (in Redox potential) affects the mobility of many metal ions, which are generally more mobile when reduced; for example, ferrous ions are more soluble and more mobile than ferric

Table 4.18 Atmospheric nutrient fluxes (g $N/m^2/yr$) in areas bordering the North-east Atlantic. Source of data: Duce *et al*. (1991).

	Position	Nitrate	Ammonium	Total N flux
Portugal	37° N, 8° W	0.043	0.036	0.079
UK	50° N, 5° W	0.218	0.212	0.43
Ireland	52° N, 10° W	0.146	0.166	0.312
Faroe Islands	61° N, 7° W	0.263	0.174	0.437

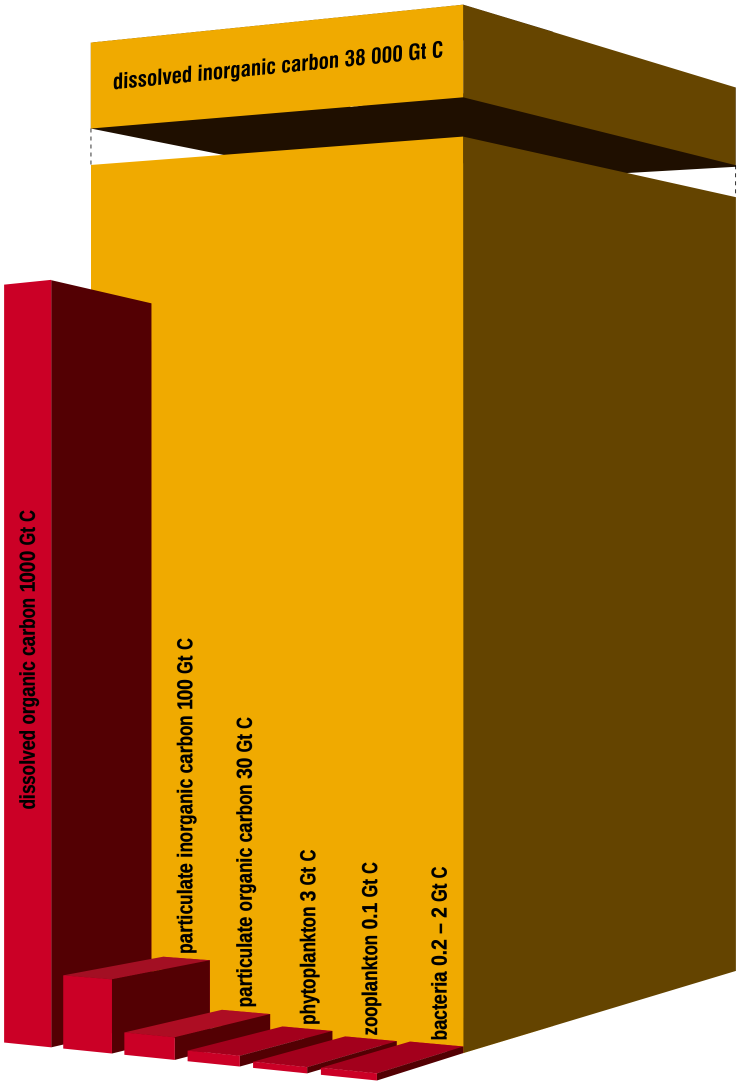
ions. Only where organic sedimentation rates are very high, does this Redox boundary move close enough to the sediment surface to influence biological activity and chemical exchanges across the water/sediment interface.

4.10 Carbon dioxide

Between 1860 and 1986 the burning of fossil fuels added an estimated 195 ± 20 Gt C to the atmosphere and another 117 ± 35 Gt have been added as a result of deforestation (Edmonds, 1992). About 50% of these emissions still remain in the atmosphere (Siegenthaler and Sarmiento, 1993). The result being that CO_2 concentrations in the atmosphere have increased from the pre-industrial pCO_2 levels of 280 μatm, to the current (1998) levels which exceed 360 μatm. However, atmospheric CO_2 concentrations have been very much higher in the geological past, for example during the Cretaceous Period (140 – 65 million years ago) atmospheric pCO_2 was several thousands of μatm and 60 million years ago was 700 μatm (Schneider and Müller, 1995). Present annual rates of input are just over 7 Gt C (Siegenthaler and Sarmiento, 1993), about 50% of which are being sequestered in the deep ocean. The atmospheric inventory of carbon is about 770 Gt – note that 25% by weight of CO_2 is carbon (Wong and Hirai, 1997) – but this is minute compared with the inventory of the major carbon pools in the oceans *(Figure 4.6)*.

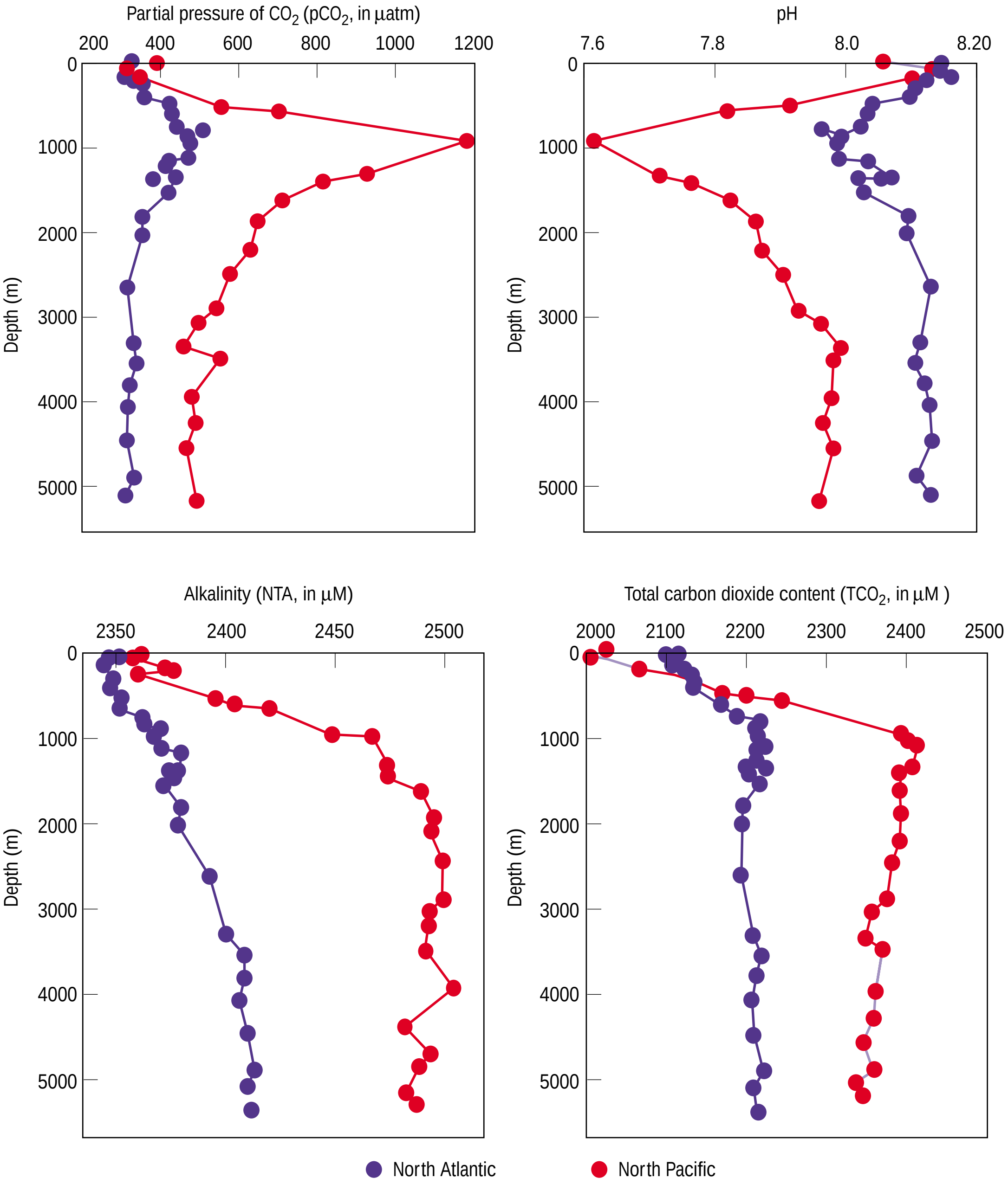
The burning of fossil fuels has already increased atmospheric concentrations of CO_2 by about 50%. World population growth rates, and the concomitant increases in

Figure 4.6 **Schematic representation of the major carbon pools in the deep ocean. Source of data: Wong and Hirai (1997).**



1 Gt C = 10^{15} grammes carbon

Figure 4.7 **Bathymetric profiles of pCO_2, pH, alkalinity and TCO_2 in the North Atlantic and North Pacific. Source: Wong and Hirai (1997).**



energy demand, are predicted to result in all presently known reserves of fossil fuels being burnt within the next 150 to 200 years. In the absence of any successful remedial action CO_2 concentrations in the atmosphere will transiently rise to a peak four-times that of the pre-industrial levels. Assuming that there is no disruption to the processes presently sequestering CO_2 in the deep ocean (see Section 4.3.2), it will take about two million years for the ocean and atmosphere to re-equilibrate, with atmospheric concentrations then being double pre-industrial levels. The oceans are currently absorbing about 2 Gt of CO_2 a year, but as yet, no changes in ocean climate have been attributed unambiguously to these increases. The potential for CO_2 emissions to change the climate has been extensively documented (Houghton *et al*., 1996). Global climate models predict a 40% decrease in the strength of the North Atlantic thermohaline circulation. There have been changes in the rates of deep-water formation in the East Greenland Sea recently, which have been linked, via a consequential weakening in the strength of the Gulf Stream, to a major shift in the phytoplankton ecology of the North Atlantic around 60º N (Reid *et al*., 1998). However, it remains arguable as to whether or not these shifts are the results of normal climatic fluctuations.

Concerns about climate change have distracted attention away from other profound changes that are likely. As it dissolves in sea water, most of the CO_2 converts into bicarbonate ions. The bicarbonate buffers sea water against pH changes; its buffering potential being measured as ‘alkalinity’. As more CO_2 dissolves the pH will drop, and it has already been estimated that anthropogenic emissions have decreased pH in the upper ocean by 0.1 unit (Siegenthaler and Sarmiento, 1993). A four-fold increase in atmospheric CO_2 concentrations will reduce the pH of the upper ocean from its present level of 7.8 – 8.0 to ~ 7.5. While this is well above any lethal limit for phytoplankton species, it may alter the competitive balance between the various phytoplankton species and so result in some unexpected changes in ocean ecology. Moreover, species using carbonates for their skeletal structures, such as corals, will find it increasingly difficult to form their skeleton. Phytoplankton communities may be altered in much the same way that the competitive balance will be changed between C_3 and C_4 terrestrial plants (i.e. between those plants that use CO_2 as the source of carbon for photosynthesis and those that use bicarbonate ions). If such changes have a proportionally greater impact on diatom communities (which are the main exporters of production according to Dugdale and Wilkerson (1997)) than on picoplankton assemblages, the biological pump may be adversely affected.

There are marked differences in the alkalinity of the deep waters of the North Atlantic and the North Pacific, which reflect the relative ‘ages’ of the deep waters ***(Figure 4.7)***. The lysocline (see Section 2.4.3) is substantially shallower in the Pacific than in the Atlantic, so as more CO_2 reaches Region V the lysocline can be expected to shoal. In the North Atlantic, the region that coincides with the formation of NADW to the north of 42º N, is estimated to be taking up 0.2 – 0.5 Gt C annually, i.e. 5 – 10% of the fossil fuel emissions (Takahashi *et al*., 1993). Any reductions in deep water formation will slow the rate of uptake by the global ocean via the solubility pump. The creation of conditions with high concentrations of CO_2 will affect pelagic and benthic species by disrupting their physiological performances and general fitness. How such changes may be translated into ecological responses within the oceanic communities and the performance of commercially exploited species can not at present be predicted and needs to be investigated (Omori *et al*., 1998). The physiological performance achieved by highly active predators, such as squid, is dpendent upon blood pigments that are highly sensitive to the internal pH of the organism (Pörtner, 1997; Pörtner and Zielinski, 1998). Reductions in environmental pH may adversely affect these species and hence the structure and function of pelagic ecosystems.

chapter 5

Biology

5.1 Introduction

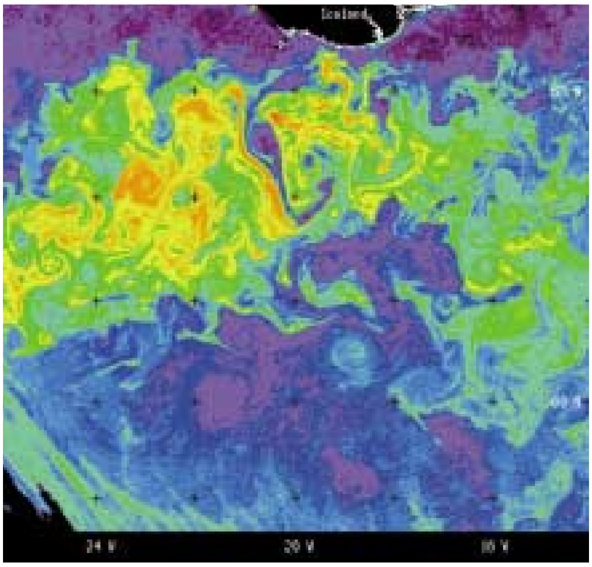
The characteristics of primary production subdivide the region into two biogeographical provinces (Longhurst, 1995). To the north of 40º N, the deep mixing of the water column during winter and its stratification in summer results in a strong seasonal production cycle. Whereas to the south, the upper water column stays stratified throughout the year so that annual productivity is both lower and less variable seasonally. This results in major differences in ecology both in the pelagic and the benthic realms. Biological activity is almost totally dependent on production in the upper few tens of metres that receive sufficient sunlight to support photosynthesis. Chemosynthesis at hydrothermal vents and cold seeps provides a small supplementary source at highly localised areas of the seafloor (see Section 5.2.13). Apart from chemoautotrophic organisms, below the euphotic zone all living systems depend ultimately on inputs of organic matter sinking or being transported down through the thermocline. Except around the coastal fringes of the Azores, all benthic communities in Region V inhabit depths that are too deep for them to be directly supported by photosynthesis.

5.2 **Overview of the ecosystem**

5.2.1 Primary production

Photosynthetic rates are regulated by *in situ* light intensities and the concentrations of available nutrients. North of 40º N, the upper ocean is stirred by storms and deep convection during the winter. This ensures a plentiful supply of nutrients to the surface layers, but also mixes the phytoplankton to depths where there is too little light for them to photosynthesise. The brief hours of sunlight and the sun's low azimuth also contribute to primary production being limited by a lack of light. In spring, as the days lengthen and the sun climbs higher in the sky, the surface of the ocean begins to warm. Once the surface waters are > 0.2 ºC warmer than the deeper water, they stratify. Since nutrients are plentiful, light is no longer limiting and the phytoplankton are no longer being mixed down, growth rates accelerate and the plant biomass increases to 'bloom' dimensions. However, this spring bloom is short-lived. The nutrients in the water above the thermocline are soon exhausted and because they are no longer replenished by vertical mixing, the bloom crashes. Phytoplankton cells, particularly those of diatoms, flocculate into large aggregates (known as marine snow) which sink rapidly into deep water. Throughout the summer conditions remain oligotrophic and the phytoplankton community becomes dominated by picoplankton, mostly tiny flagellates < 2 µm in size. These conditions persist until autumn when the stratification starts to be disrupted by equinoctial storms and atmospheric cooling. After the first autumnal storms there is usually another brief bloom, which is soon curtailed as full winter conditions set in. Thus, in the North-east Atlantic the temperate cycle is dominated by oscillations between stratified and unstratified conditions with phytoplankton blooms occurring at the times of changeover (Campbell and Aarup, 1992). Towards high latitudes, the timings of these two blooms converge, so that in the Nordic Seas there tends to be a single midsummer bloom. However, during summer to the south of Iceland, immense blooms of the coccolithophorid *Emiliana huxleyi* occur regularly (Holligan *et al*., 1993). The cells of *E. huxleyi* contain tiny calcium carbonate structures (liths) which are highly reflective to visible light and so the blooms are clearly visible in satellite images ***(Figure 5.1)***. During such blooms the coccolithophorids release large amounts of dimethyl sulphide (DMS) into the atmosphere, which acidifies rain and results in increased cloud cover. These blooms may persist for over three weeks and extend over an area $> 10^6$ km^2 north of 55º N. The 1991 bloom was estimated to release 1122 nmol DMS/m^2/hr and to have removed about 1 million t C from the upper ocean as carbonate. However, this carbonate will have increased pCO_2 in the surface waters by 50 µatm, so on balance the ocean will have de-gassed carbon dioxide back into the atmosphere (see Section 4.10).

Figure 5.1 **NOAA-11 satellite image taken on 17 June 1991 showing a vast bloom of the coccolithophorid *Emiliana huxleyi* to the south of Iceland. Source: S. Groom CCMS.**

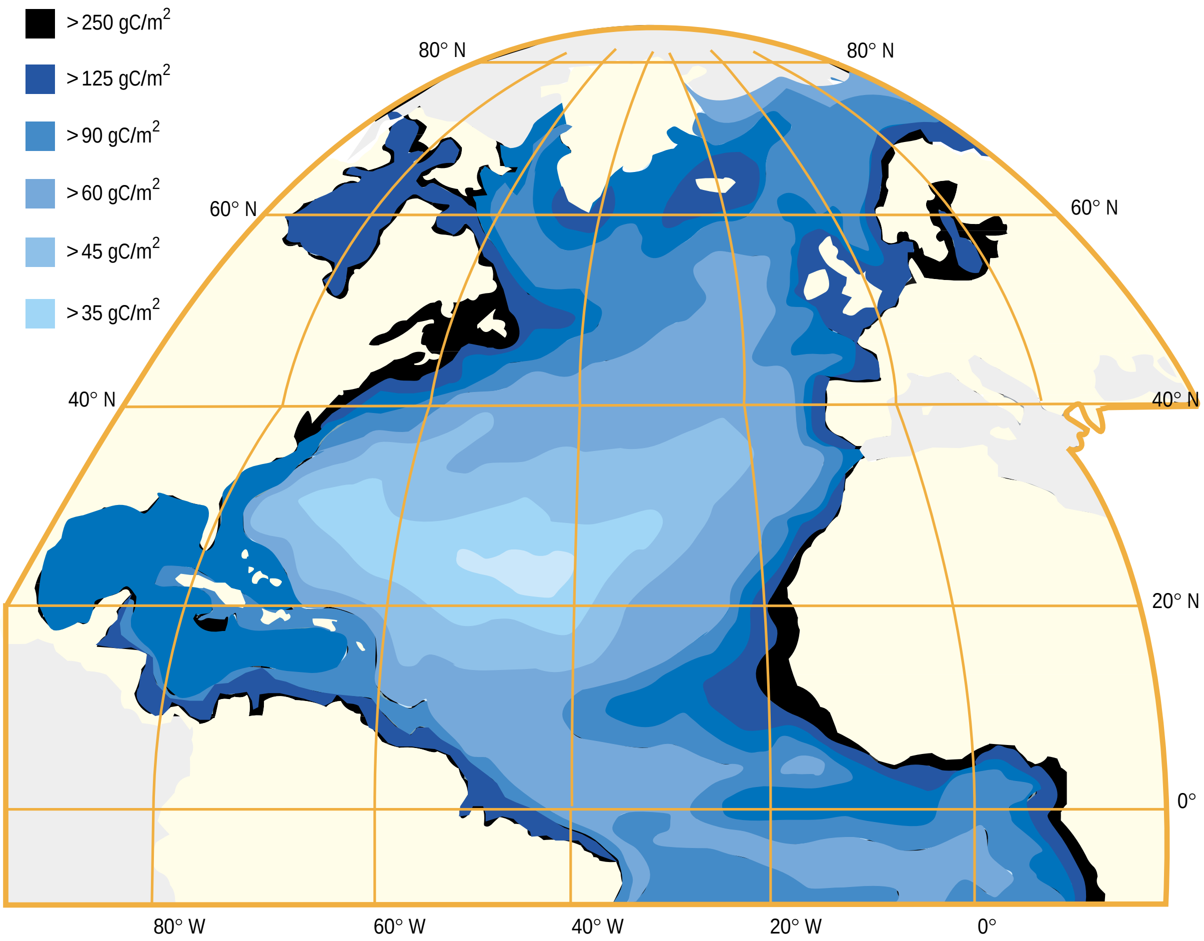


South of 40º N, productivity is less seasonal, reaching a small maximum in winter. The upper ocean remains stratified throughout the year so conditions are persistently oligotrophic. Mean annual productivity is about half that of the northern sector (see Section 5.2.2) and a greater proportion is recycled within the euphotic zone. Hence fluxes of organic matter into deep water are much lower (Lampitt and Antia, 1997). Longhurst (1995) divided the World's oceans into 55 biogeochemical provinces based on data from remote sensing, the climatology of sea surface temperatures and nutrient concentrations. He identified the boundary at 40º N, noting that it coincided with a classical zoogeographical boundary. Thus the productivity regime plays a key role in regulating the large-scale distributions of pelagic species, and probably also those of the benthos. Phytoplankton growth is stimulated locally wherever nutrient-rich subthermocline waters are brought up into the surface layers (upwelled). This occurs along the fronts that bound mesoscale eddies and where shallow seamounts disrupt current flow (see Section 2.4.5).

5.2.2 Quantification of productivity

Productivity in the North Atlantic is generally lower than in the North Pacific. The water masses at intermediate depths in the North Atlantic are relatively young (i.e. were at the surface more recently) and so contain lower concentrations of regenerated nutrients (Lozier *et al*., 1995). Maps of total annual productivity (Berger, 1989)

Figure 5.2 **Total annual productivity in the North-east Atlantic. Source: Berger (1989).**



show that annual productivity in the region ranges from 45 g C/m^2 south of 40º N, to 90 g C/m^2 in the north, exceeding 125 g C/m^2 south-west of Iceland *(Figure 5.2)*.

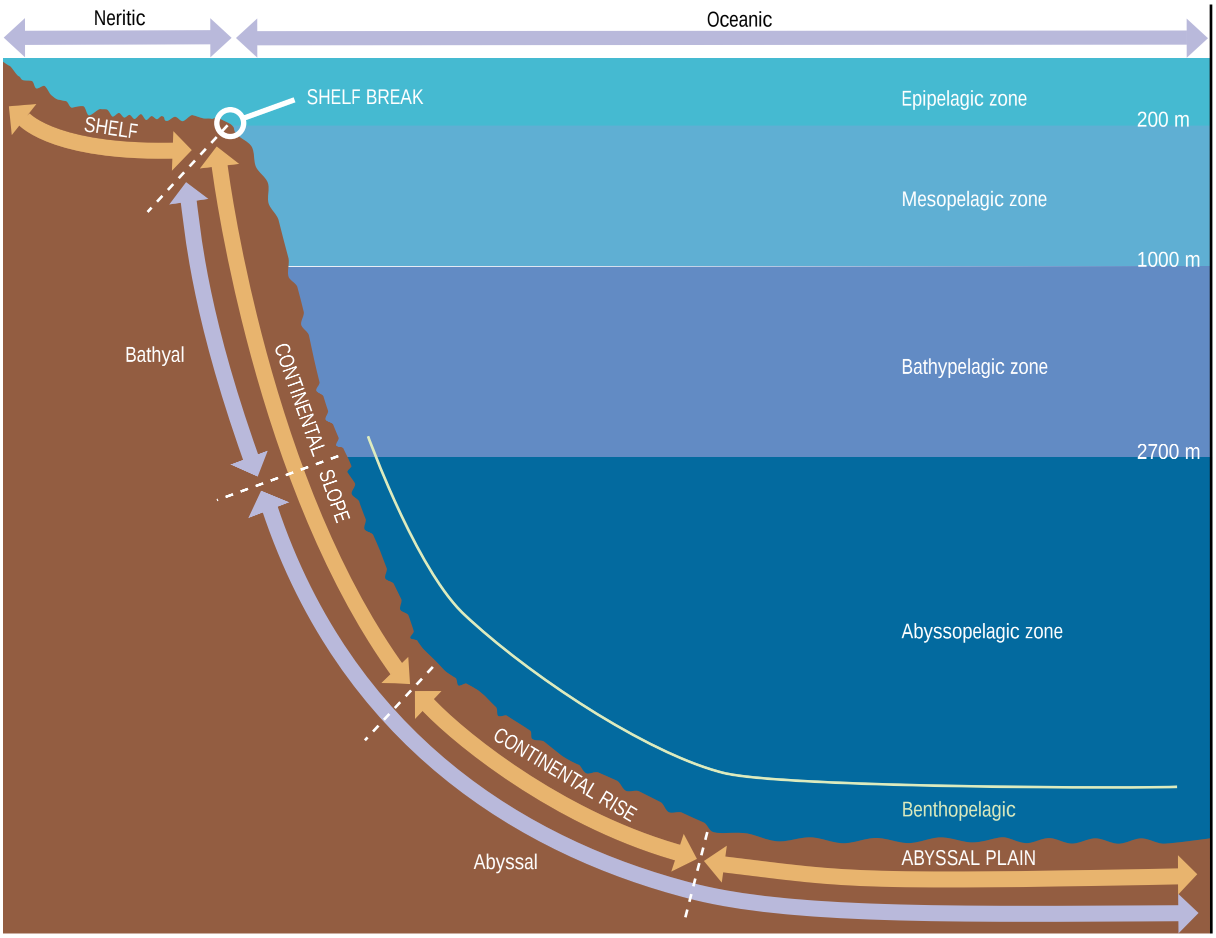
5.2.3 Harmful algal blooms

About 7% (300) of the known phytoplankton species can produce ‘red tides’ – bloom events that discolour the ocean. However, only 60 – 80 of these species, most of which are flagellates, produce harmful algal blooms (Smayda, 1997a). The frequency of harmful algal blooms has been increasing and their geographical ranges extending. These changes result from the introduction of non-indigenous species or the increasing amounts of nitrogenous compounds reaching the oceans (Vitousek, 1994; Paerl, 1997). At present most harmful algal blooms occur in shelf waters; few occur in the open ocean although potentially toxic species are present. Harmful algal blooms can be categorised into three modes of action ‘toxic’, ‘noxious’ and ‘nuisance’. *Table 5.1* summarises the modes and mechanisms of harmful algal blooms (Smayda, 1997b).

Table 5.1 Modes and mechanisms of harmful algal bloom species. Source: Smayda (1997b).

Mode	Mechanism	Species
Starvation	nutrition mismatch	
	size mismatch	
	excess prey density	
Mechanical	bumping	
	particle irritation	*Chaetoceros* spp.
Physical	viscosity barrier	*Gyrodinium aureolum*
	gelatinous barrier	*Cerataulina pelagica*
	mucoid layer reduction	*Chattonella marina*
Anoxia		*Ceratium* blooms
Ammonia toxicity		*Noctiluca* blooms
Phycotoxins	direct v. vectored toxicity	
	Saxitoxin	
	Brevetoxin	
	hemolysins	
	cytotoxins	
Allelopathic		
Ambush predation		*Pfiesteria piscicida*
Unresolved		*Aureococcus anophagefferens*

Figure 5.3 **Schematic diagram showing bathymetric zonation of pelagic fauna in the deep ocean. Source: Angel (1997).**



5.2.4 Vertical structure of pelagic communities

The strong vertical gradients of light, temperature, hydrostatic pressure and food availability generate a marked vertical zonation in pelagic communities *(Figure 5.3)*. The number of species rises to a maximum at depths of about 1000 m (Angel, 1997), although the biomass of the community is an order of magnitude lower than near the wind-mixed layer *(Figure 5.4)* (Angel and Baker, 1982; Vinogradov, 1997).

Epipelagic zone

The epipelagic zone extends to a depth of about 200 m *(Figure 5.3)*. It spans both the euphotic zone and the seasonal thermocline. During winter at high latitudes when vertical mixing is active, its lower boundary becomes indistinct. The food web within the epipelagic zone *(Figure 5.5)* is partitioned into two functional components, which depend on the sizes of the primary producers. The smallest plant cells (picoplankton) are too small (< 2 µm) to be available to large suspension feeders. Consequently they are mostly consumed by tiny ciliate and tintinnid (protozoan) grazers, which constitute

Figure 5.4 **Regressions showing the systematic decline of pelagic biomass with depth in the North-east Atlantic. Source: Angel (1997).**

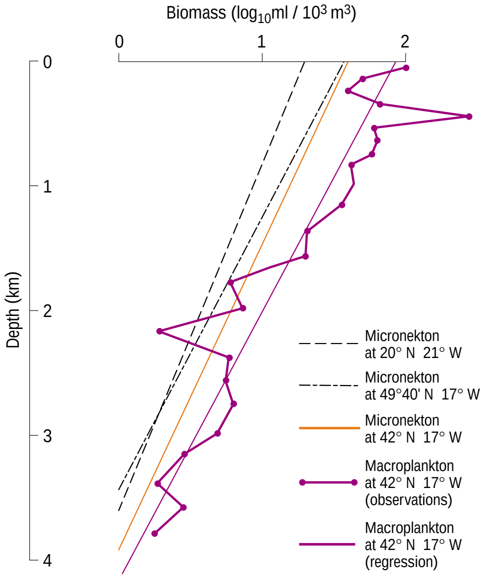
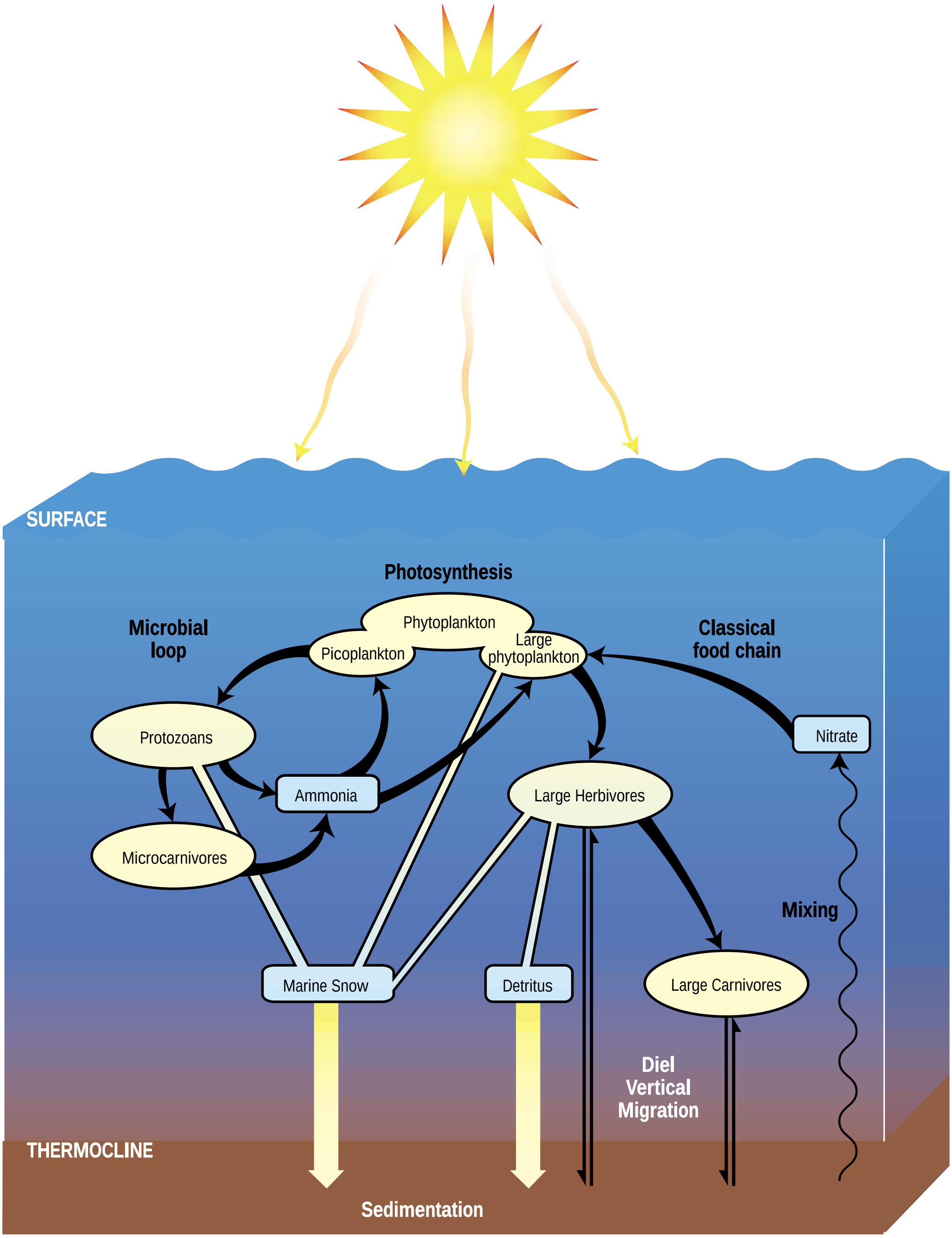


Figure 5.5 **Schematic illustration of the food web in the epipelagic and shallow mesopelagic zones of the open ocean.**



the 'microbial food web'. Most of the carbon fixed and nutrients used by picoplankton are re-cycled *in situ*. Also, because the protozoan grazers respond very rapidly to any increase in food availability, picoplankton production tends to be limited by grazing rather than by nutrient availability. The larger phytoplankton cells, particularly the diatoms, are grazed by suspension feeders such as copepods. So much of the carbon fixed by these larger cells is exported into deep water, either by sedimentation or by migrating plankton (i.e. the biological pump; see Section 4.3.2). There are non-migrant planktonic species, but they tend to be either very small or transparent (as an anti-predation strategy). Transparency (or translucence) is almost universal in the gelatinous species – salps, siphonophores, medusae, foraminiferans and chaetognaths – which tend to dominate the epipelagic communities by day.

The zooplankton of the epipelagic zone is dominated by small species ranging from protozoans to copepods, and during the spring is supplemented by larvae of deeper-living and even benthic species (Bouchet and Waren, 1985). At night, the epipelagic zone is invaded by migrants from deep water, including copepods (e.g. *Euchaeta* and *Pleuromamma*), myctophid fishes and scarlet prawns (e.g. *Acanthephyra, Systellaspis* and *Oplophorus*). Food availability, especially for herbivores, is far greater near the surface, but then so is the risk from visually-hunting predators during daylight. Diel vertical migration appears to be a strategy whereby pelagic species can find enough food, while minimising the risks of predation. It is also important as a mechanism whereby organic matter is exported into deep water (see Section 4.3.2). These migrations contribute to the marked patchiness with which pelagic species are distributed and makes accurate measurements of their abundance and biomass problematical. Some taxa, such as salps, jellyfish and pteropods, form dense swarms that can exclude other species. Swarms of the jellyfish *Pelagia noctiluca* can become totally dominant during the summer over wide areas of Region V at mid-latitudes. Swarms of salps and jellyfish are often succeeded by swarms of the predatory and scavenging amphipod, *Themisto compressa (Figure 5.6)*. The swarming behaviour of some of the larger herbivores, including species of krill such as *Meganyctiphanes norvegica (Figure 5.7)*, makes them available to baleen whales, fish and seabirds. Another important swarming organism in southern waters is the colonial luminescent tunicate *Pyrosoma*. These large salps (up to 0.5 m long) are able to consume picoplankton, and together with salps and jellyfish, are the favoured food of turtles. Seabirds tend to assemble and feed wherever food is abundant, which is often where productivity is locally enhanced or plankton has aggregated along convergent fronts. The food they take varies between species but ranges from small copepods (in the case of storm petrels) and krill, to squid and fish (in the case of auks and gannets). Around the Azores, horse mackerel, boarfish (*Capros aper*) and snipefish (*Macroramphosus scolopax*) are important components in their diets. The epipelagic plankton is exploited by numerous small to medium-sized clupeid and mackerel-like fishes, which in turn are the food of squid, dolphins, whales and large commercial fishes, such as tuna, swordfish and shark. At the other end of the size spectrum bacteria play a key role in geochemical cycling (see Section 5.2.6).

Figure 5.6 **The amphipod *Themisto compressa* dominates the planktonic biomass in near surface layers during summer (© Heather Angel).**

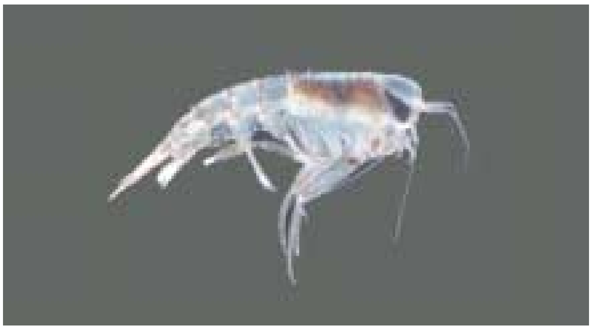
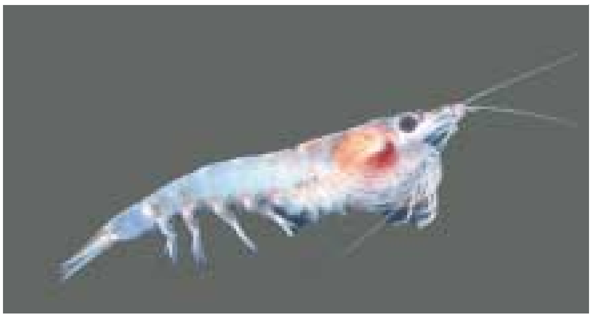


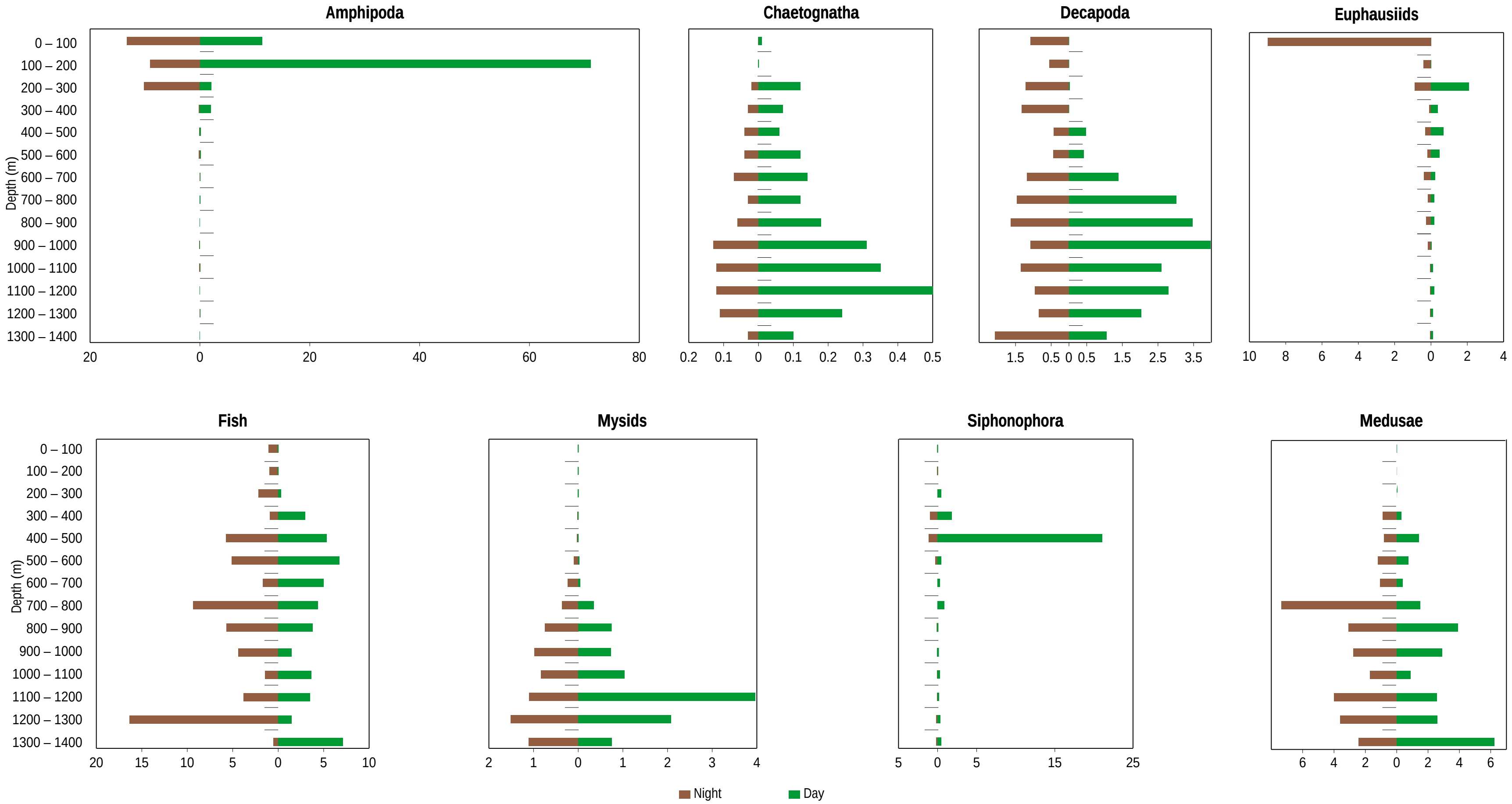
Figure 5.7 **The North Atlantic krill, *Meganyctiphanes norvegica*, is an important component in the diet of many commercial fishes and whales (© Heather Angel).**



Mesopelagic zone

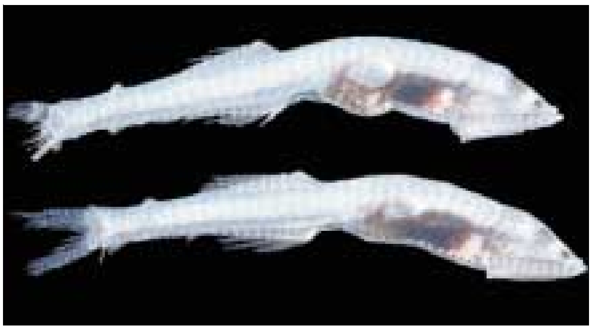
There are marked differences between the species composition of the pelagic communities inhabiting the mesopelagic and epipelagic zone *(Figure 5.8)*, and the mean size of the organisms also increases. Many of the species that are mesopelagic by day migrate up into the epipelagic zone at night to feed. Many of these species also spend their early juvenile stages in the epipelagic zone where food is more plentiful but the risks of predation are greater. However, as the depth range of a species increases, its fecundity tends to decrease. There is also an

Figure 5.8 **Day and night biomass profiles (mg C/m^2 in each 100 m sampling horizon) for the major taxonomic groups of micronekton at 47° N, 20° W in July 1988. Source of data: Pugh (1990).**



increase in the incidence of maternal care of offspring. At 300 – 400 m the communities are often dominated by gelatinous forms especially siphonophores and salps *(Figure 5.8)*. Euphausiids and large scarlet decapod crustaceans are also abundant and the fishes are dominated by myctophids (lanternfish), argyropelecids (hatchetfish) and gonostomatids. Many of these fish have highly silvered, mirror-like flanks and bellies lined with light-organs. Throughout much of the North-east Atlantic the populations of *Cyclothone braueri* *(Figure 5.9)*, an insignificant gonostomatid fish, are probably dense enough at 400 – 500 m to make it the most abundant vertebrate in the world.

Figure 5.9 **The gonostomatid fish *Cyclothone braueri* (© Heather Angel).**



In the south, at about 600 – 700 m, the mesopelagic zone is subdivided faunistically as the morphology of the dominant species subtly changes. At 40º N the dominant decapod crustaceans inhabiting the upper mesopelagic zone by day are half-red and half-transparent (e.g. *Sergestes* spp., *Systellaspis debilis* *(Figure 5.10)* and *Oplophorus spinosus*), whereas the lower mesopelagic zone is inhabited by totally red species (e.g. *Sergia* spp. and *Acanthephyra* spp.). The species composition of the dominant fish also changes to those with non-reflective, uniformly dark flanks. Vertical migrants from the shallow mesopelagic zone readily swim up through the thermocline, whereas the majority of migrants from the deep mesopelagic zone halt at its base. Most macroplankton in the deep mesopelagic depths are non-migrants.

In most environments specialised species tend to have higher rates of speciation and extinction than generalist species (Taylor, 1997). However, in the oceans the ecological gradients are dominated by light, and light gradients being determined physically have remained unchanged over evolutionary time, consequently highly specialised morphological types have evolved which can probably competitively exclude less highly adapted immigrants (Maynard Smith, 1989). Such an evolutionarily mature system may be less robust to the impacts of change.

Bathypelagic zone

The upper limit of the bathypelagic zone is at about 1000 m; the maximum limit to which detectable daylight penetrates in all but the clearest oligotrophic waters. In temperate waters, it is also the maximum depth from which there is vertical migration. In Region V, it also coincides with the oxygen minimum and the base of the permanent thermocline (Angel, 1989). Bathypelagic inhabitants have many morphological and physiological adaptations to life in these permanently dark waters *(Figure 5.11)*. Neutral buoyancy in fishes is achieved by low energy systems; swimbladders are lipid-filled rather than gas-filled, muscles are watery and bones uncalcified (Marshall, 1979). *Table 5.2* compares the differences in the adaptations of mesopelagic and bathypelagic fishes. Many species of bathypelagic fish have bizarre life histories, some undergoing sex changes (e.g. *Cyclothone microdon*), and in some anglerfish of the family ceratiidae (e.g. *Ceratias hollboelli*) the males become attached as parasites to the females.

Figure 5.10 **The mesopelagic decapod crustacean, *Systellaspis debilis*, undertakes vertical migrations from its daytime depths of 400 – 500 m to the upper 100 m at night (© Heather Angel).**

Figure 5.11 **The bathypelagic fish *Anoplogaster cornuta*, illustrating the large mouth and recurved teeth typical of many bathypelagic fishes (© Heather Angel).**

Table 5.2 A comparison of the morphological characteristics of mesopelagic and bathypelagic fishes. Source: Marshall (1979).

Feature	Mesopelagic species	Bathypelagic species
Colour	Many with silvery sides.	Uniform and usually black.
Photophores (light organs)	Numerous and well developed, particularly lining the belly.	Small or regressed, except in anglerfish which have a luminous lure, and stomiatoids which have cheek organs that function like headlamps.
Jaws	Relatively short.	Relatively long, often with recurved teeth.
Eyes	Large with sphaerical lenses and retinae consisting just of rods.	Small or regressed, except in the male of some anglerfish.
Olfactory organs	Moderately developed in both sexes of most species.	Regressed in females, but often well developed in males.
Central nervous system	Well developed throughout.	Weakly developed except for centres associated with movement detection (lateral line system) and forebrain of some males.
Myotomes (body muscles)	Well developed.	Weakly developed.
Skeleton	Well ossified, including scales.	Weakly developed, scales often absent.
Swimbladder	Usually well developed.	Absent or regressed or fat-filled.
Gill system	Numerous gill filaments carrying many lamellae.	Filaments few, often with reduced lamellae.
Kidneys	Large with numerous tubules.	Small with few tubules.
Heart	Large.	Small.

Abyssopelagic zone

A further change in the constitution of pelagic assemblages occurs at about 2500 – 2700 m. At 42º N, 17º W, fish decline in abundance (Angel, 1983) and are replaced by decapod crustaceans as the dominant group. Deeper still, the decapods are replaced by mysids. Preliminary evidence (Menzies and Wilson, 1961) suggests that these changes may result from physiological limitations to survival at high hydrostatic pressures. Throughout Region V the lower boundary of the abyssopelagic zone is at the upper limit of the benthopelagic zone, which throughout most of the region is about 100 m above the seafloor.

Benthopelagic zone

The benthopelagic zone occupies the layer of isothermal and isohaline water which immediately overlies the seafloor and is described as the benthic boundary layer. During ‘benthic storms’ (see Section 2.8.3) bottom currents can exceed 30 cm/s, extending the zone of isohaline and isothermal conditions higher into the water column (Weatherly and Kelley, 1985). Sediments and benthic organisms are swirled high into the water column and transported long distances. Within the benthic boundary layer, planktonic standing crops double (Wishner, 1980) and there are many endemic species (Angel, 1990). This reversal of the gradient in pelagic biomass close to the seabed probably reflects the increase in available food. Above the benthic boundary layer, pelagic organisms rely on intercepting particles that sink intermittently in time and space through the water column. Once these particles have arrived on the seabed however, the task of searching for them changes from being three-dimensional to two-dimensional. Moreover, microbial degradation of the particles on the bottom converts some of their organic content from indigestible to digestible compounds. Any resuspension of the particles will enhance their availability to organisms in the benthic boundary layer.

As the standing stock increases so does predation pressure. Swimming up into the water column may not only enable an animal to escape predation, but also to enter a different hydrodynamic regime where it may be able to pick up scent plumes from food packages or even potential mates. The abundance of amphipod scavengers, such as *Eurythenes gryllus*, caught in traps decreases almost to nil 50 m above the bottom (Christiansen, 1996), but individuals are occasionally caught several hundred metres above the seabed ***(Figure 5.12)***. The pelagic larvae and post-larvae of benthic species are also found in this zone, and several species of holothurians, normally considered to be megabenthos, have the ability to float up off the seabed (Billett *et al*., 1985; Billett, 1991).

5.2.5 Vertical structure of benthic communities

Benthos is the collective term for organisms inhabiting the seabed. The ‘infauna’ lives within the sediment, whereas the ‘epifauna’ lives upon it. The benthos is usually categorised arbitrarily according to the mesh sizes used in sieving. The megabenthos contains the largest organisms; these are sampled using trawls and sleds and can be identified in photographs ***(Figure 5.13)***. The

Figure 5.12 **The benthopelagic amphipod *Eurythenes gryllus* is the dominant scavenger on the abyssal seabed (© Heather Angel).**

macrobenthos is sampled using large corers and comprises species that will pass through a 1 cm mesh, but are retained on sieves with 1000 – 500 µm meshes. The meiobenthos and nanobenthos pass through 500 µm and 63 µm meshes, respectively. Deep ocean benthos tends to be much smaller than its shallow water counterparts, so the mesh sizes of the sieves used to separate it are often correspondingly smaller (e.g. 330 µm and 45 µm respectively). Quantifying and identifying benthos becomes progressively more difficult as the organisms get smaller and smaller. However, as their size decreases so the importance of the role they play tends to increase, moreover the importance of the smaller sized categories increases with depth. Knowledge of benthic communities remains inadequate for most management purposes.

Bathymetric gradients of species richness (Rex *et al*., 1997) and standing crop (Rowe and Pariente, 1992) are similar in the benthos to those of pelagic assemblages. Species richness in the megabenthos also reaches a maximum at a depth of around 1000 m (Angel, 1993). Raw data for numbers of species in the macrobenthos show similar trends, but statistical interpretations imply that the maximum in species richness may be deeper (Paterson and Lambshead, 1995). There is also controversy as to whether or not benthic assemblages are bathymetrically zoned. Along-slope variations in seafloor topography have complex interactions with currents, internal waves and tidal oscillations that may generate patterns which obscure the vertical structure (see Section 2.9.2).

Figure 5.13 **A large (15 cm long) holothurian, *Benthogone rosea*, feeding on a fine even layer of phytodetritus (left) and two hours later, the holothurian having moved on, has left behind a large faecal cast (right). May 1982, depth 2009 m in the Porcupine Seabight. Source: Billett (1991).**

Inputs of organic matter (and contaminants) to slope dwelling communities are by vertical sedimentation or by down-slope (lateral) transport (van Weering *et al*., 1998). When near seabed currents exceed 30 cm/s, particles stay in suspension and are transported laterally, unless they are intercepted by suspension feeding organisms. At latitudes > 40º N, dense flocs of ‘phytodetritus’ settle on to the seabed at abyssal depths some four to six weeks after the collapse of the spring bloom (see Section 5.2.1; *Figure 5.13*). In some years the deposition is so extensive that it almost obscures the sediment (Billett *et al*., 1983; Lampitt, 1985; Rice *et al*., 1994; Thiel *et al*., 1989; Pfannkuche and Lochte, 1993). The flocs contain bacteria and viable picoplankton (Cyanobacteria), which are eaten by benthic Foraminifera (Gooday and Turley, 1990), and their deposition stimulates several weeks of frenetic biological activity on the seafloor. The flocs are also vehicles for the rapid transportation of trace metals and contaminants scavenged from the upper water column.

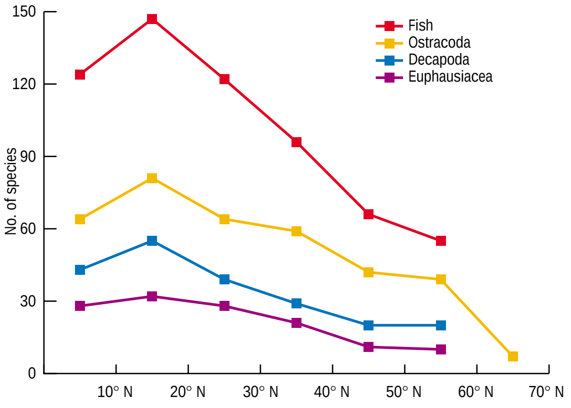
One component of benthic ecosystems which is not linked to the sedimentation of particles and aggregates is the feeding-guild of scavengers. In Region V this guild is dominated by a few species of large amphipods (Thurston, 1990; Christiansen, 1996; *Figure 5.12*) and some fishes (Gartner *et al*., 1997). These organisms exploit the large falls of food provided by the corpses of whales and large fishes that sink too quickly for them to be consumed in mid-water. When these large food packages land on the seabed they soon attract large swarms of scavengers. Most of these scavengers are just a few centimetres in length, but some are very much larger. Their presence in turn attracts large predators. Many of the deep-living commercial species of teleost fishes and sharks either belong to, or are based on, this feeding-guild.

5.2.6 Role of bacteria

Throughout the water column and on the seabed bacteria play a key but rather poorly understood role in biological and chemical processes (Lochte *et al*., 1993). In the wind-mixed layer bacteria can dominate the quantities of particulate material suspended in the water. During the spring bloom there can be 1 – 3 x 10^9 bacterial cells/l, and bacterial biomass can be 15 – 25% of the stock of particulate organic carbon in the euphotic zone. The surface area of bacteria far exceeds that of any other biological or inert particle (Honeyman *et al*., 1988). The fluxes of many substances, organic and inorganic, natural and anthropogenic, are regulated by their adsorption onto the outer membranes of bacteria. The bacteria can respond very rapidly to transient increases in the chemical substrates and their role in the recycling and reprocessing of organic and inorganic compounds in the water column is probably fundamental to all chemical budgets (Carlson *et al*., 1994, 1996; Ducklow *et al*., 1997). Bacterial biomass oscillates out-of-phase with primary production, and in temperate waters bacterial growth rates can result in the standing crop of bacteria increasing by 10 – 30% per day, so bacteria are transforming a large proportion of the carbon flow. In the subtropical seas around the Azores bacterial biomass exceeds that of phytoplankton but is cycling more slowly. Bacterial production can average 30% of primary production, metabolising most of the dissolved organic carbon produced. Bacteria also generate the organic films on both natural and artificial structures that are necessary for the settlement of fouling organisms.

Bacteria recycle the vast majority of the organic material reaching the seabed. They can survive and flourish in the most extreme of environments and their productivity probably exceeds that of all other components of the seafloor ecosystems. However, the turn-over of bacterial biomass is rapid, so it is hard to measure and easy to overlook (Lochte, 1992). The importance of the role of poorly known groups of bacteria, such as the Archaeobacteria, in hydrothermal vent systems and cold seep communities is also difficult to quantify. Bacteria make a major contribution, possibly the dominant contribution, to the geochemical reprocessing that occurs within sediments, and viable cells have been found in cores several hundreds of metres within the sediments.

Figure 5.14 **Numbers of species in the four major micronektonic taxa occurring in the upper 2000 m along 20º W. Source: Angel (1997).**



5.2.7 Biodiversity

Pelagic ecosystems are locally rich in species but the global inventory of pelagic species is unexpectedly small (see Ormond *et al*., 1997). North of 40º N, there are fewer species in the pelagic communities *(Figure 5.14)* but their mean size is larger. Many undertake seasonal migrations to overwinter in deep water. An analysis of over half a million specimens of copepod from a series of repeated tows at four depths down to 600 m at 44º N, 13º W showed there were 106 species (Roe, 1984) – nearly 5% of the total global inventory of known marine pelagic copepods. The fish were similarly diverse, including over 10% of the known pelagic species from the North Atlantic (see Section 5.2.8). Pelagic faunas contain representatives of fifteen metazoan phyla and benthic faunas at least 33. If prokaryotic organisms are included (i.e. organisms, including bacteria, which lack cell nuclei) the benthos includes > 50 phyla (Margulis and Sagan, 1987). Data on benthic species richness are sparse, even so the indications are that although there are more phyla in the benthos, there are more species in terrestrial ecosystems. However, at any oceanic low latitude locality large numbers of species are to be found. For example, identification of 272 000 specimens of macrobenthos collected in 558 box-cores from depths of 1500 – 2100 m along the eastern seaboard of the US revealed 1597 species, of which 58% were novel (Grassle and Maciolek, 1992). Extrapolations of these data to estimates of the global inventory of species have given estimates ranging from 0.5×10^6 (Gage and May, 1993) to 10^7 (Grassle and Maciolek, 1992) and even to > 10^8 (i.e. more than rivalling a tropical rain forest) (Bouchet and Lambshead, 1995). Note there will be just as many if not more species of meiobenthos. However, the higher estimates are based on the assumption that the majority of benthic species have very localised distributions, and this is not the case for the more abundant species. Undoubtedly, local species richness is exceptionally high, which empirically is associated with environmental predictability (McGrady-Steed *et al*., 1997).

In areas where there are regularly high loads of suspended organic particles in near-bottom waters, accumulations of large suspension feeders occur, such as cold water corals (e.g. Frederiksen *et al*., 1992) and sponges. These large species create a biotic habitat containing an assortment of microhabitats and are inhabited by rich assemblages of species, including commercial fishes. In the past fishermen have generally avoided these regions, because their nets get damaged and they retrieve many tonnes of useless by-catch. However, evidence is beginning to emerge that some of these areas have recently been severely damaged, presumably as a result of fishing activity (see Section 5.3.2). Localised habitats with a high species richness are often found where there are fine-scaled, complex interactions between the seabed structures and hydrographic processes.

5.2.8 Fish

There are just 589 pelagic and 505 demersal species of fish known from the whole of the North Atlantic (Merrett, 1995), a rather small number considering the vast volume of the habitat. About 10% of these species are either directly targeted by the fishing industries or are caught incidentally (see Section 3.5). Nederaas *et al*. (1993) list 86 species of demersal fish that are caught regularly during commercial fishing for Greenland halibut (*Reinhardtius hippoglossoides*), including twenty-five species of shark and ray and four chimeroid species. Many of these are slow growing and have low fecundities, and so lack resilience to fishing pressure. As top predators and scavengers they can be expected to play a key role in the dynamics and functioning of oceanic ecosystems, yet very little is understood about the impact of their removal. The large pelagic species (tunas and marlins), which tend to be fast-swimming and highly migratory ranging far beyond the limits of Region V, pose a further problem. They are heavily exploited because of their high commercial value, but because they are long-lived, relatively slow to mature and at the apex of the ecological pyramid, they tend to be the species that accumulate anthropogenic contaminants to the highest levels (see Section 4.4.3).

Sharks also illustrate the environmental management problems posed by the need to balance the impacts of exploiting wild populations and the contamination of the environment, with the need to conserve biological diversity and ecological processes. Sharks are mostly slow growing and have low reproductive potential. Many species are top predators and so probably play an important ecological role in maintaining the structure and diversity of oceanic assemblages. In Region V they range in size from the largest known species – the whale-shark, which occurs around the Azores in association with tuna shoals – to the smaller dogfish and skate. Another species of interest to conservationists is the basking shark (*Cetorhinus maximus*) which is the second largest shark, up to 12 m long, and occurs in the North-east Atlantic from the North Cape of Norway southwards along the UK and French coasts. They are regularly seen in spring and summer feeding on plankton near the surface, when water temperatures are 8 – 12 ºC (Kunklik, 1988), occasionally in large numbers close inshore. On 16 May 1998, 500 were reported off Cornwall and became a tourist attraction. Females are ovoviviparous, producing only about six young a year, each about 1.7 m long. The vulnerability of sharks to fishing mortality, whether direct or incidental, is exemplified by the rapid decline of the shark fishery off Norway, Scotland and Ireland, between 1967 and 1986. Over that period catches declined by an order of magnitude and the fishery collapsed.

Off the Azores the blue shark (*Prionace glauca; Figure 5.15*) is similarly threatened with overexploitation (da Silva *et al*., 1997), despite being one of the most abundant sharks in the Atlantic. The population in the North Atlantic is a single stock that migrates around the North Atlantic gyre. Near the Azores the population is dominated (80%) by juveniles about 1 – 1.7 m long which are taken by longlines on their feeding grounds around the shallow banks and seamounts. Concern has also been expressed about the status of many of the deep-living species.

Figure 5.15 **A blue shark, *Prionace glauca*, off the Azores (D. Perrine © *imag*DOP).**

5.2.9 Squid

Squid are another group of animals that are very likely to be vulnerable to pressure from exploitation and environmental degradation. They are extremely difficult to sample and so, despite their high abundances, the biology of these active molluscs remains poorly known. A few species are of commercial importance but their main significance is their role within the ecosystem, both as predators and as a food source for some species of whale (see Section 5.2.11), fish and seabird. The majority of the species have annual life cycles and have some of the highest known growth rates. This makes them very responsive to climatic fluctuations. In particular, the extremely high metabolic rates of the upper ocean species make them highly susceptible to quite small increases in dissolved carbon dioxide, which will reduce the oxygen-carrying capacity of their blood.

5.2.10 Seabirds

Apart from having to come ashore to breed, many seabirds are totally dependent on marine food resources and so are essentially marine organisms. The majority feed near the surface, particularly at night when food is more abundant as a result of diel vertical migration (see Section 5.2.4). Daytime feeding is often facilitated by dolphins and tuna herding their prey close to the surface

(Martin, 1986). At high latitudes where fish populations are more numerous, birds feed by diving either by plunging from the air (e.g. gannets) or from the sea surface (e.g. auks, guillemots, razorbills and puffins). They are attracted to surface slicks, which normally occur along convergent fronts where suspended particles and plankton are concentrated. This renders them vulnerable to contamination by oil which also accumulates along these fronts, and resembles natural slicks. Once oil gets on their plumage it poisons them when they preen, prevents them from flying and breaks down their thermal insulation. Birds are most vulnerable when moulting (in eclipse), when many species become flightless and gather in rafts. Few species are truly oceanic, although several are long-range migrants which regularly cross the region (e.g. great shearwaters (*Puffinus gravis*) and Arctic tern (*Sterna paradisaea*)). Terrestrial predators (rats, cats and mustelids), which have been introduced on many islands in the Azores, have now restricted the breeding colonies of most species to small islets and inaccessible cliffs, including some species of international importance, namely Bulwer's shearwater, Madeiran storm petrels and gadfly petrels (Santos *et al*., 1995). The species have also become nocturnal. The majority of species in Region V have northern distributions; only a few have distributions that are central or southern *(Table 5.3)*.

Birds are probably better researched and monitored than any other group of organism and are well placed to be used as indicators of the overall health of the environment (Monteiro and Furness, 1995). The Azores, being remote from continental sources of pollutants, are suitable sites for the investigation of global trends in contamination in marine food chains (Monteiro *et al*., 1998). The conservation status of seabirds regularly breeding on the Azores is shown in *Table 5.4*. Thirteen of the fourteen breeding species are considered to have a conservation status that is unfavourable and three of these breed nowhere else in Region V (i.e. little shearwater, Madeiran storm petrel and Bulwer's shearwater). More than 60% of Europe's roseate terns *(Figure 5.16)* breed in the Azores (Tucker and Heath, 1994), and the breeding of Manx shearwaters is also highly localised within the north and west European seas. The Azores, together with the archipelagos of Madeira, the Canary Islands and the Cape Verde Islands, form the subtropical biogeographical region of Macaronesia. Cory's shearwater, whose breeding is almost confined to Europe and whose population is highly dependent on Macaronesian seas during the breeding season, suffered a large decline between 1970 and 1990 (Tucker and Heath, 1994).

Systematic monitoring of seabird behavioural ecology can enhance fish-stock assessments by providing estimates of predator-induced mortality and technology-independent indices of fish abundance and availability. Avian indices can be particularly useful in sampling prey and sites that are not easily or usually surveyed by conventional means. Avian data can yield early indications of large-scale fluctuations in stocks of pelagic fish and

Table 5.3 Seabirds seen regularly in the Wider Atlantic.

	Nesting sites
Northern species	
northern fulmar	northern cliffs
northern gannet	northern cliffs and stacks
lesser black-back gull	UK, Iceland
greater black-back gull	UK, Iceland
glaucous gull	north of Arctic circle
Iceland gull	Greenland
Sabine's gull	Greenland
kittiwake	northern cliffs
little auk	Greenland, Iceland
razorbill	northern cliffs
common guillemot	northern cliffs
black guillemot	Iceland, Faroe Islands
puffin	northern cliffs
Central species	
Manx shearwater	throughout
British storm petrel	south-west Ireland, small colonies elsewhere
Leach's storm petrel	mostly in north
herring gull	inshore (Azores)
Southern species	
Cory's shearwater	Azores
Madeiran storm petrel	Azores, Madeira, Cape Verde Islands
little shearwater	Azores, Desertas, Canary Islands
white-faced shearwater	ex-Azores, Salvage Islands
Bulwer's shearwater	Azores
yellow-legged gull	Azores
red-billed tropic bird	(Azores)
Fea's petrel	Deserts, Madeira (?Azores)
roseate tern	Azores
Migrants	
red-necked phalarope	Iceland, UK, high latitudes
red phalarope	high latitudes
Pomarine skua	Arctic circle
Arctic skua	north, including Faroe Islands, Scotland
long-tailed skua	high latitudes
great skua	Iceland, Scotland
common tern	Azores, Madeira
Arctic tern	northern coasts
great shearwater	South Atlantic
sooty shearwater	Southern Ocean (Azores)
Wilson's storm petrel	Southern Ocean

perturbations of oceanographic conditions (Montevecchi and Myers, 1995).

A few of the bird species are exploited directly, e.g. adults and chicks of Cory's shearwater are taken for oil, fishing bait and human consumption. But the main threats to most seabird species are the loss and degradation of their breeding sites through coastal developments and introduced predators, their fatal attraction to lights at night, disruption of their food chains by overfishing and by being foul-hooked on longlines. Factors resulting in the degradation of breeding sites can be unexpected and unrelated to factors in the ocean. For example, the introduction of non-indigenous plants to the Azores, such as *Arundo donax, Nicotina glauca* and *Hedychium gardeneri*, has changed the vegetation growing at the breeding sites and resulted in such dense root growth that the birds are unable to burrow effectively.

Figure 5.16 **A roseate tern, *Sterna dougalli*, on the Azores. Source: Univ. Azores.**

5.2.11 Marine mammals

Thirty-two species of whale have been recorded in the region *(Table 5.5)*. Many are rarely encountered and are difficult to identify. In the past, marine mammals were heavily, and often excessively, exploited (Sigurjónsson, 1997). Populations crashed and even now, several decades after the ban on commercial whaling was introduced as a result of the International Whaling Convention, populations of many species have not recovered to pre-exploitation levels. Pilot whales are hunted around the Faroe Islands, and small numbers of minke whales (*Balaenoptera acutorostrata*) are harvested in the Norwegian Sea. Assessments of the current sizes of whale stocks based on sightings *(Table 5.6)* are subject to controversy between those who wish the ban on whaling to continue and those who wish to increase the catches. Recordings from hydrophone arrays, originally deployed by NATO to monitor movements of naval vessels, have revealed that the rarer species of whale occur somewhat more frequently in the region than previously thought, and the presence of a few blue whales had been completely unsuspected. This poses the question as to whether or not activities associated with oil exploration and military exercises (e.g. Frantzis, 1998) have had any deleterious effect on these precarious whale populations.

Most whaling has stopped in the region, and whales have become the focus for ecotourism. Whalewatching is a booming aspect of the tourist industry off the Azores *(Figure 3.2)* and Scotland.

Strandings of whales appear to be on the increase. These events cause considerable public concern but their significance to population size is unclear. One positive outcome is that strandings provide material for biopsies. Analyses of some of the 49 specimens (thirteen species) of whales and dolphins stranded on five islands of the Azores in 1992–6 showed that pollutant concentrations were so low that toxicity was unlikely to have contributed to the cause of death (Goncalves *et al*., 1996). Nor was there much evidence of wounds inflicted by fishing activities. Reports of strandings peaked in spring 1996. This may have been a result of the wide media publicity given to the earlier stranding of a minke whale, but may also have been associated with a period of bad weather. In 1995 three bull sperm whales stranded in Belgium became well-documented (Jacques and Lambertsen, 1997). In the report it was noted that between 1919 and 1994, 96 sperm

Table 5.4 Conservation status of seabirds regularly breeding on the Azores. Source: Tucker and Heath (1994).

	Breeding population (pairs)	Criteria*	Status†
Fea's petrel	presence	< 250 pairs	endangered (1)
Bulwer's shearwater	500 – 1 000	< 10 000 pairs (a)‡	vulnerable (3)
Cory's shearwater	50 000 – 100 000	(b) ‡	vulnerable (2)
Manx shearwater	200 – 400	localised	localised (2)
little shearwater	1 000	< 10 000 pairs (a)	vulnerable (3)
Madeiran storm petrel	1 200	< 10 000 pairs (a)	vulnerable (3)
roseate tern	1 000	< 2 500 pairs (b)	endangered (3)
common tern	4 000	-	favourable conservation status
yellow-legged gull	2 000	-	favourable conservation status

* indicates the population levels below which there are conservation concerns; † (1) species of global conservation concern, (2) conservation status of concern – concentrated in Europe, (3) conservation status of concern – not concentrated in Europe; ‡ (a) moderate decline, (b) large decline.

Table 5.5 Cetaceans occurring in the North-east Atlantic. Source: after Evans (1997) and Jefferson *et al*. (1993).

	Comments
Baleen whales	
minke whale	widespread, exploited off Norway
sei whale	migrates through region
blue whale	detected with hydrophone arrays
fin whale	migrates through region
Bryde’s whale	in far south of region
humpback whale	migrates through region
northern right whale	extinct in region?
Beaked whales	
Sowerby’s beaked whale	north of 30° N
Blainvill’s beaked whale	in far south-west of region
Gervais’ beaked whale	rare in far south
True’s beaked whale	rare, deep water
Cuvier’s beaked whale	widespread, deep water
northern bottlenosed dolphin	deep water
Sperm whales	
sperm whale	widespread
pygmy sperm whale	south of 50° N
dwarf sperm whale	south of 40° N

	Comments
Dolphins	
white (beluga) dolphin	rare vagrants
short-beaked common dolphin	widespread inshore
Atlantic white-sided dolphin	north of 50° N, deep water
white beaked dolphin	north of 50° N, shelf-break
bottle-nosed dolphin	widespread but inshore
striped dolphin	south of 50° N, deep water
Atlantic spotted dolphin	in far south of region
melon-headed whale	in far south of region
pigmy killer whale	in extreme south
false killer whale	mostly south of 40° N
killer whale	widespread
Risso’s dolphin	mostly south of 50° N
short-finned pilot	mostly south of 40° N
long-finned pilot	mostly north of 40° N
harbour porpoise	inshore, seldom over deep water
rough-toothed dolphin	in far south of region

Table 5.6 Estimates of current baleen whale stocks in the North Atlantic based on large-scale sighting surveys.

	Stock size		
	Sigurjónsson (1997)	IWC data, mostly for 1989	Status
blue whale	1 – 2 000	n.d.	Stock at low level, occurs mainly off Iceland and the Gulf of St Lawrence. Few occur in other old whaling grounds. Off Iceland increasing ~ 5% per year.
fin whale	> 50 000	21 700 – 58 160	Numerous but still depleted off Norway and the UK; estimates based on recent surveys but off Canada based on past tag returns.
sei whale	> 13 500	6 100 – 17 700	Relatively numerous but still depleted off Norway. Estimates for Canada and US based mainly on tag returns.
minke whale	> 180 000	96 700 – 145 000* 21 600 – 31 400†	Stock reduced but still abundant. Estimate refers to OSPAR region; more probably occur in the North-west Atlantic.
humpback whale	> 7 770	n.d.	In North-west Atlantic nearly recovered to pre-exploitation numbers. Off Iceland has been increasing at ~ 10% per year. ‘Eastern’ stock still depleted.
right/bowhead whale	~ 500	n.d.	Remains very depleted and endangered.
pilot whales		440 000 – 1 370 000	

* estimate for the region to the east of 20º W and north of 60º N extending north-eastwards into the Norwegian Sea; † estimate for the rest of Region V and northwards beyond Iceland.

whales had been stranded along the North-west European coast (Evans, 1997), all of these whales must have originated from Region V. The frequency of strandings increased after 1980 and averaged 6.6 per year in 1987–94. Early records indicate that the stranded whales were mostly large bulls, but they now include smaller specimens < 14 m in length. Two factors put forward to explain the increase are not necessarily mutually exclusive. Firstly, that the increase merely reflects an increase in the whale populations since whaling stopped, and secondly that the effects of anthropogenic activities are increasing. Many of the whales are chronically contaminated with PCBs and other persistent residues, also there has been a modest increase in the frequency of underwater explosions as a result of seismic surveys, military exercises and scientific research. However, there are no reports, even anecdotal, that during the Second World War, when military activity was both more extensive and more intensive, strandings increased. Normally bull sperm whales migrate beyond the shelf-break; whatever causes them to divert from their normal migration routes remains speculative. Around the Azores, sperm whales tend to be associated with the mesoscale eddies that are spawned from the Azores Current and where predominantly they are eating squid. Recent estimates suggest that these whales consume $67 – 374 \times 10^3$ t of squid each year, which is four to twenty times the current landings of fish on the islands (Clarke, 1996; Clarke *et al*., 1998). It has also been estimated that present stocks of both large and small whales in Icelandic and adjacent waters consume 6×10^6 t of food, of which about a third is likely to be fish (Sigurjónsson and Vikingsson, 1997). The total annual landings of fish in Iceland are $1 – 1.5 \times 10^6$ t; the dynamics of the interactions and the competition between the fishing and natural mortality is poorly understood.

Seals are rare vagrants in Region V. Monk seals, which were common in the Azores at the time of initial colonisation, have long since disappeared.

5.2.12 Turtles

Five species of turtle have been recorded off the Azores (Santos *et al*., 1995): loggerhead (*Caretta caretta; Figure 5.17*), green (*Chelonia mydas*), hawksbill (*Eretmochelys imbricata*), Kemp's ridley (*Lepidochelys kempii*) and leatherback (*Dermochelys coriacea*). Only the loggerhead turtle is common. Large leatherback turtles regularly turn up off the coast of Ireland and the UK. No turtles breed along the Western European margin. Genetic studies have linked the loggerhead turtles occurring off the Azores and Madeira with the populations that breed in Florida and the Caribbean, rather than those that breed in the Mediterranean and Brazil (Bolten *et al*., 1998). A programme of satellite-tracking marked and released turtles from the Azores was started in 1994 (Santos *et al*., 1995). Despite being fully protected by law, turtles are still being caught in fishing nets and on longlines. They are also vulnerable to injury through the ingestion of plastic debris accumulating along convergent fronts, as this resembles the gelatinous species on which they feed (Carr, 1987).

Figure 5.17 **A loggerhead turtle, *Caretta caretta*, encountered off the Azores (P. Wirtz © *imag*DOP).**

Recent reports indicate a global epidemic of a form of non-cancerous tumour affecting most species of turtle. These debilitating tumours cover the eyes and noses and infection rates of 50% have been reported from Florida, with even higher rates off Hawaii. The virus is similar to those causing herpes and chickenpox in humans. It is speculated that pollutants, by weakening the turtles' immune systems, make them more susceptible to viral infections.

5.2.13 Key habitats

Coastal habitats

The coastline of the Azores consists mostly of rocky cliffs, with numerous islets and stacks that tend to fall steeply to great depths. There are a few sheltered bays and flat shallow intertidal to submarine basaltic platforms. Shallow reefs emerging steeply from deeper water are common features close to many of the islands. There are a few shallow banks and offshore islands that are inhabited by coastal species (e.g. the banks of João de Castro and the Formigas/Dollabarat complex). Sandy habitats dominate some of the submarine coastal regions and where there are beaches within the bays. There are a few coastal wetlands and lagoons around the islands of São Jorge and Pico.

The animal and plant communities of the coastal habitats around the Azores are isolated from their mainland counterparts. The various species originally reached the Azores as larvae carried long distances by ocean currents, transported by birds or even man, or rafted on floating objects. Some species have reached the area through active swimming (e.g. fish of the family

Balistidae). The communities are a random mix of cold-temperate, temperate and subtropical species, and colonisation by many probably occurred after the Pleistocene Epoch when the current regime was somewhat different to that of today. Despite the main current flow coming from the west, the geographical affinities of most shallow water species around the Azores are with Madeira, the North-east Atlantic and the Mediterranean. Since gene flow between these island populations and their mainland counterparts is presumably intermittent, the species are likely to be genetically differentiated. The shallow water marine communities are in general more diverse than their terrestrial counterparts, but show a lower degree of endemism.

Hydrothermal vents

The characteristics of the hydrothermal vent assemblages found locally in the median valley of the Mid-Atlantic Ridge (see Section 2.4.2) are reviewed in Gebruk *et al*. (1997). These communities occur closely clustered around the discharges of hot, sometimes superheated, fluids which are rich in metallic sulphides, methane and carbon dioxide. The communities are large in biomass but consist of rather few species. Their organic supplies are derived mainly from the chemosynthetic oxidation of sulphides or methane by bacteria. The bacteria are either free-living or live as symbionts within the bodies of the larger animals. Most vent species are endemic to these special habitats and the community composition varies with depth. Only three vent systems, ‘Lucky Strike’, ‘Menez Gwen’ and ‘Rainbow’ have been found so far in Region V. These occur in relatively shallow water and their faunas are dominated by aggregations of *Bathymodiolus* mussels. Bresiloid shrimps, which are specialised to living close to vents by having a reflective photoreceptive organ extending along their backs, are quite numerous but not as abundant as around the deeper vents further south (van Dover *et al*., 1996). Despite the spatial and depth separation of these two sites settlement of the larvae of the various mussel species appears to be synchronised (Comtet and Desbruyères, 1998). Temperatures within the mussel beds ranged from 13.7 ºC to close to the ambient temperature of 4.7 ºC, and 95% of the mussels examined contained commensal polynoid worms. Over 100 species have been collected from around these Mid-Atlantic Ridge vents, many of which still await full scientific description (Gebruk *et al*., 1997). There are marked differences between the faunas found at Lucky Strike and at other Atlantic vents, for example Lucky Strike lacks the peripheral fauna found at other vents such as the beds of anemones and chaetopterid polychaetes, and large gastropods and galatheid crabs are rare. The boundaries between its vent communities and the ‘normal’ benthic communities are abrupt. These differences may result from the influence of depth (especially if hydrothermal species are tolerant of a limited range of *in situ* temperatures), or from the Lucky Strike system being isolated from the more southerly systems by the 120 km offset of the Oceanographer Transform Fault. Vents have also been reported at very shallow depths near the island of São Miguel and on the João de Castro seamount (Santos *et al*., 1995).

Shelf-break front

The shelf-break that delimits the inshore margin of the region in the north-east, is a zone of intense biological activity. Spawning migrations of commercial fish species such as blue whiting (*Micromesistius poutassou*) and the seasonal migrations of the copepod *Calanus finmarchicus*, a keystone species in the north-eastern sector of Region V, appear to be tuned to the characteristics of the current. Interactions between the slope current, tides, internal waves, mesoscale eddies and the variable topography of the seabed, result in local patches of vertical mixing (see Section 2.9.2). The wave climate also tends to be at its most extreme. Primary production is enhanced at the shelf-break front and the zone is used by many pelagic species for feeding, breeding and migration routes. Exchanges between shelf seas and oceanic waters are generally restricted, which results in a clear demarcation in physical, chemical and biological properties across the shelf-break. However, in some regions there are regular, albeit intermittent, on-shelf exchanges and in others off-shelf exchanges (van Weering *et al*., 1998). These regions are critical for understanding the transport of contaminants into deep water. The regions are now coming under increased pressure from the competing activities of fishing and the exploitation of hydrocarbons. Future needs for more renewable energy sources will probably result in wave energy generators being located in the zones. Generally, knowledge of these complex regions is poor compared with that for shelf seas and open water conditions and needs to be improved.

Seamounts

Seamounts are important habitats in the open ocean (Rogers, 1994), particularly in the south of Region V. Pelagic fishes and cetaceans tend to aggregate around their summits for feeding and spawning. There is greater vertical mixing (see Section 2.4.5) over the summits and so productivity is enhanced in their vicinities. The summits are often well scoured by currents but the flanks are often inhabited by dense concentrations of suspension feeding benthic species. For benthic species in particular, seamounts function as islands, so there is a high degree of endemism, because the populations of shallow-living species inhabiting the summits are genetically isolated.

Abyssal plains

Abyssal plains of 4500 – 4850 m in depth cover a substantial part of the region (see Section 2.4.3). Their topography is almost uniformly flat, with gradients of $< 0.05°$ and with changes in height of < 1 m/km (Heezen *et al*., 1954). There are some low topographical features, which have been scoured by intermittent turbidity flows. To the north of 40º N the deposition of phytodetritus creates marked seasonality in biological activity. The surface of the sediment is covered with Lebensspuren, tracks of the abundant holothurian, their faecal castes ***(Figure 5.13)*** and the pits and mounds of burrowing infauna. These create considerable fine-scale structure on the seabed. Tidal oscillations and eddies generate swirling currents, generally < 15 cm/s, but which are sufficient to shift the phytodetritus into hollows and to the lee-side of the mounds. Time-lapse photographs show that biological activity continues year-round but peaks immediately after the phytodetritus has sedimented out (Rice *et al*., 1994). Baited cameras reveal that large populations of amphipod and fish scavengers are attracted to the baits. There are richly diverse populations of macrofauna and meiofauna, largely supported by the flourishing bacteria flora of the surficial sediment. Based on Russian grab sampling programmes Belyaev *et al*. (1973) estimated that benthic biomass (in terms of wet weight) ranges from 0.1 – 1.0 g/m^2 in the south-east of Region V, to 1 – 10 g/m^2 in the north-east, to 10 – 50 g/m^2 in the far north of the region. Annual secondary production for abyssal regions varies between 0.005 and 0.05 g C/m^2. Within the abyssal fauna, deposit-feeding surface and subsurface fauna as well as omnivorous scavengers predominate. Specialist carnivores are scarce, because of the low density of potential prey (see Section 5.2.4).

South of 40º N, where there is no seasonal deposition of phytodetritus, biological activity is much lower. The surface of the sediment remains smoother and almost totally free of Lebensspuren. Macrofaunal and meiofaunal abundances are lower, and megafaunal species, particularly holothurians, are almost totally absent. However, baited cameras have revealed there are still large populations of scavengers but with a species composition that differs from that further north.

5.3 Impact of human activities

In the deep waters of Region V the impact of human activities is currently less acute than in the other OSPAR regions that cover the shallow, inshore waters around the continental margins. Even in the shallow water areas around the Azores, contamination levels are low because the islands are not industrialised and their small land-based discharges have only very localised impacts. However, the exploitation of resources, both inshore and offshore, is on the increase. A precautionary approach is needed until the potential risks posed by any further increases in fishing activity, particularly over seamounts along the Mid-Atlantic Ridge and in the deeper reaches of the continental slopes, can be satisfactorily evaluated. Especially as these fragile populations and habitats can be expected to show little resilience. Similarly, until the environmental risks associated with the further extension of hydrocarbon extraction from deeper slope waters can be satisfactorily assessed, developments should be subject to the precautionary principal. At present the guidelines delimiting the acceptability of impacts are inadequate.

5.3.1 Non-indigenous species

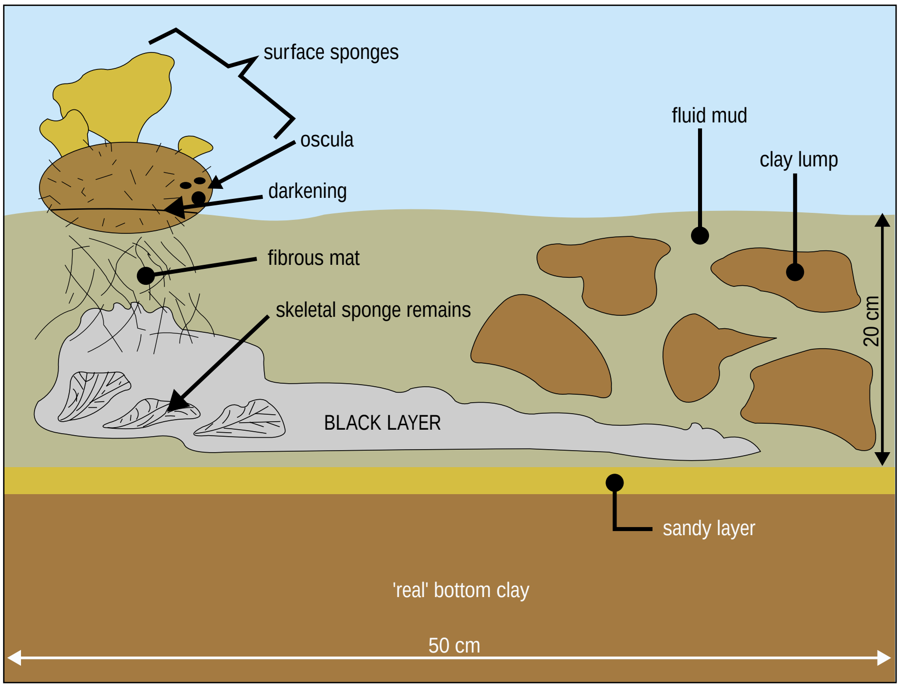
Jansson (in press) reports that very few non-indigenous marine species have been introduced into Region V. In the harbour at Horta on Faial, a few species of hydroid, found only on sheltered pontoons in the yachting marina, are probably non-indigenous (Cornelius, 1992). Such introductions can be of serious concern in inshore waters, where they may disrupt the local ecology and pose threats to human health and resources. The few non-indigenous species that have been introduced into Region V are currently posing no problems.

5.3.2 Fisheries

Open ocean fishes, especially those inhabiting deep water tend to be vulnerable to overexploitation, because they are at the ends of long food chains, are slow growing and have low fecundities. Evidence is beginning to emerge that the sorts of mechanical damage being inflicted upon North Sea benthic habitats and communities by trawling (Lindeboom and de Groot, 1998) is also being inflicted on some of the deeper ecosystems. The initial indications are that these impacts may not only be quite extensive already but may also be more persistent *(Figure 5.18)*. Several core samples and seabed photographs have shown clear signs of disturbance, including plough marks, the burial of sponges, strong odours of hydrogen sulphide and snagged nets *(Figure 5.19)*.

There are no data specific to the Atlantic that indicate how long the scars from trawling persist in deeper water, but in the Pacific an experiment was conducted to investigate the impact of possible seabed mining. This experiment showed that plough marks were still clearly visible after seven years (Thiel and Forschungsverbund TUSHE, 1995) and that the macrofaunal populations still showed clear signs of perturbation (Borowski and Thiel, 1998). The technical challenges posed by the exploitation of deepwater stocks means that they tend to be fished once other more accessible stocks no longer provide adequate returns, either because of overfishing or because quotas have been filled. Thus fishing for the deeper-living species tends to be more intermittent, less predictable

Figure 5.18 **Schematic diagram illustrating extensive disturbance of the bottom sediment at a depth of 800 m sampled with a box corer during an Atlantic Margin Environmental Survey (RRS Charles Darwin, cruise 112C). Source: B.J. Bett, SOC.**



and so less manageable than shallow-living stocks. Deep-living fish assemblages are highly diverse and there are markets for only a few of the species. Hence by-catches and discard rates tend to be high. Discards are the fish that are brought onto the deck of a fishing vessel but are subsequently thrown back, because they have little or no commercial value, because they are undersized or damaged, or because the allocation for landing that particular species has already been exceeded. The majority of deep-living fish are dead by the time they arrive on deck, so virtually all discards are contributing to the fishing mortality but go largely unrecorded. For example, a recent study of a French deepwater fishery around Rockall showed that similar quantities of fish were being discarded as were being landed. An analysis of the species composition of the discards from Scottish and French deepwater fleets recorded 82 species (Blasdale and Newton, 1998). Multi-species fisheries are inherently harder to manage sustainably.

By-catch in pelagic fisheries poses equally serious problems for the conservation of key species. Observers

Figure 5.19 **A trawl net snagged on a carbonate mound in the Porcupine Seabight May 1999. Source: George Deacon Division, SOC.**

Table 5.7 **Numbers of cetaceans observed as by-catch in 25% of vessels involved in the French tuna fishery 1992–3. Source of data: Goujon *et al*. (1996).**

	1992	1993
striped dolphin	330	243
common dolphin	114	90
long-fin pilot whale	13	16
bottlenosed dolphin	10	8
sperm whale	1	6
fin whale	2	0
minke whale	1	0
Risso’s dolphin	1	7
pygmy sperm whale	0	1
unidentified	4	5
vessel trips	58	63

on 25% of vessels involved in the French tuna longline fishery between 51 – 53º N and 10 – 20º W in 1992 and 1993 recorded large numbers of whales and dolphins being taken as by-catch *(Table 5.7)*. Heavy exploitation of commercial fishes may result in the diminution of resources for non-commercial species such as marine mammals and seabirds.

Fisheries for tuna and tuna-like fishes are particularly prone to catching non-targeted species. ICCAT (1997) recorded an extensive list of species taken as by-catch during a small-scale observer programme *(Table 5.8)*. Of 51 205 fishes landed by the Spanish swordfish fleet, which operates in the south of Region V and beyond, only 9990 were swordfish and 40 198 shark; 63.7% of the catch was blue shark (Biencuepo *et al*., 1998). This study just concerned landed fish so did not include data on discards.

Owing to the mismatch between ICCAT reporting areas and the five OSPAR regions, many of the species referred to in *Table 5.8* will not have been taken in Region V. Moreover, several of the species designated as being ‘coastal’ are actually associated with continental slopes and seamounts. Nevertheless, the list highlights the problem. In addition to fish species, the list includes worrying numbers of turtles and birds. During longlining, if baits are thawed thoroughly and a few simple precautions are taken to prevent birds taking the baits during deployment, far fewer birds are killed and the efficiency of the fishing is improved.

An impact of fishing on the general ecosystem that has not been quantified, is the effect of removing top predators. This is known to have profound effects on the structure of littoral and terrestrial communities, since in the absence of controls by top predators, the populations of the herbivores and detritivores become unstable, fluctuate and the overall diversity decreases. Discarding by-catch and offal will also upset competitive balances within the communities by favouring the scavenging species. Pauly and Christensen (1995) estimate that 25 – 35% of the primary production is being consumed (or discarded) by fisheries in some shelf seas, and for the total ocean their estimate is about 8%. Removing this proportion of the primary production must be having an impact.

5.3.3 Offshore activities

There is no evidence, as yet, that the early stages of exploitation of deepwater hydrocarbon reserves have had any deleterious impact on marine communities in Region V.

5.3.4 Shipping

With the abandonment of deep-sea dumping and the regulations imposed by MARPOL on ships at sea, inputs of most contaminants via direct discharges from vessels have been reduced. These now make a contribution (~ 13% according to IWCO, 1998) which is relatively small compared to those from other sources, particularly inputs from the atmosphere. Ships in ballast now routinely change their ballast waters in the open ocean to reduce the likelihood of introducing non-indigenous species into coastal waters. There is no evidence that this practise is creating any environmental problems.

5.3.5 Contaminants

Compared with inputs from land-based sources entering the region via the coastal seas, those entering via the atmosphere, despite being poorly quantified, are probably large enough to be of serious concern. For example, mercury levels have been substantially enhanced by human activity. Human exposure to MMHg via marine fish is one of the principal human health concerns associated with mercury in the environment (Fitzgerald *et al*., 1998) and long-range transport of anthropogenic mercury in the atmosphere has resulted in increases in the concentrations of MMHg in fishes remote from the sources. Ultraclean technologies are essential for monitoring, because sample contamination can totally obscure the minute quantities of mercury involved in natural fluxes. The maximum natural flux appears to be 6 nmol/m^2/d (i.e. 1.8 mmol/m^2/yr).

As a result of these analytical difficulties, there are insufficient data of adequate quality to link anthropogenic atmospheric discharges to human exposure or to that of aquatic ecosystems. One example of where regulations have proved successful is lead. Lead concentrations in the atmospheric and oceanic environments have diminished following the phasing out of lead additives in petrol.

Table 5.8 Numbers of species reported as by-catch in pelagic fisheries in the Atlantic. Source of data: ICCAT (1997).

Fishing method	Skates and rays	Coastal sharks	Pelagic sharks	Teleosts	Turtles	Birds	Mammals
Longlining	10	40	10	43	3	8	3
Gillnet	7	19	7	49	4	2	16
Purse seining	8	6	5	38	5	n.d.	16
Baitboat	n.d.	n.d.	n.d.	6	n.d.	n.d.	n.d.
Harpoon fishery	2	4	6	n.d.	n.d.	n.d.	n.d.

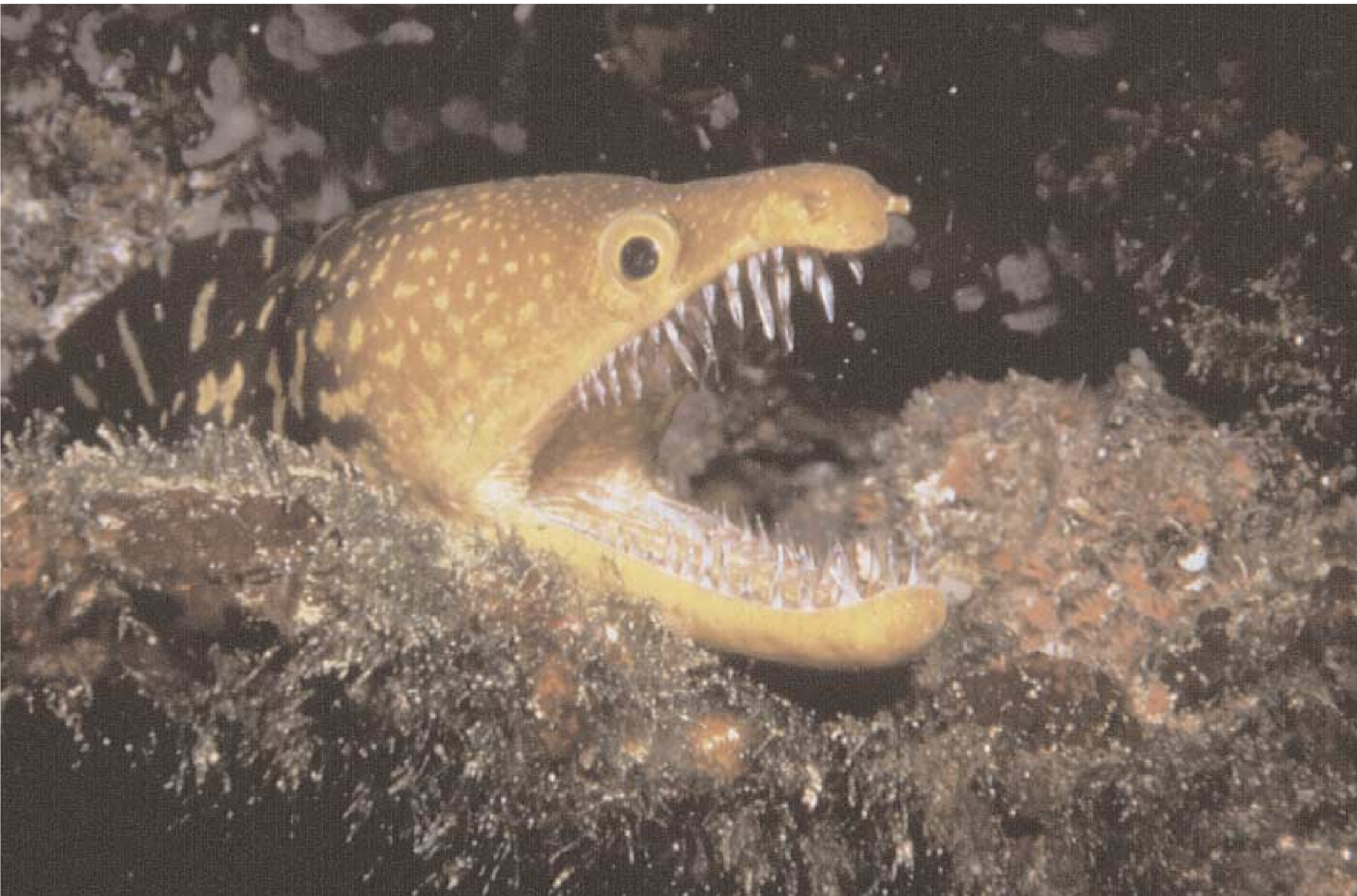
The wide-scale accumulation of synthetic organic compounds in organisms inhabiting remote ocean areas is of concern, and the pathways whereby some find their way into marine mammals and large fishes are often unknown. The effects of some of these environmentally unique substances in disrupting hormonal function in certain animal taxa can be expected to have subtle, but far-reaching, long-term impacts on ocean ecosystems and human populations. The question must be asked as to whether the short-term advantages of the manufacture and use of such substances are worth the longer-term risks to society. How can the introduction of new chemicals be regulated in order to minimise future environmental risks?

5.3.6 Litter

Litter, comprising packaging and items of fishing gear etc., is still to be seen accumulating in considerable quantities at convergent fronts. The sources are now mainly recreational uses of the open and coastal ocean and the fishing fleets, rather than commercial shipping. The accidental ingestion of such debris has been recorded in whales, turtles and some fish, often causing an obstruction in the digestive tract and occasionally death.

5.3.7 Carbon dioxide

Increases in the carbon dioxide content of the atmosphere may already be inducing changes in the global climate, but there is no evidence that the present increase to about 150% of the pre-industrial levels has had any deleterious effect on open ocean ecosystems. Despite sea water being well buffered, it has been estimated that the pH of the upper ocean has been reduced by about 0.1.



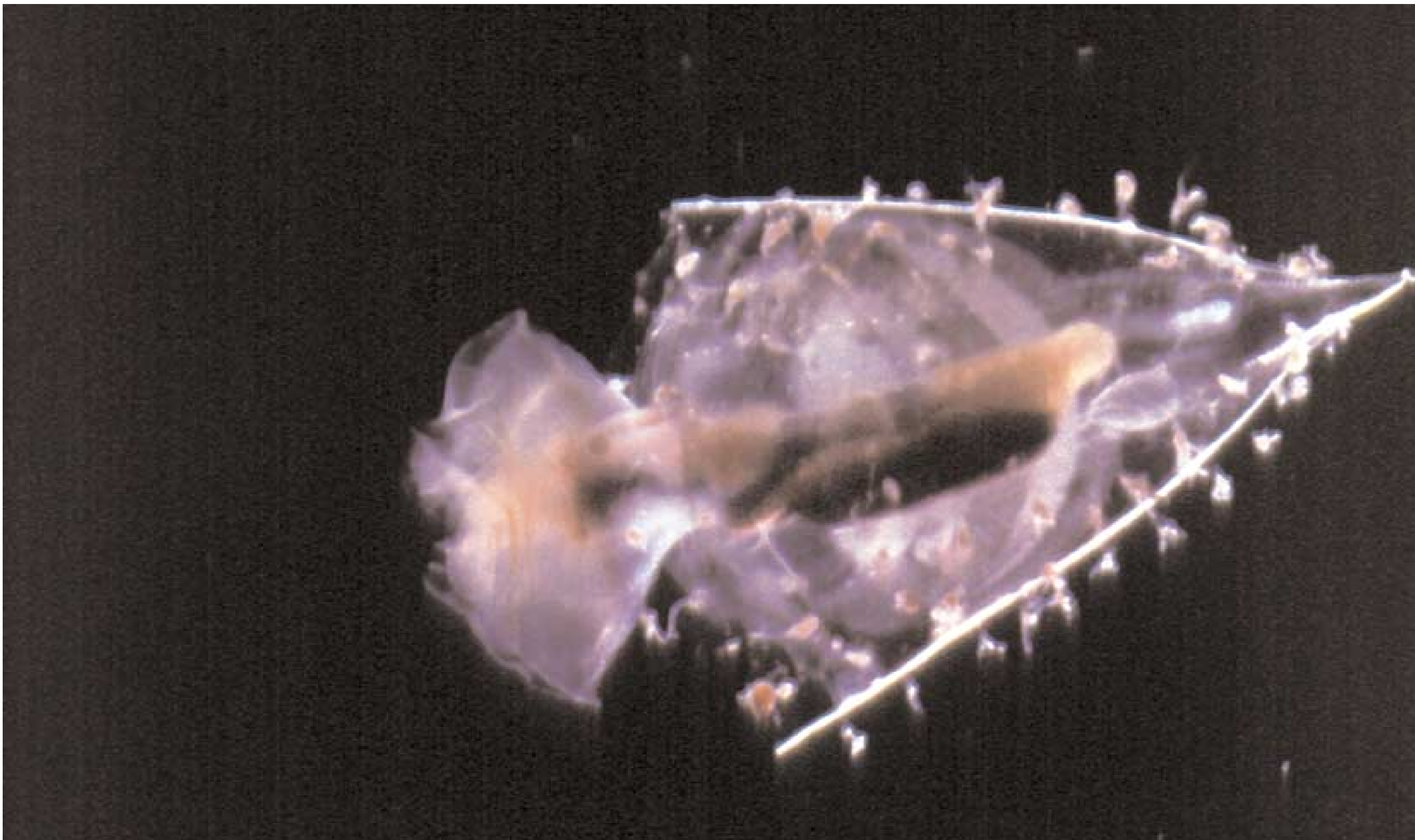
chapter

6

Overall assessment

6.1 Introduction

This chapter summarises the assessments discussed in the previous chapters and ranks the current concerns about the environmental health of Region V using the issues listed in OSPAR's Joint Assessment and Monitoring Programme. The chapter should be read within the context of various principles and strategies; those agreed at the 1997 Intermediate Ministerial Meeting on the Integration of Fisheries and Environmental Issues (held within the framework of the International Conferences on the Protection of the North Sea) to ensure the sustainable use of marine living resources, and those embodied in the OSPAR strategies on biodiversity, eutrophication, hazardous substances and radioactive substances, as adopted at the 1998 Ministerial Meeting of the OSPAR Commission. The objectivity of establishing levels of concern was hampered by the inadequacy of data on contaminant concentrations in Region V, but was aided by some of the remarkable recent advances in scientific understanding. Where information was sparse, the assessments of risk and concern tended to be more subjective and precautionary. *Table 6.1* presents the impacts in order of current concern, grouped according to those which represent regional level impacts and those which represent basin and global scale impacts. Sections 6.2 and 6.3 summarise the assessments in the order in which they are presented in *Table 6.1*, describing the impacts, the reasons for concern and where possible the effectiveness of current measures to address the impacts. Section 6.4 describes the relationship between Region V and the other OSPAR regions, while Section 6.5 summarises the limitations in the current knowledge and understanding of the processes, which inhibit objectivity in the assessments. Section 6.6 provides an overview of the overall health of Region V and Section 6.7 draws conclusions and presents recommendations.



It is clear that anthropogenic influences affect Region V over scales ranging from local to global. While there are many influences that emanate from activities within the OSPAR area, and so can be effectively controlled by OSPAR and reduced by regulation and agreement, others emanate from beyond the Convention area. For example, substantial proportions of the inputs of heavy metals and organochlorine compounds come from sources outside the OSPAR area (see Section 4.4.4) and their reduction will necessitate agreements with other international or national bodies. This will be a problem, if for example, the use of a particular insecticide is the only means of controlling a specific pest. Countries still using the product (whose use may be banned in OSPAR countries) may consider that the short-term economic and social benefits of continuing its use far outweigh any longer-term environmental costs. The prioritisation given to the relative importance of environmental and ethical issues versus economic and social issues by other nations will almost certainly differ from the strategy agreed by OSPAR for implementing its Joint Assessment and Monitoring Programme. There are also emissions emanating from both within and beyond the OSPAR area, which are having an impact at the global scale. These present a different category of problem, for example, reductions in emissions of greenhouse gases and CFCs must be undertaken at a global level if OSPAR's objectives are to be achieved. Even worse, if there is a failure to ameliorate these global scale influences then the hard won achievements of the regional actions will be undermined. If world population continues to grow as predicted, achieving solutions will become progressively more difficult because the short-term economic sacrifices will become less acceptable politically. A more holistic and long-term global approach is needed, which may require policies to be adopted and actions to be taken that are not necessarily favourable for the wealth and social structure of OSPAR countries in the short-term (as was the case with CFCs).

The OSPAR Convention defines 'the polluter pays' principle, whereby the costs of pollution prevention, control and reduction measures are to be borne by the polluter. In addition, to help ensure the sustainable use of

Table 6.1 Order of concern regarding regional level impacts and basin and global scale impacts within Region V, together with the level of scientific evidence for these impacts.

Ranking	Issue	Degree of concern	Impact potential	Comment
Regional level impacts				
1	Fisheries	high	1 or 2	Clear evidence of impacts on some but not all species and ecosystems
2	Habitat changes	high/medium	2	Induced by fishing activity and industrial exploitation
3	Hydrocarbons	medium	2	Tar balls on beaches; environmental impacts limited
3	Radionuclides	medium	3	Can disperse within biota
4	TBT	medium/low	3	Localised in inshore waters
4	Litter	medium/low	2	Impact on charismatic species and amenity
5	Heavy metals	low	3	Atmospheric inputs dominant
5	PCBs	low	3	
5	PAHs	low	3	
5	Other persistent organic compounds	low	3	
5	Shipping	low	3	
5	Ecosystem health	low	3	
5	Tourism	low	3	
6	Dioxin and furans	none	3	
6	Offshore activities	none	n.a.	
6	Nutrients	none	n.a.	Except inshore waters
6	Mariculture	none	n.a.	
6	Non-indigenous species	none	n.a.	
Basin and global scale impacts				
	CO_2	high	2	
	UV-B	high	2	
	Tourism	low	3	

* 1: clear evidence, 2: some indications, 3: potential; n.a.: not applicable.

ocean resources in the North-east Atlantic, the OSPAR Convention also requires that Contracting Parties ‘shall apply the precautionary principle, by virtue of which preventive measures are to be taken when there are reasonable grounds for concern that substances or energy introduced, directly or indirectly, into the marine environment may bring about hazards to human heath, harm living resources and marine ecosystems, damage amenities or interfere with other legitimate uses of the sea, even when there is no conclusive evidence of a causal relationship between the inputs and the effects’.

6.2 Assessment of human impacts at the regional level

These are considered as far as possible on the basis of objective scientific criteria, and without paying too much attention to possible future trends, despite the concept of sustainability necessitating assessments to be forward-looking. Moreover, perceptions of risk and the time and space scales over which sustainability should be sought differed between individuals and national policies (e.g. marked differences in the perception of radioactive contamination). The approach taken was essentially anthropocentric, in the belief that what is best for human society will best serve the wider environment. Hence the setting of priorities is likely to change with increasing knowledge and understanding, with changing circumstances and with the identification of new risks (such as endocrine disrupters). It is recommended therefore that priorities are reviewed biennially.

This section considers those issues that are predominantly internal and fall within the OSPAR sphere of influence.

6.2.1 Fisheries

The major current concern is the manner in which the fishing industry is operating. Fisheries are estimated to be exploiting as much as 8% of global ocean primary production (Pauly and Christensen, 1995). Subjectively, such a level of exploitation would seem to be close to the maximum level that can be sustained, but with the global human population set to double within the next century demands for fish as a source of high quality protein will continue to grow. Moreover, fishing is a vital industry for the many remote communities which contribute to the cultural diversity of Region V. Hence achieving sustainability in fisheries is a high priority. Even so, for many of the stocks there is clear evidence that the current levels of exploitation exceed estimated rates of replacement. Deep-water species are particularly vulnerable to overexploitation because they tend to be long-lived, slow to grow and mature, and to have low fecundities and recruitment rates. Deep-water fisheries tend to be multi-specific, which exacerbates the difficulties of rational management. In addition, evidence is emerging that deep-water benthic habitats tend to be more fragile and therefore less resilient and more susceptible to long-term damage by trawling, than most shallow-water habitats (see Section 5.3.2).

Exploitation levels for many of the tuna-like fishes are reported to be well in excess of the estimated replacement rates, and doubts have also been expressed about the effectiveness of the reporting procedures. Many of the fish are caught in international waters where there are legal and practical limitations to regulation. There has been little reduction in fishing effort despite the steady decline in catches. This is partly because rising prices have maintained the economic returns, but also because some states use subsidies to buffer their fishing industry from economic realities. These fisheries inflict considerable mortality on whales, turtles and seabirds, as well as on other fish species including sharks. There is widespread disregard of size restrictions on the landings of several species, because the fishing techniques are unselective for both size of fish and the species caught (for fish and other groups – see *Tables 5.7* and *5.8*). However, if the ban on landing undersized fish were more rigorously implemented it would merely increase the discards and contribute little to a reduction in fishing mortality. Tuna-like fishes are highly migratory and range well beyond the OSPAR area, to locations with many artisanal fisheries. It is impractical and may also be socially inequitable to try to limit artisanal fisheries. Management of stocks in international waters is difficult to enforce and it is striking that many Asian countries find it profitable to fish in Region V.

Sports and recreational fishing also contribute to the mortality of these large pelagic fishes. However, this is being reduced by the practice, increasingly adopted by sports fishermen, of releasing rather than landing the fish. Nevertheless, the impact of this activity on particular species should not be disregarded.

The importance of the work by the Scientific Committees of the various Regional Fisheries Organisations is recognised, as is the need to reinforce the activities of these Committees.

There is a lack of coherence between the reporting areas used by ICES and ICCAT, and the five subregions into which the OSPAR Convention area has been divided. This makes it difficult to use catch data to develop a coherent management strategy.

Management of fisheries for deep-living species encounters similar problems. The stocks are generally widely dispersed and extremely diverse in composition (see *Table 3.4*). Fishing at depths of > 500 – 1000 m is technically and economically demanding. Knowledge of the biology of many of the species and the structure, distribution and functioning of the deep-water ecosystems is rudimentary and inadequate for the formulation of rational science-based management. Levels of by-catch and discards tend to be excessive. Regulation of the deep-living stocks is made more difficult because fishing effort tends to be intermittent and to increase when quotas of the more accessible shallow-living species are restricted. Reports of landings are often inadequate, because species identification is difficult, and reports of by-catches and discards are seldom accurate unless a vessel is carrying an observer specifically to report such data. There are few, if any, baseline data for the majority of the stocks being exploited, so even if reporting procedures were improved, an evaluation of trends in stock sizes would remain difficult for the foreseeable future. Economic returns from deep-sea fishing are relatively small, and this tends to discourage investment in the resources needed to improve baseline data and stock assessments. Hence a precautionary approach for the management of these stocks could be encouraged. There are examples from many OSPAR countries of success in developing sustainable fisheries management systems based on rigorous scientific assessment, observation and monitoring. There has also been successful cooperation in jointly achieving sustainable management of straddling and migratory fish stocks. All member states should be encouraged to engage in effective cooperation for scientifically-based sustainable management of the region’s stocks otherwise, in the absence of substantive agreements to reduce fishing effort, other methods of conservation will have to be sought. Some of the special features, such as carbonate mounds, sponge aggregations, seamounts and hydrothermal vents, should be given protection and some specifically designated as sites for scientific research.

Fisheries associated with seamounts pose rather different problems. They are mostly mixed species fisheries operating within very restricted and often remote geographical areas, where fishery control vessels can not operate efficiently and the monitoring of stocks and fishing effort depends on voluntary compliance by fishermen. Few of the seamounts being exploited in Region V have been comprehensively studied. Because of their isolation, their benthic faunas are likely to be unusual with a high endemic component, whereas their pelagic fauna will be indistinguishable from that of the surrounding oceanic waters.

Even when there has been convincing scientific evidence of overexploitation, there has been a total lack of will by nations to reduce the fishing mortality, because of the internal short-term socio-economic problems this would engender. Hence, in many of the fisheries in Region V, there is overexploitation of targeted stocks and evidence of excessive by-catches and discards.

6.2.2 Habitat changes

There is concern about the clear signs of damage being inflicted by trawling on soft-bottom habitats and biological aggregations centred at depths of around 1000 m (*Figures 5.18* and *5.19*). Without baseline data from systematic surveys prior to the exploitation it is impossible to evaluate the extent of any damage caused. Some of the fishing techniques used, particularly trawling, are known to cause severe and probably persistent mechanical damage locally to deep-sea habitats. Signs of mechanical disturbance are frequently noticed during scientific investigations at slope depths of 500 – 1000 m (although such observations were not the objective of the investigation). Particularly vulnerable are those habitats which are created by biological structures, such as the dense aggregations of sponges (or ostur) and the carbonate mounds created by deep-sea corals *(Figure 6.1)*. It seems unlikely that all such damage is accidental; some carbonate mounds are 200 m high and so easily large enough to be detected by sonar. Anecdotal reports that chains have been towed across such features ‘to improve’ the fishing ground need to be taken seriously, if only to discount them.

Habitat changes also result from dumping and the sinking of vessels. However, sunken vessels are the targets of treasure hunters rather than foci for studies to understand the chemical and biological impacts of sunken ships on deep-sea environments and there have been very few assessments of the old dump sites. Those that have been carried out have focused on detecting chemical contamination rather than assessing impacts on the biological communities.

6.2.3 Hydrocarbons

Offshore, oil is a far less serious environmental hazard than close inshore. However, concern has been expressed about the widespread incidence of tar-balls accumulating at fronts and on the beaches of the Azores. The tar-balls affect coastal biota, inshore living resources and seabirds, and reduce the amenity of beaches. Most of the oil inputs to Region V result from tank washing. While changes in the operational procedures by large bulk carriers and the availability of waste disposal facilities in many ports have reduced such inputs to the open ocean, the problem persists. The implication is that a minority of operators continue to clean tanks at sea, possibly to avoid charges for port waste facilities.

The expansion of the hydrocarbon industry offshore is increasing the risk of accidental spillages, particularly because of the extreme weather and sea conditions that occur in the vicinity of the shelf-break. Most oil companies have now adopted a far more responsible attitude to the environment than when the North Sea reserves were first exploited. They are regulating their

Figure 6.1 **Deep-water corals growing on a carbonate mound at 51° 25.7' N, 11° 46.3' W and about 900 m. The photograph shows a variety of living hard corals, soft corals and bryozoans (white) in May 1999. Source: B.J. Bett, SOC.**

operational procedures accordingly, and are also more open in their planning procedures. However, in the absence of adequate biological and hydrographic surveys of the regions being opened for exploitation, the drawing up of environmental impact assessments at an early stage of development remains a problem.

Transportation of hydrocarbons presents relatively few risks to Region V. The majority of accidents to tankers and gas-carriers occur close inshore as a result of running aground or collision in busy shipping-lanes. The impact of accidents occurring remote from land are not generally considered serious enough to merit clean-up operations. Undoubtedly the most effective approach to reducing contamination by hydrocarbons is to continue to reduce the risk of accidents; by ensuring that all ships are operated to the highest safety standards, by the installation of automatic collision warning devices and by the routine routing of vessels well clear of potential hazards. Also, improvements in weather forecasting are enabling vessels to avoid extreme weather conditions.

The other potential source of hydrocarbon contamination is through the exploitation of offshore reserves that is just beginning along the continental slope to the north-east. Environmental impact assessments have been conducted by the industry, but neither the evaluation criteria nor the results of the surveys and assessments, have been open to public scrutiny. While there is no reason to doubt that the assessments have been properly conducted, greater public openness is both desirable and necessary. Thus, as the exploitation of hydrocarbon resources progressively extends into deeper and deeper water, it is proving extremely difficult to evaluate the potential environmental risks.

6.2.4 Radionuclides

The impact of radionuclides on oceanic environments continues to be of considerable concern to many countries. Most of the inputs have resulted from the testing of nuclear weapons, the dumping of wastes in deep water, the floundering of nuclear warships, accidents during transportation and discharges from coastal installations. The majority of these inputs have been drastically reduced. However, there is still concern about leakage from sunken nuclear submarines, leakage from the old dump sites and the coastal discharges from nuclear facilities that are now reaching Region V. Monitoring has focused on the spread of contaminants from these sources; there have been no studies on their *in situ* impacts on biological communities. While there is evidence for slight leakage leading to contamination of biota (but not sediments) particularly detritivores, there must be concern as to the long-term impact of these sources.

6.2.5 Tributyltin

Concern about TBT is focused on inshore waters of the Azores, particularly in the vicinity of harbours. Currently there is no evidence of significant levels of TBT contamination in Region V. However, recent information concerning endocrine disruption may result in much lower concentrations being considered significant.

6.2.6 Litter

Despite regulations controlling the disposal of litter at sea, considerable quantities are still observed at sea and washed up on beaches. The persistence of certain types of litter, particularly plastic and polystyrene, means that litter is originating from far beyond the limits of Region V. For example, some litter collected on UK beaches has crossed the Atlantic. The unsightliness of litter is only one of the concerns. There are many records of turtles, whales and large fish being entangled in pieces of fishing line or being choked by plastic. While such mortalities are probably a relatively small supplement to those resulting from other activities, they are avoidable and are contributing to the population declines of some species, such as turtles.

6.2.7 Heavy metals

Evidence of contamination is to be found in all ecological compartments of the deep ocean; in solution or suspension within the water column, within sediments and within pelagic and benthic biota. In open ocean environments, the main inputs of heavy metals are via the atmosphere (see Sections 4.4.3 and 4.4.4), since the majority of heavy metals discharged to coastal waters are retained in inshore environments, dumping has ceased and direct discharges from vessels have been substantially reduced. Compared to terrestrial ecosystems, oceanic food chains tend to have more links and cross-links, which means that even under pristine conditions top predators and some detritivores naturally accumulate higher concentrations of heavy metals. Enhancement of these naturally high levels by anthropogenically-derived contaminants may have two widely differing outcomes: firstly those species with a high tolerance are unlikely to be affected by the anthropogenic increases, as is clearly the case for species living in the vicinity of hydrothermal vents and may also be true for pilot whales, while secondly, for species living close to the limits of their physiological tolerance, particularly at certain stages in their life cycles, quite small anthropogenic supplements may cause severe physiological stress. The eggs of some seabirds have been found to contain high concentrations of some metals, although there is little direct evidence that these high levels are necessarily linked to reduced survival in chicks. The main problem is to identify the major sources of the atmospheric contaminants so that these can be targeted. The reductions in anthropogenic lead inputs show that substantial improvements are achievable if the sources are clearly identified.

Metal concentrations in the muscle tissue of most deep-sea fishes and squid caught in Region V are not high enough to present a human health risk, whereas concentrations of cadmium and mercury in some pilot whales caught and consumed in the Faroe Islands are high enough to present a moderate human health risk (see Section 4.4.2). With this exception, the most important impacts of heavy metal contamination in Region V are on ecosystem function.

Considerable reductions in anthropogenic inputs of heavy metals have already been achieved through abandonment of ocean dumping and the implementation of MARPOL regulations. While progress in these activities should be maintained, greater emphasis should be placed on reducing atmospheric inputs. Priority should be given to reducing mercury inputs and to the identification of the major anthropogenic sources. At present, there are almost no data on which to assess current trends in mercury concentrations in the region; this should be addressed by establishing an appropriate mercury monitoring programme, probably based on an analysis of levels in seabird feathers.

6.2.8 Polychlorinated biphenyls

Concentrations of PCBs in oceanic fauna are low relative to those observed in biota from heavily contaminated inshore environments. High, but very variable, concentrations of PCBs and organochlorine compounds have been identified in whales *(Tables 4.10 and 4.12)*. Nevertheless, even the highest concentrations appear to be well below the thresholds for an impairment of immune response. Any measures that successfully reduce inputs and concentrations in inshore environments, will also reduce concentrations in the open ocean. Current limitations on the manufacture of PCBs should be extended and greater consideration should be given to the destruction, both of PCBs in storage and PCBs still in use.

6.2.9 Polycyclic aromatic hydrocarbons

PAH concentrations in Region V are not currently of serious concern. The levels of some PAHs that occur naturally are being increased by human activities that result in forest fires and changing land use. The vulnerability of organisms to PAHs often increases at certain stages of the life cycle and fecundity may be reduced. With the extension of the hydrocarbon industry into deep-sea environments, concentrations of certain PAHs can be expected to increase locally unless careful controls are placed on their release. The impact of these substances on species from the shelf seas ranges from interference with immune systems, to the mimicking and disruption of hormonal functions, to direct toxic effects. As more information about the toxicity of these compounds becomes available, and more of the chemical species are routinely monitored, the degree of concern may well change.

6.2.10 Other persistent organic contaminants

Traces of persistent organic contaminants are ubiquitous in all compartments of the deep ocean ecosystems. However, as many of these compounds are uniquely anthropogenic their source must be human activities. There is no evidence for persistent organic contaminants having a deleterious effect on species within Region V, but it remains an open question as to whether this reflects a lack of studies or a true absence of impact. For deep ocean biota, dilution effects (in terms of the volume of water and the diffuseness of the biota) probably keep the severity of any impacts well below those experienced by shallow-water biota. There remains the persistent concern that the risks associated with the constant stream of new synthetic substances being introduced into world markets are currently underplayed by the chemical industries. Despite widespread awareness of the serious and deleterious consequences that have arisen from the introduction of some of these substances (e.g. DDT, CFCs and dioxins), the public perception is that genetic engineering and ecosystem manipulation associated with mariculture are far more threatening. Hence there is relatively little pressure on the chemical industries to develop more effective testing procedures for new synthetic products. It is suspected that high concentrations of some persistent organic contaminants could be leading to pathological responses, for example through the depression of immune response. Specific actions to reduce the inputs of persistent organic contaminants to Region V are not required since successful measures to reduce inputs to, and impacts on, shallow water ecosystems will be equally effective at reducing impacts on deep ocean ecosystems.

6.2.11 Shipping

Currently activities associated with shipping are not of high concern. Considerable advances in reducing discharges have been achieved through MARPOL. Also, direct inputs to Region V are probably smaller than to the four other OSPAR regions, as these have extensive areas of shelf seas and busier shipping lanes. Losses of vessels at sea have neither declined nor increased, despite marked increases in the sizes of ships and in the volumes of goods and bulk cargoes being transported, and are also more likely to occur inshore than offshore. The volume of ship movements are likely to continue to increase as global population increases. Provision of adequate waste facilities in ports is still not universal and the charges levied discourage their use by a minority of operators who resort to illegal dumping. Means of ensuring these facilities are used will reduce direct discharges.

6.2.12 Ecosystem health

Apart from concerns associated with the manner in which the fishing industry is operating (see Section 6.2.1), there is little current concern about the general state of ecosystem health in Region V. However, this must not result in complacency, especially as the impact of global climate change is likely to result in extensive modification to the ecology of the region.

6.2.13 Tourism

Tourism is emerging as a financially rewarding means of exploiting the oceanic resources of the region, particularly around the Azores. However, its expansion should not be too rapid as this may result in unexpected stresses on the islands' ecosystems and infrastructure. A major benefit of tourism is that it generates greater public awareness of the value of the environment and its resources. However, concerns have been expressed that the current trend towards larger cruise ships may begin to overload facilities and increase environmental pressures in very popular regions.

6.2.14 Other impacts

These include contamination by dioxins and furans, the development of offshore activities, increases in nutrient concentrations, mariculture and the introduction of non-indigenous species, and do not currently appear to be having a significant impact on Region V. However, the expansion of offshore activities needs to be closely monitored to ensure that the operators implement high environmental standards.

Nutrient inputs, notably of nitrogenous compounds, do not appear to be affecting the ecology of Region V. This is not unexpected since primary production is nutrient-limited throughout most of the year in most of Region V and the current regimes are extremely dynamic. There are no records of harmful or nuisance blooms occurring in the region. Many of the species responsible are shallow water species with life cycles that involve propagules which remain in the sediments until conditions favour their development. Even within the sheltered embayments of the Azores, where the physical environment is more suitable for their development, there are no records of such blooms. Water exchanges may be sufficiently dynamic to keep the nutrient concentrations, derived from agriculture and sewage inputs, below the thresholds that trigger the development of algal blooms or result in eutrophication.

Few non-indigenous species have been introduced into Region V. So, while no bulk carriers routinely arrive under ballast in the Azores, aquaculture remains undeveloped and there is no extensive aquarium trade with the islands, the likelihood of further introductions remains low.

6.3 Assessment of human impacts at the basin and global scale

Impacts occurring at basin or even global scale cannot be resolved by actions taken solely by OSPAR signatories; these require wider international agreements. These impacts tend to be longer-term, larger in scale and harder to reverse. So, even in the absence of clear scientific evidence of changes driven by anthropogenic influences, precautionary actions should be taken. The rationale for actions to ameliorate or prevent such large-scale impacts will include ethical considerations and the concept of stewardship. Similarly, prioritisation of these impacts will depend on the time frames and spatial scales adopted by the management bodies, the response times of the system and whether or not the action is pragmatically feasible.

6.3.1 Carbon dioxide

Carbon dioxide is a greenhouse gas, which means its impact is global. Historical increases in atmospheric concentrations and to a lesser extent in ocean environments are well documented (see Section 4.10). These increases are expected imminently to have a major influence on global climate patterns and to alter the ecological characteristics of terrestrial and marine ecosystems.

To avert the most deleterious of the impacts forecast, a substantial change is required in the patterns of global energy consumption over the next few decades. This includes urgent and substantial investments in energy efficiency and the use of sustainable, preferably renewable, energy sources.

6.3.2 UV-B radiation

The manufacture of CFCs has been phased out in most industrialised countries, including all OSPAR signatories. However, they continue to be manufactured in large quantities elsewhere. CFCs do not affect the ecology of oceanic ecosystems directly, but by depleting ozone levels in the stratosphere (25 – 40 km high) they allow an increase in the intensity of UV-B radiation reaching the Earth's surface. This will increase the incidence of human skin cancer and harm ecosystem processes in the ocean's euphotic zone (SCOPE, 1993). Over the Arctic, stratospheric ozone concentrations have been decreasing by 8% per decade (AMAP, 1997). The first ‘ozone hole’ appeared over the Arctic in January 1996 (AMAP, 1997), together with small reductions in concentration over Region V. In the Antarctic, increases in UV-B radiation have been shown to depress primary production (Smith *et al*., 1992) and to disrupt other biological interactions (Prezelin *et al*., 1993). The steps already taken to reduce emissions of CFCs and other ozone-depleting compounds are yet to be fully effective. There seems to be no alternative but to halt the manufacture of all compounds that cause the breakdown of stratospheric ozone, whatever their other socio-economic values.

6.4 Relationship with the other OSPAR regions

Processes occurring within Region V are critical to the other OSPAR regions. Region V is a source of heat and various other physical properties, including NADW, which is formed in Region I from the mixing of Overflow Waters with the ambient intermediate water close to the northern boundary. NADW is exported to all the other major oceans. Hence Region V is a pivotal region in the thermohaline circulation of the global ocean; it is the route whereby subtropical water flows via the North Atlantic Drift into Region I and has a major ameliorating influence on the climate of Northern Europe and the Arctic. During the 1990s there have been substantial changes in the formation of LSW, possibly as a result of shifts in polar influences, and these are having an impact on the deep and midwater circulation in Region V. A series of major salinity anomalies have circulated around the subpolar gyre (Belkin *et al*., 1998) and these events appear to have generated responses in the biological system at high latitudes (Reid *et al*., 1998). While it is too early to determine whether these biological responses have occurred in response to long-term changes in climate or to shorter-term oscillations, they are of concern and need to be properly monitored. If they persist or become accentuated, the implications for future climate and for the sustainable exploitation of living resources are far-reaching. Causal links between these changes and greenhouse gas emissions are probable, but remain scientifically unproven.

The boundaries between Region V, Region IV (the Bay of Biscay and the Iberian Coast) and Region I (Arctic Waters) are arbitrary and have no environmental significance. Their deep-water ecosystems are intimately linked and cannot be treated in isolation. The boundary between Region V and Region III (the Celtic Seas) follows the shelf-break and is thus aligned with a significant environmental front across which there are sharp transitions in the biology and chemistry of the system. Nevertheless, there are dynamic exchanges of water, containing dissolved and suspended material and sediments, plus associated substances. Active and passive movements of biota also occur across this boundary. There have been few attempts to quantify these many exchanges (van Weering *et al*., 1998).

Region V tends to be a sink for land-based contaminants, which it receives in dissolved or particulate form via exchanges of water, sediments and biota across the shelf-break, or via the air/sea interface. Hence material cycles in Region V, including contaminant cycles, are linked to the physical and biological processes occurring in the other OSPAR regions, such that the open waters of the Wider Atlantic are a conduit for the long distance transport of contaminants to and from the other regions (see Section 4.5.4). Moreover, the regulation of inputs to Region V can not be achieved without reducing inputs from outside the OSPAR region. Ultimately a global solution will be required.

6.5 Limitations in knowledge and understanding

6.5.1 The Azores

The Azores Archipelago is a special area within Region V. The marine ecosystems of the islands and associated seamounts remain understudied and hence poorly understood. Such isolated ecosystems can be expected to hold endemic species and sub-species. Such islands are natural laboratories and study of their marine ecosystems is likely to provide basic insights into the evolution and maintenance of natural communities. Development and exploitation of these marine ecosystems needs a precautionary approach. The development of the islands’ one major resource – tourism – has major implications for coastal zone management, conservation and the development of commercial and recreational fisheries. It will be important to avoid significant increases in the input of contaminants and the introduction of non-indigenous species.

The economic benefits of the developing tourist industry are partially offset by the increasing pressures exerted on the local infrastructure (i.e. demands for water, sewage treatment and refuse disposal) and the urbanisation of the coastal strip with hotel, leisure and transport facilities (Tapper, 1997). EIAs need to take account of the local impacts of each new development and the overall effects of the expanding tourist industry. Maintaining buffer zones around protected areas must become an integral factor in the EIA for each new development. Provision of adequate sewage treatment and solid waste disposal facilities is essential. All staff employed in tourist facilities must be well trained in maintaining high environmental standards.

There has been a rapid expansion in knowledge of the oceans over the 1980s and 1990s as a result of dramatic improvements in observational technology and computational power. Much remains to be understood, but the establishment of priorities and the setting of environmental goals are becoming increasingly objective tasks, provided agreement is reached as to which time/space scales are to be targeted. Ideally the oceans should be managed in real time, but their immense spatial scales and long-term responses mean that predictions of the physical circulation and the biological responses over annual to decadal time scales will be adequate and are likely to be feasible in the near future. The importance of the role played by the oceans in influencing climate and weather, makes the assimilation of observational data into predictive global circulation models a top priority, and one that should be achieved within a few years. This should lead to dramatic improvements in long-term weather forecasting and the ability to predict climate on decadal scales. The major bottleneck is the current inability to survey the interior of the oceans with sufficient resolution to run the predictive models effectively. However, robotic devices are at an advanced state of development and will provide some of the capability needed. Some critical scales and parameters will probably remain inaccessible.

An impediment to progress is the subdivision of oceanography into separate disciplines. A truly integrated interdisciplinary ocean science needs developing, but without any loss of the key skills and techniques needed to advance understanding in the various disciplines, particularly taxonomy.

The success of the MAST projects in improving scientific understanding of oceanic processes has greatly assisted in the preparation of this report and the continued support offered by the EU to scientific research in the open ocean, as well as in coastal areas, is welcomed.

6.5.2 Physical data

Fluctuations in the physical environment are the most important natural source of ecosystem variability. Hence knowledge of the physical processes is therefore essential if a distinction is to be made between natural variations in the environment and those that have been anthropogenically induced.

Uncertainties for Region V include:

- how the circulation patterns of the North-east Atlantic will respond to climate change;
- how to predict climatological change;
- the principal processes that result in the variations in deep-water formation;
- how to link physical processes with chemical and biological processes;
- how the NAO influences circulation within Region V;
- the causes of the salinity anomalies recently observed circulating around the subpolar gyre; and
- whether the belief that we are close to predicting climate change is over-optimistic.

Physical processes are more amenable to mathematical description than either chemical or biological processes, and methods for interpolating missing data points are more efficient. The mathematical models of physical processes that are needed for objective management are close to operational development. To run these models in a predictive mode, data from routine fine-scale observations must be assimilated in near real-time in order to keep the models tuned to reality. The ultimate goal must be to generalise these models by embedding biological and chemical models.

6.5.3 Chemical data

Understanding and predicting the chemistry of the oceans is a highly demanding task. There are three main themes in chemical oceanography. One is the analysis of nutrients and tracers to provide the data needed to support multidisciplinary studies on circulation, productivity, remineralisation and biogeochemical cycling. The second is the measurement and monitoring of chemical contaminants in water, sediment and biota in order to understand their sources, fluxes and ultimate fate. These are the data that link with impact assessments and underpin management strategies. The third is to understand fully the dynamics of carbon cycling in the deep ocean and its exchange with the atmosphere.

Applied chemical oceanography has to deal with a vast and growing array of chemical species that need to be assessed and monitored, and the complex factors that regulate their distributions require understanding. Very few of these chemical species can be measured automatically or routinely analysed in sea water. So individual samples of water, sediments or biota must be analysed. Isotopic analyses can often distinguish between natural and anthropogenic inputs, but are not amenable to monitoring. In addition many hundreds of new substances are being introduced into the marine environment each year by the chemical and pharmaceutical industries, many specifically designed to have biological effects. For each individual substance there is probably a very small chance of long-term danger to humanity or the ocean environment. However, if these small chances are multiplied by the number of new substances then the risks begin to increase considerably.

Uncertainties for Region V include:

- a lack of adequate baseline data against which contaminant levels can be evaluated and changes detected;

- the pathways whereby the majority of the contaminants (organic and inorganic) reach the deep ocean and the dynamics of their fluxes;
- the dynamics of many of the chemical transformations that occur in the biota, water column and sediments;
- the relative contributions of anthropogenic and natural inputs for many substances;
- a comprehensive understanding of the links between biological and chemical parameters;
- the identities of many organic compounds whose signatures appear in analyses;
- adequate quantification of atmospheric inputs of contaminants;
- the impact of long-term chronic exposures to low doses of contaminants;
- the impact of radioactive contaminants on biota and community functioning; and
- the ability to predict which substances will disrupt hormonal systems, including human hormonal systems.

6.5.4 Biological data

Uncertainties for Region V include:

- basic systematic information about the majority of benthic taxa, especially the smaller organisms;
- the importance of gelatinous organisms in pelagic ecosystems, mainly because they cannot be adequately sampled;
- the role of microorganisms in food webs and many aspects of biogeochemical cycling;
- the zoogeographical patterns and distributions of many keystone species and communities;
- the life cycles of many keystone species;
- the structure and dynamics of most deep-water food webs;
- the biological pathways for contaminants in deep ocean ecosystems;
- the natural variability against which contemporary changes in biological systems can be assessed;
- how long-term cycles in the physical environment affect midwater and seabed communities and processes;
- the links between biodiversity, productivity and other ecological processes;
- the impact of removing top predators, such as fish, from the oceanic ecosystems; and
- how to distinguish between natural variation and anthropogenically-generated change.

6.5.5 Fisheries data

Most of the stocks currently exploited in Region V come from sparsely distributed multi-species communities, which are difficult to assess in a non-destructive manner. Analyses of catch data are fraught with difficulty. Reported data are prone to inaccuracies because of uncertainties in identification and the lack of reporting for some species and discards. There are no data on mortality during fishing. Many of the stocks are migratory, which compounds the problems of designating appropriate reporting areas and in interpreting data on catches and landings. Some fishing methods inflict considerable mechanical damage on deep-water ecosystems.

Unknowns and uncertainties include:

- data to evaluate sustainable catch rates for many deep-sea species;
- stock structure and recruitment for many of the multi-species fisheries;
- the environmental impact of fishing techniques on fragile deep-sea ecosystems;
- life histories for many of the exploited species;
- the delimitation of deep-sea stocks – an urgent requirement that will probably need molecular genetic studies;
- the best means of optimising the sustainable exploitation of migratory stocks;
- improvements in the reporting of by-catch and discards; and
- the increasing interest in the exploitation of deep-sea species for natural products, pharmaceuticals and genetic material needs to be carefully monitored.

6.5.6 Regional intercomparability

Region V is predominantly deep ocean, and so very different in character from the other OSPAR regions which, with the exception of Region I, are predominantly shallow sea areas. Thus, even with a set of agreed management criteria for the whole of the OSPAR area, the priorities for achieving sustainable management in Region V will be quite different to those for the other regions.

6.6 Quality status of Region V

Generally, the environmental quality of Region V has not been seriously compromised. Contamination is widespread so the region cannot be regarded as being pristine, however, the contaminant concentrations are generally more diffuse and lower than in the shallow waters of the other OSPAR regions. There is no evidence that productivity or biodiversity have been reduced, or that ecological processes have been altered. Even so, the scientific evidence is compelling that deep water habitats in Region V are neither so extensive nor so remote that they will continue to be immune from human impacts indefinitely. However, the Atlantic is so variable across the whole spectrum of time and space scales that the discrimination of anthropogenically-induced change from natural variability will be extremely difficult. For example, in the 1970s and 1980s a series of papers originating from the CPR programme (see Section 2.13) suggested there was a persistent and deteriorating trend in the plankton ecology of the North-east Atlantic (Aebischer *et al*., 1990); the implication being that this was the result of human activities. However, since then long-term cycles have been identified with periodicities of decades or centuries, such as the 70 yr oscillation of the NAO (see Section 2.13 and *Figure 2.13*). These oscillations result in environmental fluctuations which, in the absence of long time series of observations, are easily confused with the effects of anthropogenic forcing. Without more information and a far better understanding of the region's biological, chemical and physical characteristics and processes, the discrimination between natural and anthropogenically-driven change may be delayed until it is too late to reverse the latter. To detect a cycle, observations must span more than a single oscillation. A critical gap remains between the time scales that can be extracted from records preserved in sediment sequences and ice cores on the one hand, and the few tens of years of scientific observations and monitoring of the deep ocean. There is also a conceptual difficulty in that long-term observational and monitoring programmes tend to be evaluated in some influential political and scientific management circles as poor quality science that provides a low investment return in terms of material wealth and maintaining the quality of life. Also, within the scientific community greater intellectual excitement is engendered by seeking for evidence of life on Mars, than in ensuring the continuation of human life on Earth. It is critically important to overcome these prejudices.

Human activities have been modifying material fluxes to the deep ocean ever since the land clearances by Neolithic man. Ice cores from the Greenland ice cap contain traces of lead deposited as a result of mining during the Roman era. But such inputs have accelerated considerably following the industrial revolution and the recent phase of exponential growth in the human population that has followed improvements in medical and agricultural sciences. The synthetic chemical industry has been particularly influential in modifying the global environment. Vitousek (1994) listed three impacts on global ecosystems resulting from human activities:

a. changes in land use resulting from population growth. These are dramatically modifying geochemical fluxes to the oceans both directly and indirectly via the atmosphere;
b. the rapidly increasing emissions of carbon dioxide from the burning of fossil fuels and the felling of forests. These threaten to disrupt the natural progression of the climate and to alter the competitive balance within plant communities on land and possibly in the oceans; and
c. massive increases in the amounts of nitrogen compounds available in the environment. These have more than doubled as a result of atmospheric nitrogen fixation in the manufacture of fertilisers, emissions from internal combustion engines and the extensive cultivation of leguminous crops.

Other critical impacts include the increasing number of synthetic compounds that are being manufactured by the chemical industry, particularly those containing halogens. Efforts to establish whether the introduction of these new substances results in any chronic, long-term effects have failed repeatedly. For example, it is now known that a large array of these synthetic substances disrupt endocrine and other physiological activities in organisms, including humans (see *Table 4.15*). The transfers and transformations of these contaminants, and the ways in which combinations may act synergistically are poorly understood.

The shear size and volume of the North Atlantic ecosystem gives it considerable inertia in its response to such modifying influences. However, it also means that once the system begins to change, halting or reversing the change may take considerable time and effort, even if it is possible to do so. The wise strategy is to be to be far more cautious about the introduction of new products.

There is also concern about the impact of the present levels and methods of exploiting living resources in the deep ocean. The fishes being exploited are adapted to a resource-limited environment and have life history strategies that result in low fecundity, so the resilience (or powers of recovery) of these ecosystems may be unusually low, particularly if the fishing changes the community structure by selectively removing top predators and scavengers. Similarly, there is some preliminary evidence that suggests the mechanical damage caused by fishing activity is more persistent in the deep ocean than in shelf seas.

Deleterious impacts on ocean systems may have to be discounted against environmental improvements in other components of the global ecosystems. For example, the impact of schemes to extract energy from wind, tides and waves will need to be discounted against benefits derived from reducing the emission of greenhouse gases. There should also be contingency planning as to how to deal with the consequences of major environmental change should the policies aimed at reducing these emissions fall short of the necessary targets.

The present approach to the sustainable exploitation of several of the region's deep-sea fish stocks is far from successful and an increasing amount of evidence is emerging that suggests deep-water environments are being damaged. Some improvement will be gained from better reporting procedures for by-catch and discards. Coherence between the reporting areas of the various regulatory bodies would be beneficial. However, if no reductions in fishing mortality can be achieved within the prevailing regime, then alternative approaches will have to be considered. At present, there are few conservation measures in place to give deep ocean systems adequate protection. Top priority should be given to establishing protected areas in the deep ocean to conserve some exemplar seamount and hydrothermal vent ecosystems. Examples of habitats where special biological communities occur, such as the ‘ostur’ sponge communities and the carbonate mounds (bioherms) of deep water corals such as *Lophelia pertusa*, should be given protection. A code of conduct is also needed to regulate scientific research at hydrothermal vents.

6.7 **Conclusions and recommendations**

6.7.1 Conclusions

At present there are few indications that the anthropogenic impacts in Region V are as worrying as those in the shelf seas of the other OSPAR regions. However, the continuing increase in world population will increase the pressure to exploit the ocean’s living resources and to expand its use for trade, transport and the exploitation of non-living resources, since a significantly large proportion of the natural terrestrial resources are already exploited. Inputs of contaminants from land-based sources and via direct inputs are much smaller and more dispersed than in coastal waters. Population growth will increase these inputs and vigilance will be required to ensure they do not increase too far.

There is a serious mismatch between the time scales of socio-economic management procedures and the complex interactions between ocean and atmosphere, and between the physics, chemistry and biology of the North-east Atlantic system, which will need to be resolved if Region V is to be sustainably managed. This will require a coordinated interdisciplinary and international approach, which is linked to programmes already in operation or at the planning stage, such as GOOS, meteorological observations and studies of atmospheric chemistry. The scope of the necessary programmes of baseline observations, monitoring and modelling will be beyond the resources of individual nations. The interaction between climate regulation, shelf seas, the environmental quality of the coastal zone and the dynamics of the open ocean gives urgency to the development of such an approach.

Moreover, a management regime that is restricted to the OSPAR area may not be adequate to deliver the objectives. There is already some evidence that substances whose use and manufacture are banned within Western Europe, are reaching the North-east Atlantic from other areas. Atmospheric inputs of contaminants are of particular concern, especially those that tend to accumulate within biological systems. These include some of the volatile metals and organochlorine compounds, which are accumulating in oceanic taxa at levels sufficiently high to cause concern. However, generally there is a lack of information on the concentrations of such contaminants within the deep ocean ecosystem.

In the longer term, increases in atmospheric carbon dioxide and climate change could interfere directly with biological processes in the upper water column, through changing the pH of the surface waters and hence the competitive balance between different components of the phytoplankton communities. Although in the geological past, atmospheric concentrations of carbon dioxide were higher than those likely to result from fossil fuel combustion, the rate at which the concentrations are currently increasing is likely to exceed the adaptive capability of key species. The end result is totally unpredictable at present.

If the socio-economic impacts of these changes, whether caused by or exacerbated by human activities, are to be kept within tolerable limits, greater predictive capabilities must be developed for weather and long-term climate. Remote sensing is providing the means to monitor the atmosphere and ocean surface at global scales, but greater observational capability is required for the interior of the ocean, if the models are to be maintained close to reality.

A key issue is how to resolve the problems of scale. Optimum solutions to environmental problems vary according to their context and to the scales in time and space at which they are addressed. While preparing this quality status report it became evident that, even if all the technologies required were available, the extent of the resources required to monitor all relevant parameters across all relevant time and space scales throughout the whole of Region V, are far in excess of what can realistically be expected to be deployed. In applying the precautionary principle, ameliorative action must be taken well in advance of achieving full scientific proof to link an effect with its suspected cause. Since such actions will often have considerable socio-economic implications, far greater emphasis must be placed on ensuring that society understands these implications and has ready access to all the relevant information.

6.7.2 Recommendations

Ideally the environmental management of Region V should be based on sound science. However, as there are still many gaps in scientific knowledge for this region, management decisions and priorities must be kept under constant review and modified as the scientific basis improves. Priorities for action must be developed that take into account local and regional requirements and circumstances, are consistent with holistic assessments of global sustainability and have the overall goal of reducing inputs into the OSPAR area.

The recommendations in the following sections address: how to continue to reduce inputs of anthropogenic contaminants into Region V; how to improve the scientific basis needed for sustainable management, on a regional and global basis; how to improve environmental management procedures; and the Azores as a special area within Region V.

6.7.3 Anthropogenic inputs

Taking into account the human activities identified in this quality status report, their impact on the marine environment and the evaluation of existing measures, it is recommended that the appropriate authorities consider the following actions to reduce anthropogenic inputs:

- give maximum priority to filling the critical gaps in qualitative and quantitative knowledge which currently inhibit objective decisions on how best to reduce atmospheric inputs;
- initiate programmes of research into sources and pathways, together with monitoring programmes to identify the critical regions;
- draw the attention of the appropriate fora to concerns and information about the impact on the marine environment of substances originating from outside the OSPAR Convention area (accepting that the implementation of the OSPAR strategies (see Section 6.1) should lead to a substantial reduction in discharges, emissions and losses from within the OSPAR area);
- initiate monitoring programmes for nesting seabirds and deep-living oceanic biota such that an increase in contaminant concentrations can be identified at an early stage;
- improve society's awareness as to the environmental risks of allowing the degradation of oceanic environments; and
- continue to seek improvements in the use of port waste facilities and in marine safety.

6.7.4 Improvements in the scientific and technical base

It is critical to establish the sources, pathways and fate of anthropogenic inputs to the region, and their impact on natural resources and ecological function, particularly in association with potential change in climate. To this end it is recommended that the appropriate authorities consider the following actions:

- give priority to continuing the few long time series of ocean observations and initiating new time series;
- utilise the extensive data sets obtained during international and EU-funded observational programmes, such as WOCE and JGOFS, in the development of models of ocean-atmosphere interactions and material fluxes;
- characterise the potential effects of the increasing carbon dioxide fluxes on deep-living biological communities;
- encourage active participation in the planning and implementation of GOOS and the relevant regional GOOS programmes;
- study the role of eddies, the interaction between oceanographic and atmospheric processes, and the relative importance of local processes and external forcing;
- evaluate the impact of common contaminants on oceanic biota, including phytoplankton, keystone planktonic species and fishes;
- undertake a further survey of the NEA radioactive waste dump site, specifically to establish whether the presence of the waste materials has induced any changes in the local community, and establish the range over which any such changes are detectable;
- develop a better understanding of the NAC in the northern sector of Region V, and the AzC in the southern sector of Region V, which dominate circulation in the upper layer of the North Atlantic;
- continue to ensure that all environmental data are of the optimum quality and freely exchanged;
- develop the technology to undertake routine surveillance of oceanographic parameters, to provide the data required for running climatological models;
- study the implications of climate change for the exploitation of living resources and the conservation of biodiversity;
- improve the information required to conserve the biodiversity of Region V by encouraging:
  - expertise in the systematics of deep-ocean species;
  - programmes to investigate the structure and dynamics of deep ocean food webs;
  - biogeographical surveys of community distributions within the water column and the benthos, such that the importance of special communities (e.g. those associated with seamounts, hydrothermal vents, sponge associations and deep water coral communities) can be objectively assessed; and
  - programmes to investigate the physiological implications of new contaminants.

6.7.5 Environmental management of the Wider Atlantic

This quality status report has drawn attention to the need for management of the Wider Atlantic. To this end, it is recommended that the appropriate authorities consider the following actions:

- develop a set of basic criteria for the management of the ocean that can be used in future environmental impact assessments. These criteria should take into account, *inter alia*, the need to conserve biodiversity, and to maintain water quality, ocean productivity and the sustainable exploitation of natural resources;

- apply the precautionary approach to fisheries management; and
- establish measures, such as marine protected areas, to ensure the conservation and sustainable use of special ecosystems and habitats, for example seamounts, hydrothermal vents, sponge associations and deep water coral communities.

6.7.6 The Azores

The unique and isolated ecosystems of the Azores have been highlighted in this report. To this end it is recommended that the appropriate authorities consider the following actions:

- develop sustainable tourism;
- apply a precautionary approach to the exploitation of living marine resources;
- study the marine ecosystem of the Azores and associated seamounts; and
- develop a code of conduct to regulate scientific research at hydrothermal vents.

SPECIES

Reference list of species mentioned in this report (sorted by common (English) name within categories)

Common (English) name	Scientific name
Mammals	
Atlantic spotted dolphin	*Stenella frontalis*
Atlantic white-sided dolphin	*Lagenorhynchus acutus*
Blainville's beaked whale	*Mesoplodon densirostris*
Blue whale	*Balaenoptera musculus*
Bottle-nose dolphin	*Tursiops truncatus*
Bryde's whale	*Balaenoptera edeni*
Common dolphin (short-beaked common dolphin)	*Delphinus delphis*
Cuvier's beaked whale	*Ziphius cavirostris*
Dwarf sperm whale	*Kogia simus*
False killer whale	*Pseudorca crassidens*
Fin whale	*Balaenoptera physalus*
Gervais' beaked whale	*Mesoplodon europaeus*
Harbour porpoise	*Phocoena phocoena*
Humpback whale	*Megaptera novaeangliae*
Killer whale	*Orcinus orca*
Long-fin pilot whale	*Globicephala melaena*
Melon-headed whale	*Peponocephala electra*
Minke whale	*Balaenoptera acutorostrata*
Narwhale	*Monodon monoceros*
Northern bottlenosed dolphin	*Hyperoodon ampullatus*
Northern right whale	*Eubalaena glacialis*
Pigmy killer whale	*Feresa attenuata*
Pygmy Sperm whale	*Kogia breviceps*
Risso's dolphin	*Grampus griseus*
Rough-toothed dolphin	*Steno bredanensis*
Sei whale	*Balaenoptera borealis*
Short-fin pilot whale	*Globicephala macrorhyncha*
Sowerby's beaked whale	*Mesoplodon bidens*
Sperm whale	*Physeter macrocephalus*
Striped dolphin	*Stenella coeruleoalba*
True's beaked whale	*Mesoplodon mirus*
White whale (beluga)	*Delphinapterus leucas*
White-beaked dolphin	*Lagenorhynchus albirostris*
Birds	
Arctic skua	*Stercocarius parasiticus*
Arctic tern	*Sterna paradisaea*
Black guillemot	*Cepphus grylle*
Bulwer's shearwater	*Bulweria bulwerii*
Common guillemot	*Uria aalge*
Common tern	*Sterna hirundo*
Cory's shearwater	*Calonectris diomedea*
English storm-petrel	*Hydrobates pelagicus*
Fea's petrel	*Pterodroma mollis feae*
Glaucous gull	*Larus hyperboreus*
Great shearwater	*Puffinus gravis*
Great skua	*Catharacta skua*
Greater black-backed gull	*Larus marinus*
Herring gull	*Larus argentatus*
Iceland gull	*Larus glaucoides*
Kittiwake	*Rissa tridactyla*
Leach's storm petrel	*Oceanodroma leucorhoa*
Lesser black-backed gull	*Larus fuscus*
Little auk	*Alle alle*
Little auk	*Plautus alle*
Little shearwater	*Puffinus assimilis baroli*
Long-tailed skua	*Stercocarius longicaudus*
Madeiran storm petrel (Madeiran shearwater)	*Oceanodroma castro*
Manx shearwater	*Puffinus puffinus*
Northern fulmar	*Fulmarus glacialis*
Northern gannet	*Morus bassanus*
Pomarine skua	*Stercocarius pomarinus*
Puffin	*Fratercula arctica*
Razorbill	*Alca torda*
Red phalarope	*Phalaropus fulicarius*
Red-billed tropic bird	*Phaethon aethereus*
Red-necked phalarope	*Phalaropus lobatus*
Roseate tern	*Sterna dougallii*
Sabine's gull	*Larus sabini*
Sooty shearwater	*Puffinus griseus*
White-faced shearwater	*Pelagodroma marina*
Wilson's storm petrel	*Oceanites oceanicus*
Yellow-legged gull	*Larus cachinnans*
Reptiles	
Green turtle	*Chelonia mydas*
Hawksbill sea turtle	*Eretmochelys imbricata*
Kemp's ridley	*Lepidochelys kempii*
Leatherback turtle	*Dermochelys coriacea*
Loggerhead turtle	*Caretta caretta*
Fish	
Abyssal grenadier	*Coryphaenoides armatus*
American plaice	*Hippoglossoides platessoides*
Anglerfish	*Ceratias hollboelli*
Anglerfish	*Lophius piscatorius*
Anglerfish	*Lophius* sp.
Argentine	*Argentina silus*
Argentine	*Argentina sphyraena*
Armourhead	*Pseudopentaceros wheeleri*
Atlantic bluefin tuna	*Thunnus thynnus*
Atlantic wolf-fish	*Anarhichas lupus*
Baird's smooth-head	*Alepocephalus bairdii*
Basking shark	*Cetorhinus maximus*
Bigeye tuna	*Thunnus obesus*
Big-eye/deep water cardinal fish	*Epigonus telescopus*
Birdbeak dogfish (deep sea catshark)	*Deania calceus*
Black dogfish	*Centroscyllium fabricii*
Black marlin	*Makaira indica*
Black scabbardfish	*Aphanopus carbo*
Black-mouthed dogfish	*Galeus melastomus*
Blue ling	*Molva dipterygia*
Blue marlin	*Makaira nigricans*
Blue shark	*Prionace glauca*
Blue whiting	*Micromesistius poutassou*
Blue-mouth	*Helicolenus dactylopterus*
Boarfish	*Capros aper*
Bristlemouth	*Cyclothone braueri*
Bristlemouth	*Cyclothone microdon*
Capelin	*Mallotus villosus*
Chub mackerel	*Scomber japonicus*
Common seabream	*Pagrus pagrus*
Conger	*Conger conger*
Deepwater redfish	*Sebastes mentella*
Deepsea cat shark	*Apristurus laurussonii*
Eelpout	*Lycodes* sp.
Fangtooth	*Anoplogaster cornuta*
Forkbeard	*Phycis phycis*
Great lantern shark	*Etmopterus princeps*
Greater forkbeard	*Phycis blennoides*
Greenland halibut	*Reinhardtius hippoglossoides*
Greenland shark	*Somniosus microcephalus*
Grenadier	*Coryphaenoides mediterraneus*
Gulper shark	*Centrophorus granulosus*
Haddock	*Melanogrammus aeglefinus*
Hake	*Merluccius merluccius*
Halibut	*Hippoglossus hippoglossus*
Horse mackerel	*Trachurus trachurus*
Kitefin shark	*Dalatias licha*
Knifetooth dogfish	*Scymnodon ringens*
Large eyed lepidion	*Lepidion eques*
Leafscale gulper shark	*Centrophorus squamosus*
Lemon sole	*Microstomus kitt*
Ling	*Molva molva*
Long nose velvet dogfish	*Centroscymnus crepidater*
Longfin hake	*Phycis chesteri*
Long-finned tuna (albacore)	*Thunnus alalunga*
Megrim	*Lepidorhombus* sp.
Mora	*Mora moro*
Offshore jack mackerel	*Trachurus picturatus*
Orange roughy	*Hoplostethus atlanticus*
Portuguese dogfish	*Centroscymnus coelolepis*
Ratfish	*Chimaera monstrosa*
Red bream/alfonsino	*Beryx decadactylus*
Red mullet	*Mullus surmuletus*
Red seabream/blackspot seabream	*Pagellus bogaraveo*
Redfish	*Sebastes marinus*
Rough-head grenadier	*Macrourus berglax*
Roughnose grenadier	*Trachyrhynchus trachyrhynchus*
Round ray	*Raja fyllae*
Round-nose grenadier	*Coryphaenoides rupestris*
Saithe/coley	*Pollachius virens*
Silver roughy	*Hoplostethus mediterraneus*
Silver scabbardfish	*Lepidopus caudatus*
Six-gill shark	*Hexanchus griseus*
Skate	*Raja batis*
Skate	*Raja* sp.
Skipjack	*Katsuwonus pelamis*
Smooth grenadier	*Nezumia aequalis*
Snipefish	*Macroramphosus scolopax*
Spearsnouted grenadier	*Coelorhynchus labiatus*
Splendid Alfonsino	*Beryx splendens*
Spotted moray ee	*Muraena helena*
Swordfish	*Xiphias gladius*
Thick-lipped grey mullet	*Crenimugil labrosus*
Tusk	*Brosme brosme*
Velvet belly	*Etmopterus spinax*
Whale-shark	*Rhincodon typus*
White seabream	*Diplodus sargus cadenati*
Witch	*Glyptocephalus cynoglossus*
Wreckfish	*Polyprion americanus*
Yellowfin tuna	*Thunnus albacares*
Lower animals	
Amphipod	*Eurythenes gryllus*
Amphipod	*Themisto compressa*
Barnacle	*Megabalanus tintinnabulum*
Copepod	*Calanus finmarchicus*
Copepod	*Euchaeta* sp.
Copepod	*Pleuromamma* sp.
Cuttlefish	*Loligo forbesii*
Deep sea cucumber	*Benthogone rosea*
Deep sea shrimp	*Pandalus borealis*
Deep water coral	*Lophelia pertusa*
Deep water coral	*Madrepora* sp.
Deepwater red crab	*Chaceon affinis*
Dogwhelk	*Nucella lapillus*
Edible crab	*Cancer pagurus*
Giant red shrimp	*Aristaeomorpha foliacea*
Goose barnacle	*Dosima fascicularis*
Goose barnacle	*Lepas pectinata*
Jellyfish	*Pelagia noctiluca*
Limpet	*Patella* sp.
Long-fin squid	*Loligo pealeii*
Mussel	*Bathymodiolus*
North Atlantic krill	*Meganyctiphanes norvegica*
Scarlet prawn	*Acanthephyra* sp.
Scarlet prawn	*Oplophorus spinosus*
Scarlet prawn	*Systellaspis debilis*
Shrimp	*Sergia* sp.
Shrimp	*Sergestes* sp.
Shortfin squid	*Illex illecebrosus*
Tunicate	*Pyrosoma* sp.
Plants	
Giant reed	*Arundo donax*
Ginger	*Hedychium gardeneri*
Micro alga	*Chattonella marina*
Micro alga	*Emiliana huxleyi*
Micro alga	*Chaetoceros* sp.
Micro alga	*Gyrodinium aureolum*
Micro alga	*Noctiluca* sp.
Micro alga	*Cerataulina pelagica*
Micro alga	*Ceratium* sp.
Micro alga	*Pfiesteria piscicida*
Tobacco	*Nicotina glauca*
Other organisms	
Bacteria	*Aureococcus anophagefferens*

ABBREVIATIONS

µ (prefix)	micro, 10^{-6}
ΣPCB	Sum of concentrations for individual chlorinated biphenyl congeners
Σ (prefix)	Sum (of concentrations)
°C	Degrees Celsius
2,4-D	2,4-dichlorophenoxy acetic acid
2,4,5-T	2,4,5-trichlorophenoxy acetic acid
ACG	Assessment Coordination Group (OSPAR)
ACOPS	Advisory Committee on Protection of the Sea
AEE	Anomalously Enriched Element
Ah	Aryl hydrocarbon
AMAP	Arctic Monitoring and Assessment Programme
ASMO	Environmental Assessment and Monitoring Committee (OSPAR)
Atm	1 atmosphere = 1.013 x 10^5 Pascal
AzC	Azores Current
BC	Before Christ
Bq	Becquerel (1 disintegration per second)
C	Carbon
CCMS	Centre for Coastal and Marine Science, Plymouth Marine Laboratory
CEFAS	Centre for Environment, Fisheries and Aquaculture Science (UK)
CFC	Chlorofluorocarbon
cm	Centimetre
CPR	Continuous Plankton Recorder
CPUE	Catch Per Unit Effort
d	Day
DDE	1,1-dichloro-2-(2-chlorophenyl)-2-(4-chlorophenyl)ethene
DDT	4,4’-dichlorodiphenyl-1,1,1-trichloroethane
DIN	Dissolve Inorganic Nitrogen
DIP	Dissolved Inorganic Phosphorous
DMHg	Dimethylmercury
DMS	Dimethyl sulphide
DNA	Deoxyribonucleic acid
dpm	Disintegrations per minute
dw	Dry weight
EC	European Commission
EEA	European Environment Agency
EEZ	Exclusive Economic Zone
EIA	Environmental Impact Assessment
EU	European Union
FAO	UN Food and Agriculture Organization
fw	Fat weight
G (prefix)	Giga, 10^9
GOOS	Global Ocean Observation System
GSA	Great Salinity Anomaly
HCB	Hexachlorobenzene
HCH	Hexachlorocyclohexane
IAEA	International Atomic Energy Agency
ICCAT	International Commission for the Conservation of Atlantic Tuna
ICES	International Council for the Exploration of the Sea
ICRW	International Convention for the Regulation of Whaling
IFREMER	Institut Français de Recherche pour l’Exploitation de la Mer
IMO	International Maritime Organization
IWC	International Whaling Commission
IWCO	Independent World Commission on the Oceans
JAMP	Joint Assessment and Monitoring Programme (OSPAR)
JGOFS	Joint Global Ocean Flux Study
kg	Kilogramme
km	Kilometre
km^2	Square kilometre
km^3	Cubic kilometre
LC	London Convention
LC	Labrador Current
LSW	Labrador Sea Water
lw	Lipid weight
m	Metre
M	Molar mass
M (prefix)	Mega, 10^6
MARPOL	International Convention for the Prevention of Pollution from Ships (1973/1978)
MAST	European Union’s Marine Science and Technology Programme
MEDDIES	Mediterranean water EDDIES
mm	Millimetre
MMHg	Monomethylmercury
mo	Month
MW	Mediterranean Water
n (prefix)	nano, 10^{-9}
NAC	North Atlantic Current
NACW	North Atlantic Central Water
NADW	North Atlantic Deep Water
NAMMCO	North Atlantic Marine Mammal Commission
NAO	North Atlantic Oscillation
NATO	North Atlantic Treaty Organization
NEA	Nuclear Energy Agency
nm	Nautical mile
ODP	Ocean Drilling Program
OECD	Organisation for Economic Cooperation and Development
OSPAR Commission	The term ‘OSPAR Commission’ is used in this report to refer to both the OSPAR Commission and the former Oslo and Paris Commissions. The 1972 Oslo Convention and the 1974 Paris Convention were replaced by the 1992 OSPAR Convention when it entered into force on 25 March 1998.
OTEC	Ocean Thermal Energy Conversion
p (in pCO_2)	Partial pressure
p (prefix)	pico, 10^{-12}
PAHs	Polycylic Aromatic Hydrocarbons
PCBs	Polychlorinated Biphenyls
PVC	Polyvinyl chloride
QSR	Quality Status Report
QSR 2000	Quality Status Report for the entire OSPAR maritime area published by OSPAR in 2000
QUASIMEME	Quality Assurance of Information for Marine Environmental Monitoring in Europe
RTT	Regional Task Team (OSPAR)
s	Second (time)
SAIW	Subarctic Intermediate Water
SIME	Working Group on Concentrations, Trends and Effects of Substances in the Marine Environment (OSPAR)
SOC	Southampton Oceanography Centre
SPM	Suspended Particulate Matter
Sv	Sievert (1 J kg^{-1} x (modifying factors))
SWODDIES	Slope Water Oceanic eDDIES
t	Tonne
T (prefix)	Tera, 10^{12}
TBT	Tributyltin
UNCLOS	United Nations Convention on the Law of the Sea
UV-B	Ultraviolet radiation with wavelenght of 315 – 280 nm
W	Watt
WOCE	World Ocean Circulation Experiment
ww	Wet weight
yr	Year

GLOSSARY

Abyssal plain	The more or less flat region of the deep ocean floor below 4000 m, excluding ocean trenches, formed by deposition of pelagic sediments and turbidity currents that obscure the pre-existing topography
Advection	The transfer of heat or matter by horizontal movement of water masses
Aeolian	Pertaining to the action or effect of the wind
Anomalously Enriched Elements (AEE)	Elements that occur in particles in proportions that are in excess of their mean abundance in natural rocks
Anoxia	A complete absence of oxygen
Anthropogenic	Caused or produced by human activities
Background concentrations of natural compounds	The concentration of a natural compound that would be found in the environment in the absence of human activity. Natural compounds are those produced by biosynthesis from natural precursors or by geochemical, photochemical or chemical processes
Baroclinic	Referring to a condition and type of motion in which the pressure is not constant on the surfaces of constant density, e.g. due to internal tides and other internal waves
Baroclinic instability	Imbalance of the pressure distribution between adjacent water bodies of different densities leading to a turnover of water
Bathypelagic	The depth zone of the oceanic water column below the level of light penetration at depths between 1000 m and 2500 m. Also an adjective describing species and conditions found in the bathypelagic zone
Benthic boundary layer	The layer of water with homogeneous physical and chemical characteristics that immediately overlies the seabed. Usually the layer is up to 100m thick but can extend further into the water column during benthic storms
Benthic storm	An intermittent event occurring close to the seabed when currents exceed 30 cm/s for several hours or days. Benthic storms are usually associated with the passage of mesoscale eddies over the area
Benthos	Those organisms attached to, living on, in the seabed. Benthos is categorised by its diameter into: - nanobenthos: passes through 63 µm mesh - microbenthos: passes through 100 µm mesh - meiobenthos: within the 100 – 500 µm range - macrobenthos: passes through 1 cm mesh but is retained on 1000 – 500 µm mesh - megabenthos: visible, sampled using trawls and sieves
Bioaccumulation	The accumulation of a substance within the tissues of an organism. This includes 'bioconcentration' and uptake via the food chain
Bioherm	A mound-like accumulation of debris of biological origin (including calcium carbonate). The term describes the reef-like structures formed by deepwater corals
Biomagnification	The process whereby concentrations of certain substances increase with each step in the food chain
Biomass	The total mass of organisms in a given place at a given time
Biota	Living organisms
Bloom	An abundant growth of phytoplankton, typically triggered by sudden favourable environmental conditions (e.g. excess nutrients, light availability, reduced grazing pressure)
By-catch	Non-target organisms caught in fishing gear
Calcite	A mineral form of calcium carbonate that occurs in many shells and in the skeletons of living organisms
Cascading	Cascading occurs when a large volume of dense shelf water slides down slope into deep water
Chemosynthesis	The synthesis of organic compounds using chemical energy derived from the oxidation of simple inorganic substrates
Climate	The long-term average conditions of the atmosphere and/or ocean
Cold seeps	Discharges of water from the sediments that often have anomalous salinities, but not temperatures, and contain unusual concentrations of dissolved organic compounds and gases
Compensation Depth	The depth at which the gain in organic matter resulting from photosynthesis is exactly balanced by the losses resulting from respiration so there is no net production
Contaminant	Any substance detected in a location where it is not normally found
Continental margin	The ocean floor between the shoreline and the abyssal plain, including the continental shelf, the continental slope and the continental rise
Continental rise	The gently sloping seabed from the continental slope to the abyssal plain
Continental shelf	The shallowest part of the continental margin between the shoreline and the continental slope; not usually deeper than 200 m
Continental slope	The steeply sloping seabed from the outer edge of the continental shelf to the continental rise
Contour current	An ocean current flowing approximately parallel to the bathymetric contours on the ocean bottom
Contourite	Sediments deposited on the continental rise by contour currents
Convergence	An oceanic region in which surface waters of different origins come together and where the denser water sinks beneath the lighter water
Core rings	Mesoscale eddies that are pinched off from meanders along fronts bordering major current flows
Coriolis effect	This is the apparent force generated by the rotation of the Earth that is produced by the conservation of angular momentum. In the northern hemisphere this imparts a clockwise rotation to a body of moving air or water
Cross-shelf exchanges	Exchanges of water across the shelf-break between the open ocean and shelf waters
Crust	Rocks overlying the Earth's mantle; in the oceans, crust is formed along mid-ocean ridges
Diagenesis	The chemical and physical processes, in particular compaction and cementation, involved in rock formation after the initial deposition of a sediment
Diel vertical migration	Daily (24 hour) migrations undertaken by pelagic animals that generally move up towards the surface at dusk and then return to deeper water at dawn
Discards	Fish and other organisms caught by fishing gear and then thrown back into the sea
Dissolved Organic Carbon (DOC)	Carbon in organic compounds that are in solution in sea water
Diversity	The genetic, taxonomic and ecosystem variety in organisms in a given marine area
Drift deposits	Unconsolidated sediments transported from one place to another by wind or water currents
Dumping	The deliberate disposal in the maritime area of wastes or other matter from vessels or aircraft, from offshore installations, and any deliberate disposal in the maritime area of vessels or aircraft, offshore installations and offshore pipelines. The term does not include disposal in accordance with MARPOL 73/78 or other applicable international law of wastes or matter incidental to, or derived from, the normal operations of vessels or aircraft or offshore installations (other than wastes or other matter transported by or to vessels of offshore installations for the purpose of disposal of such wastes or other matter or derived from the treatment of such wastes or other matter on such vessels or aircraft of offshore installations)
Ecosystem	A community of organisms and their physical environment interacting as an ecological unit
Ecotoxicology	The study of the effects of toxic substances on the ecological function and structure of natural communities
Emission	A release into air
Endemic	Native, and restricted, to a particular locality or specialised habitat
Endocrine disrupter	An exogenous substance that causes adverse health effects in an intact organism, or its progeny, consequent to changes in endocrine function. In applying this definition to the marine environment it will be necessary to consider substances that are likely directly or indirectly to affect the hormonal regulation in whole organisms by the mimicking of hormones or by affecting enzyme systems responsible for hormone equilibria
Epipelagic	The depth zone of the oceanic water column extending from the surface to about 200 m. Also an adjective describing species and organisms that live in the epipelagic zone
Euphotic zone	The upper layers of the sea with sufficient light penetration for net photosynthesis to occur
Eutrophication	The enrichment of water by nutrients causing an accelerated growth of algae and higher forms of plant life to produce an undesirable disturbance to the balance of organisms present in the water and to the quality of the water concerned, and therefore refers to the undesirable effects resulting from anthropogenic enrichment by nutrients
Fisheries management	In adopting Annex V to the 1992 OSPAR Convention, on the Protection and Conservation of the Ecosystems and Biological Diversity of the Maritime Area, OSPAR agreed that references to 'questions relating to the management of fisheries' are references to the questions on which action can be taken under such instruments as those constituting: - the Common Fisheries Policy of the European Community; - the corresponding legislation of Contracting Parties which are not Member States of the European Union; - the corresponding legislation in force in the Faroe Islands, Greenland, the Channel Islands and the Isle of Man; or - the North East Atlantic Fisheries Commission and the North Atlantic Salmon Commission; whether or not such action has been taken. For the avoidance of doubt, in the context of the OSPAR Convention, the management of fisheries includes the management of marine mammals
Focus areas	An area of special attention in the QSRs. They may consist of a typical and valuable habitat for marine life, may be under (anthropogenic) stress, may be of strategic or economic importance, or scientific research may have resulted in a relatively large amount of information on the area.

Food web	The network of interconnected food chains along which organic matter flows within an ecosystem or community
Fossil fuel	Mineral fuels (coal and hydrocarbons) rich in fossilised organic materials which are burnt to provide energy
Fracture zone	A zone along which displacement has occurred; major fractures are found at right angles to the mid-ocean ridges
Fronts	The boundary zone between two water masses differing in properties, such as temperature and salinity. Fronts can be either convergent or divergent
Geochemical	Relating to the natural chemistry of the Earth
Glacial deposit	Sediment deposits resulting from large-scale movements of glaciers and ice-rafting during glacial periods
Glacial periods	Cool to cold climatic periods, characterised by advancing ice sheets and caps, within the Quaternary Period
Great Salinity Anomaly (GSA)	Large-scale advective features that take several years to progress around the subpolar gyre in the North Atlantic
Gyre	Large-scale ocean circulation pattern generated by the interaction of winds and the rotation of the earth
Haemocyanin	The respiratory pigment found in many invertebrate animals, particularly crustaceans
Harmful Algal Blooms (HAB)	Blooms of phytoplankton that result in harmful effects such as the production of toxins that can affect human health, oxygen depletion and kills of fish and invertebrates and harm to fish and invertebrates e.g. by damaging or clogging gills
Hepatopancreas	The combined stomach and pancreatic glands typical of crustaceans
Hydrography	The study of water characteristics and movements
Hydrothermal	Related to the circulation of fluids in the crust driven by pressure and geothermal heat. In the ocean this results in the discharge from underwater vents of chemically modified and often superheated water
Imposex	A condition in which the gender of an organism has become indeterminate as a result of hormonal imbalances or disruption, as in the case of the effect of tributyltin on gastropods
Inshore waters	Shallow waters on the continental shelf, a term usually applied to territorial waters within 6 miles of the coasts
Interglacial periods	Warm to temperate periods between glaciations within the Quaternary Period
Internal waves	Waves occurring on density surfaces within the ocean and most commonly generated by the interaction between tidal currents and the sea bed structure
Intrusion	Water that is intermediate in density between two contiguous water masses and so flows between them
Isohaline	A line connecting points of equal salinity
Isopycnal	A surface of equal density within a water body
Isotope	A form of an element chemically identical to another but with a different atomic weight
Key species	A species whose loss would have a detrimental or disproportionate effect on the structure, function and/or biological diversity of the ecosystem to which it belongs
Keystone species	A species which is one of the hubs of the interactions within the food web. Also used to describe a species whose impact on its community or ecosystem is large and much greater than would be expected from its abundance
Lethal limit	The maximum or minimum concentrations or conditions that result in the death of an organism
Levée	A sediment bank along the course of a water or turbidity current
Liths	Concretions of calcium carbonate that are formed in certain species of picoplankton (coccolithophorids) and can result in the upper ocean having a high reflectance
London Convention	The 1972 Convention on the Prevention of Marine Pollution by Dumping of Wastes and other Matter. The Convention is administered by the International Maritime Organization
Lysocline	The oceanic depth zone between the carbonate dissolution depth (about 4000 m), where calcium carbonate (usually in the form of calcite) begins to dissolve, and the carbonate compensation depth (about 5000 m). Sediments laid down at depths greater then the lysocline lack calcium carbonate
Mantle	The ductile layer of the Earth between the crust and the core
Marine biotoxins	Toxins produced by phytoplankton species (e.g. some dinoflagellates) and accumulated through the food chain to levels dangerous for human consumers or for the species itself
Marine snow	Organic and inorganic debris that aggregates around mucus and appears like tiny snow flakes in the lights of submersibles. Marine snow is most abundant just below the thermocline, and is an important food source for many planktonic animals. Over a period of time this material settles towards the bottom
MARPOL 73/78	The International Convention for the Prevention of Pollution from Ships, 1973, as modified by the Protocol of 1978 relating thereto
Mass wasting	A catastrophic failure of the continental slope which results in underwater slides of large volumes of sediment down the continental slope and out over the abyssal plain. It also generates turbidity flows
Meddy	A mesoscale eddy of Mediterranean Outflow Water which occurs at a depth of around a kilometre in the North-east Atlantic
Mesopelagic	The depth zone of the oceanic water column between 200 and 1000 m. Also an adjective describing organisms which occur in the mesopelagic zone.
Mesoscale eddy	An eddy with dimensions of 10 – 200 km
Meteorology	The study of weather and climate
Methylation	The addition of a methylgroup (-CH$_3$) to a compound
Microbial food web	The food web that is sustained by picoplankton cells that are too small to be filtered from the water by suspension feeders
Micronekton	The larger pelagic animals that are routinely sampled by large trawls (usually with mesh sizes of 3 – 5 cm)
Mid-ocean ridge	A continuous topographical feature of the ocean floor comprising rifts and mountain ridges; it is a broad, fractured swell with a central rift valley and unusually rugged topography; the ridge is the place where new oceanic crust is formed by volcanic activity
Miocene	A geological epoch within the Upper Tertiary Period (*c.* 26 to 5 million years ago)
Multi-species approach	A form of management that takes into account interaction between the different components in the food webs of the ecosystems
Nepheloid layers	Layers of water containing high concentrations of suspended particulate material, which are readily identified by their light scattering properties (as measured by nephelometers)
Nordic Seas	Collective term for the Norwegian, Iceland and Greenland Seas
North Atlantic Oscillation (NAO)	The North Atlantic Oscillation index is defined as the difference in atmospheric pressure at sea level between the Azores and Iceland and describes the strength and position of westerly air flows across the North Atlantic
Nutrients	Dissolved phosphorus, nitrogen and silica compounds
Ocean Conveyor	A popular term for the global ocean circulation pattern, which results in the exchange of water between all the major oceans
Ocean Thermal Energy Conversion (OTEC)	The extraction of renewable energy from the ocean by exchanging heat from the warm upper surface waters of the ocean with cooler deeper waters. A temperature differential of about 20 °C is required for OTEC to work
Offsets	Faults which result from moving a solid plate laterally over a curved surface
Oligotrophic	Pertaining to waters having low levels of the nutrients required for plant growth, and thus low levels of primary productivity
Ontogenetic migration	The occupation by an animal of different habitats at different stages of development
Organohalogens	Substances in which an organic molecule is combined with one or more of the halogen group of elements (i.e. fluorine, chlorine, bromine, iodine)
Overflow waters	Cold high density waters that spill over the relatively shallow sills that lie between Greenland, Iceland and Scotland, or flow through the deep channels dissecting these sills
Pangea	The single supercontinent comprising the present continental land-masses joined together, which formed about 300 million years ago and began to break up about 200 million years ago; its fragmentation lead to the formation of the Atlantic Ocean and the Mediterranean Sea
Particulate Organic Carbon (POC)	The organic carbon that is not in solution in sea water; usually separated from dissolved organic carbon by 45 µm filtration
Pelagic deposits	Deep ocean sediments containing no significant terrigenous component and derived mainly from the sinking of lithogenic and biological particles formed in the oceanic water colum
pH	Quantitative measure of the acidity or basicity of aqueous or other liquid solutions
Phytodetritus	The accumulations of biological material, that appear in deep water after surface phytoplankton blooms collapse
Phytoplankton	The collective term for the photosynthetic members of the nano- and microplankton
Plankton	Those organisms that are unable to maintain their position or distribution independent of the movement of the water. Plankton is categorised by its diameter into: - picoplankton: < 2 µm - nanoplankton: 2 – 20 µm - microplankton: 20 – 200 µm - macroplankton: 200 – 2000 µm - megaplankton: > 2000 µm
Plate boundary	Edges of lithospheric plates where seismic and tectonic activities occur
Pollutant	A substance (or energy) causing pollution
Pollution	The introduction by man, directly or indirectly, of substances or energy into the maritime area which results, or is likely to result, in hazards to human health, harm to living resources and marine ecosystems, damage to amenities or interference with other legitimate uses of the sea

Production, primary	The assimilation of organic matter by autotrophs (i.e. organisms capable of synthesising complex organic substances from simple inorganic substrates; including both chemoautotrophic and photoautotrphic organisms). Gross production refers to the total amount of organic matter fixed in photosynthesis and chemosynthesis by autotrophic organisms, including that lost in respiration. Net production is that part of assimilated energy converted into biomass and reflects the total amount of organic matter fixed by autotrophic organisms less that lost in respiration
Production, secondary	The assimilation of organic matter by heterotrophic organisms (organisms unable to synthesise organic compounds from inorganic substrates)
Pycnocline	A density discontinuity in a water column. This is commonly used to refer to the narrow depth zone at the base of the relatively uniform surface mixed layer within which the density of the water increases sharply either because of a decrease in temperature (thermocline) or an increase in salinity (halocline)
Quaternary Period	A geological period of the Cenozioc Era (1.6 million years ago to the present) that is subdivided into the Pleistocene (the glacial age) and the Holocene (10 000 years ago to the present) epochs
Radionuclide	Atoms that disintegrate by emission of electromagnetic radiation, i.e. emit alpha, beta or gamma radiation
Recruitment (fisheries)	The process by which young fish enter a fishery, either by becoming large enough to be retained by the gear in use or by migrating from protected areas into areas where fishing occurs
Redox potential	A measure of the tendency of a given system to act as an oxidizing or reducing agent
Remineralisation	The conversion of a substance from an organically bound form back to a water-soluble inorganic form, resulting in the release of inorganic nutrients (e.g. nitrate, phosphate), carbon dioxide or methane back into solution
Salinity	A measure of the total amount of dissolved salts in sea water
Seamount	An elevated area of limited extent rising 1000 m or more from the surrounding ocean floor, usually conical in shape
Seismic activity	Earthquake events that result from sudden releases of energy related to volcanic activity or rock movements caused by crustal movements
Sequestration	The long-term storage of material or energy
Shelf break	The outer margin of the continental shelf marked by a pronounced increase in the slope of the seabed; usually occurring at around 200 m in depth along European margins
Slope current	A current that follows the shelf break along a continental margin
Standing crop	The biomass of organisms per unit volume at a given time
Subduction	The process by which crustal material is returned to the upper mantle and occurs where dense oceanic crust slips beneath less dense continental crust
Subthermocline	The depth zone immediately below the base of the thermocline
Sverdrup	A unit of transport used in oceanography to quantify flow in ocean currents. It is equivalent to 10^6 m^3/s
Tectonic processes	Pertaining to movement of the rigid plates that comprise the Earth's crust and to ocean floor spreading
Terrigenous	Derived from land
Thermocline	A boundary region in the sea between two layers of water of different temperature, in which temperature changes sharply with depth
Thermohaline circulation	Oceanic circulation caused by differences in density between water masses, which is itself determined primarily by water temperature
Topography	The land forms or surface features of a geographical area
Toxaphene	A chlorinated insecticide with an average chemical composition of $C_{10}H_{10}C_{18}$. Primarily used in cotton farming
Toxin	A biogenic (produced by the action of living organisms) poison, usually proteinaceous
Transform faults	A large horizontal displacement in a mid-oceanic ridge
Trench	A narrow, elongated U-shaped depression of the deep ocean floor between an abyssal plain and the continental margin where subduction of oceanic crust occurs
Trophic	Pertaining to nutrition
Tsunami	A large ocean wave, of long wavelength but small amplitude, caused by submarine volcanic or earthquake activity. When such waves encounter land they grow to catastrophic heights and cause extensive flooding and damage; commonly referred to as 'tidal waves'
Turbidite	A marine sediment deposited at the base of a submarine slope by a turbidity current
Turbidity flow	A rapid undercurrent of relatively high density flowing down a submarine slope and transporting suspended sediment, often in great quantities
Upwelling	An upward movement of cold, nutrient-rich water from ocean depths; this occurs near coasts where winds persistently drive water seawards and in the open ocean where surface currents are divergent
Water column	The vertical column of water extending from the sea surface to the seabed
Water mass	A body of water within an ocean characterised by its physicochemical properties of temperature, salinity, depth and movement
Wind-mixed layer	The upper layer (usually a few tens of metres deep) of sea water that shows no vertical structure in its temperature, salinity and chemical composition, due to mixing by the action of waves caused by the wind
Zooplankton	The animal component of the plankton; animals suspended or drifting in the water column including larvae of many fish and benthic invertebrates

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