HERMES
Hotspot Ecosystem Research on the Margins of European Seas

Deep-sea biodiversity and ecosystems

A scoping report on their socio-economy, management and governance

UNEP WCMC

Regional Seas

Deep-sea biodiversity and ecosystems

A scoping report on their socio-economy, management and governance

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ISBN: 978-92-807-2892-7

Prepared for

UNEP World Conservation Monitoring Centre
(UNEP-WCMC) in collaboration with
the HERMES integrated project

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CITATION

UNEP (2007) *Deep-Sea Biodiversity and Ecosystems: A scoping report on their socio-economy, management and governance.*

URL

UNEP-WCMC Biodiversity Series No 28
(www.unep-wcmc.org/resources/publications/
UNEP_WCMC_bio_series)
UNEP Regional Seas Reports and Studies N° 184
(www.unep.org/regionalseas/Publications/Reports/Series
_Reports/Reports_and_Studies)

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ACKNOWLEDGEMENTS

The authors are grateful to Salvatore Arico, Claire Armstrong, Antje Boetius, Miquel Canals, Lionel Carter, Teresa Cunha, Roberto Danovaro, Anthony Grehan, Ahmed Khalil, Thomas Koetz, Nicolas Kosoy, Gilles Lericolais, Alex Roger, James Spurgeon, Rob Tinch and Phil Weaver for their insightful comments on earlier versions of this report. Thanks also for the additional comments provided by UNEP Reginal Seas Programme Focal Points, and to all individuals and institutions who gave permission to use their pictures. Special thanks to Vikki Gunn and Angela Benn for their input and support and to Stefan Hain from UNEP for his significant input, dedication and immense enthusiasm. Any error or inconsistency, as well as the views presented in this report, remain the sole responsibility of the authors.

HERMES (Hotspot Ecosystems Research on the Margins of European Seas) is an interdisciplinary research programme involving 50 leading research organisations and business partners across Europe. Its aim is to understand better the biodiversity, structure, function and dynamics of ecosystems along Europe's deep-ocean margin, in order that appropriate and sustainable management strategies can be developed based on scientific knowledge. HERMES is supported by the European Commission's Framework Six Programme, contract no. GOCE-CT-2005-511234. For more information, please visit www.eu-hermes.net.

A Banson production
Design and layout Banson
Printed in the UK by The Lavenham Press

Foreword

"For too long, the world acted as if the oceans were somehow a realm apart – as areas owned by none, free for all, with little need for care or management… If at one time what happened on and beneath the seas was 'out of sight, out of mind', that can no longer be the case."

Kofi Annan, UN Secretary General, Mauritius, 2005

Billions of people live at, or in close proximity to, the world's coastlines. Many depend on the narrow strip of shallow waters for their food, income and livelihoods, and it is here that most efforts to conserve and protect marine ecosystems are concentrated, including the sustainable management and use of the resources they provide. We tend to forget that coastal waters less than 200 metres deep represent only 5 per cent of the world's oceans, and that their health and productivity, indeed all life on Earth, is closely linked to the remaining 95 per cent of the oceans.

THE DEEP SEA

Remote, hidden and inaccessible, we rely on deep-sea scientists using cutting-edge technology to discover the secrets of this last frontier on Earth. Although only a tiny amount (0.0001 per cent) of the deep seafloor has so far been subject to biological investigation, the results are remarkable: the bottom of the deep sea is not flat – it has canyons, trenches and (sea)mounts that dwarf their terrestrial counterparts. The deep sea is not a uniform environment with stable conditions and very little environmental change, but can be highly dynamic through space and time. The deep sea is not an inhospitable, lifeless desert but teems with an amazing array of organisms of all sizes and types. Indeed, it is believed to have the highest biodiversity on Earth.

One of the remaining misconceptions about this environment – that the deep oceans are too remote and too vast to be affected by human activities – is also rapidly being dispelled. Destroyed or damaged deep-water habitats and ecosystems, depleted fish stocks, and the emerging/predicted effects of climate change and rising greenhouse gas concentrations on the temperature, currents and chemistry of the oceans are proof to the contrary. Further pressures and impacts on the deep sea are looming: with traditional natural resources on land and in coastal waters becoming ever more depleted and regulated, commercial operations such as fishing, mining, and oil and gas exploration are increasingly taking place in deeper waters.

In the light of these alarming findings and trends, various international fora, including the UN General Assembly, are starting to consider the need for measures to safeguard vulnerable deep-sea ecosystems, especially in areas beyond national jurisdiction, and to ensure their sustainable use. Amongst others, three key questions need to be answered:

- What are key deep-sea ecosystems, and what is their role and value?
- Are existing governance and management systems appropriate to take effective action?
- What are the areas for which we need further data and information?

In order to begin seeking answers, and to establish a direct link between the deep-sea science community and policy and decision makers, UNEP became a partner in the inter-disciplinary, deep-sea research project HERMES in October 2006. This report is the product of this fruitful partnership and demonstrates that the findings and discoveries from the deep waters of the European continental shelf can easily be transferred and are applicable to similar deep-sea areas around the world. It also highlights the benefits, and short-comings, of looking from a socio-economic perspective at deep-sea ecosystems and the goods and services they provide.

The intention of this report is to raise awareness of the deep-sea and the impacts and pressures this unique environment faces from human activities. We are confident that this report provides substantial input to the ongoing discussions about vulnerable deep- and high-sea ecosystems and biodiversity, so that action will be taken to preserve the oldest and largest biome on Earth – before it is too late.

Ibrahim Thiaw
Director of the Division of
Environmental Policy Implementation
UNEP

Jon Hutton
Director
UNEP World Conservation
Monitoring Centre

Phil Weaver
HERMES Coordinator
National Oceanography Centre
UK

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LIST OF ACRONYMS

ABNJ	Areas Beyond National Jurisdiction
BRD	Bycatch Reduction Device
EEZ	Exclusive Economic Zone
FAO	United Nations Food and Agriculture Organization
GHG	Greenhouse gases
HDI	Human Development Index
IEA	International Energy Agency
IMO	International Maritime Organization
ISA	International Seabed Authority
ITQ	Individual Transferable Quotas
IUU	Illegal, Unreported and Unregulated fishing
IWC	International Whaling Commission
MA	Millennium Ecosystem Assessment
MPA	Marine Protected Area
MSR	Marine Scientific Research
NGL	Natural Gas Liquids
NGO	Non-Governmental Organization
OSPAR	Convention for the Protection of the Marine Environment of the Northeast Atlantic, 1992
PAH	Polycyclic Aromatic Hydrocarbon
PCB	Polychlorinated Biphenyl
RFMO	Regional Fisheries Management Organization
ROV	Remotely Operated Vehicles
SIDS	Small Island Developing States
TAC	Total Allowable Catch
TBT	Tributyltin
TEV	Total Economic Value
UN	United Nations
UNCLOS	United Nations Convention on the Law of the Sea, 1982
UNFSA	United Nations Fish Stocks Agreement, 1995

Introduction

The objective of this report is to provide an overview of the key socio-economic, management and governance issues relating to the conservation and sustainable use of deep-sea ecosystems and biodiversity. The report highlights our current understanding of these issues and identifies topics and areas that need further investigation to close gaps in knowledge. It also explores the needs and means for interfacing research with policy with a view to contributing to the political processes regarding deep-sea and high-seas governance, which are currently ongoing in various international fora within and outside the UN system. In addition, this report provides guidance on the future direction and focus of research on environmental, socio-economic and governance aspects in relation to the deep sea.

The deep sea, as defined and used here, includes the waters and seabed areas below a depth of 200 metres. This corresponds to 64 per cent of the surface of the Earth and 90 per cent of our planet's ocean area. The average ocean depth is 3 730 metres and 60 per cent of the ocean floor lies deeper than 2 000 metres. The volume of the oceans, including the seabed and water column, creates the largest living space on Earth, roughly 300 times greater than that of the terrestrial environment (Gage, 1996).

For millennia, the oceans have been used for shipping and fishing. More recently, they became convenient sinks for waste. This usage was guided by the perception that the seas are vast, bottomless reservoirs that could not be affected by human activity. Today, we know that the seas are not limitless, and that we are approaching (or in some cases, may even have overstepped) the capacity of the marine environment to cope with anthropogenic pressures. In the light of this knowledge, over the last 10–15 years the international community has adopted increasingly ambitious goals and targets to safeguard the marine environment and its resources. During the 2002 World Summit on Sustainable Development held in Johannesburg, world leaders agreed inter alia on: the achievement of substantial reductions in land-based sources of pollution by 2006; the introduction of an ecosystems approach to marine resource assessment and management by 2010; the designation of a network of marine protected areas by 2012; and the maintenance or restoration of fish stocks to sustainable yield levels by 2015 (UN, 2002: Chapter IV).

In this context, issues related to deep-sea governance are increasingly appearing on the political agenda at different levels. There is presently a heavy international policy focus on deep-sea ecosystems and resources in various fora at the global level, such as the UN General Assembly (UNGA) and the UN Convention on the Law of the Sea (UNCLOS), the UN Fish Stocks Agreement, the Convention on Biological Diversity (CBD), and under regional multilateral agreements and conventions, for example. We are also in a time of rapid change in the way we think about marine resource management both in shallow waters and offshore. We are moving away from sector-based management to more holistic integrated ecosystem-based management approaches. Sustainable deep-sea governance presents additional specific challenges linked to the criss-cross of legal and natural, vertical and horizontal, boundaries applying to the deep-sea and deep-seabed areas. Deep-sea waters and seabed can be within or beyond areas of national jurisdiction of coastal states, which further complicates policy design and implementation, and challenges the establishment of effective links with shallow-water governance regimes.

Despite existing political commitments, deep-sea resources are increasingly exploited. On the one hand, the depletion of some shallow-water resources (in particular fish stocks and fossil fuels) has drawn more commercial interest in deep-water ones and, on the other hand, the advances in technology over the last decades have made the exploitation of the deep waters and deep seabeds feasible and more economically attractive. The same technological advances have also revolutionized deep-sea research. Until recently, research on deep-sea ecosystems and biodiversity was restricted by the complexity of the systems, their inaccessibility and the associated technological and methodological challenges. Our knowledge started to expand with the rise of sophisticated sampling technologies, remotely operated vehicles, acoustic mapping techniques, ocean observatories and remote sensing (Koslow, 2007). We now know that the deep sea harbours rich, complex and vulnerable ecosystems and biodiversity. As we discover the natural wonders of the last frontier on Earth, we also realize that the deep biosphere is no longer too remote to remain unaffected by the human footprint. The enduring misconception of the oceans as bottomless reservoirs of resources and sinks for wastes is rapidly eroding in the face of scientific evidence of the finiteness and fragility of the deep oceans. We have proof that several deep-sea habitats and ecosystems are impacted, threatened, and/or in decline because of human activity. But the knowledge gaps are still huge. It is estimated that the amount of properly mapped seafloor in the public domain is around 2 or 3 per cent

(Handwerk, 2005). This figure could reach 10 per cent if classified military information is taken into account. Only 0.0001 per cent (10^{-6}) of the deep seafloor has been scientifically investigated. Although we know that species diversity in the deep sea is high, obtaining precise data and information is problematic: current estimates range between 500 000 and 100 million species (Koslow, 2007). As of today, the bulk of these species remains undescribed, especially for smaller organisms and prokaryotes (Danovaro *et al.*, 2007).

Meanwhile, anthropogenic impacts on vulnerable ecosystems and habitats are rising. Direct impacts of human activities relate to existing or future exploitation of deep-sea resources (for example, fisheries, hydrocarbon extraction, mining, bioprospecting), to seabed uses (for example, pipelines, cable laying, carbon sequestration) and to pollution (for example, contamination from land-based sources/activities, waste disposal, dumping, noise, impacts of shipping and maritime accidents). Indirect effects and impacts relate to climate change, ocean acidification and ozone depletion.

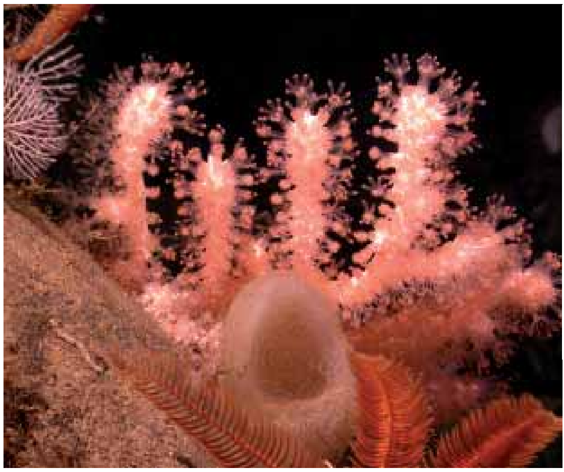
The recent advances in research have also shown that deep-sea processes and ecosystems cannot be addressed in isolation. They are not only important for the marine web of life; they also fundamentally contribute to global biogeochemical patterns that support all life on Earth (Cochonat *et al.*, 2007). They also provide more direct goods and services that are of growing economic significance. Most of today's understanding of the deep oceans comes from the natural sciences, supplemented by data from industry (such as, open file seismic data from the hydrocarbon industry that provides information on the structure of the seabed in certain areas). But socio-economic research in support of the sustainable use and conservation of deep-sea resources is lagging behind (Grehan *et al.*, 2007). Collapsing fisheries, degraded and destroyed habitats and ecosystems, changes in ocean chemistry and qualities, are all indications of direct and indirect human interactions with the deep-sea environment, which affect the role of the oceans, their buffer functions and their future uses. There is a clear need to identify the societal and economic implications of these activities and impacts, and for documenting the key socio-economic and governance issues related to the conservation, management and sustainable use of the deep seas.

This report constitutes a first step in that direction. It is structured along four chapters. Chapter 1 offers a short introduction to habitats, ecosystems and biodiversity of the deep sea. Chapter 2 explores ecosystem functions, goods and services, and issues pertaining to their valuation. It then turns more specifically to deep-sea goods and services and their valuation. Chapter 3 describes the main human activities and impacts on deep-sea biodiversity and ecosystems. Following the same structure as Chapter 2, Chapter 4 identifies key elements for environmental management and governance and then turns more specifically to deep-sea governance issues. Based on the gaps identified in previous chapters, the Conclusions summarize strategic research needs on socio-economic, governance and management issues and suggests priority actions to improve science-policy interfaces.

A jelly fish of the genus *Crossota*, collected from the deep Arctic Canada Basin with an ROV.

Kevin Raskoff/NOAA

Coral, sponge, and feather star at 3 006 meters depth on the Davidson Seamount, located 120 kilometres to the southwest of Monterey, California (US).



NOAA/MBARI 2006

1. Habitats, ecosystems and biodiversity of the deep sea

Deep waters or "deep seas" are defined in this report as waters and sea-floor areas below 200 metres, where sunlight penetration is too low to support photosynthetic production.

From a biological perspective, the deeper waters below the sunlit epipelagic zone comprise: the mesopelagic or the "twilight" zone (200 to about 1 000 metres), where sunlight gradually dims depending, for example, on water turbidity, seasons, regions; the bathypelagic zone from approximately 1 000 metres down to about 2 000 metres; the abyssal pelagic zone (down to 6 000 metres); the hadalpelagic zone, which delineates the deepest trenches; the bentho-pelagic zone, which includes waters directly above the bottom in areas of at least 200 metres depth; and the seafloor itself (Figure 1.1).

The structure and topography of the deep-seafloor is as complex and varied as that of the continents – or even more so. Many submarine mountains and canyons/trenches dwarf their terrestrial counterparts. Numerous larger and smaller geomorphologic features (Table 1.1) strongly influence the distribution of deep-sea organisms. Many of these features rise above, or cut into, the seafloor, thereby creating a complex, three-dimensional topography that offers a multitude of ecological conditions, habitats and niches for a wide variety of unique marine ecosystems.

Biodiversity in the deep seas depends among other

Figure 1.1: The main oceanic divisions *Source: http://en.wikipedia.org/wiki/Ocean*

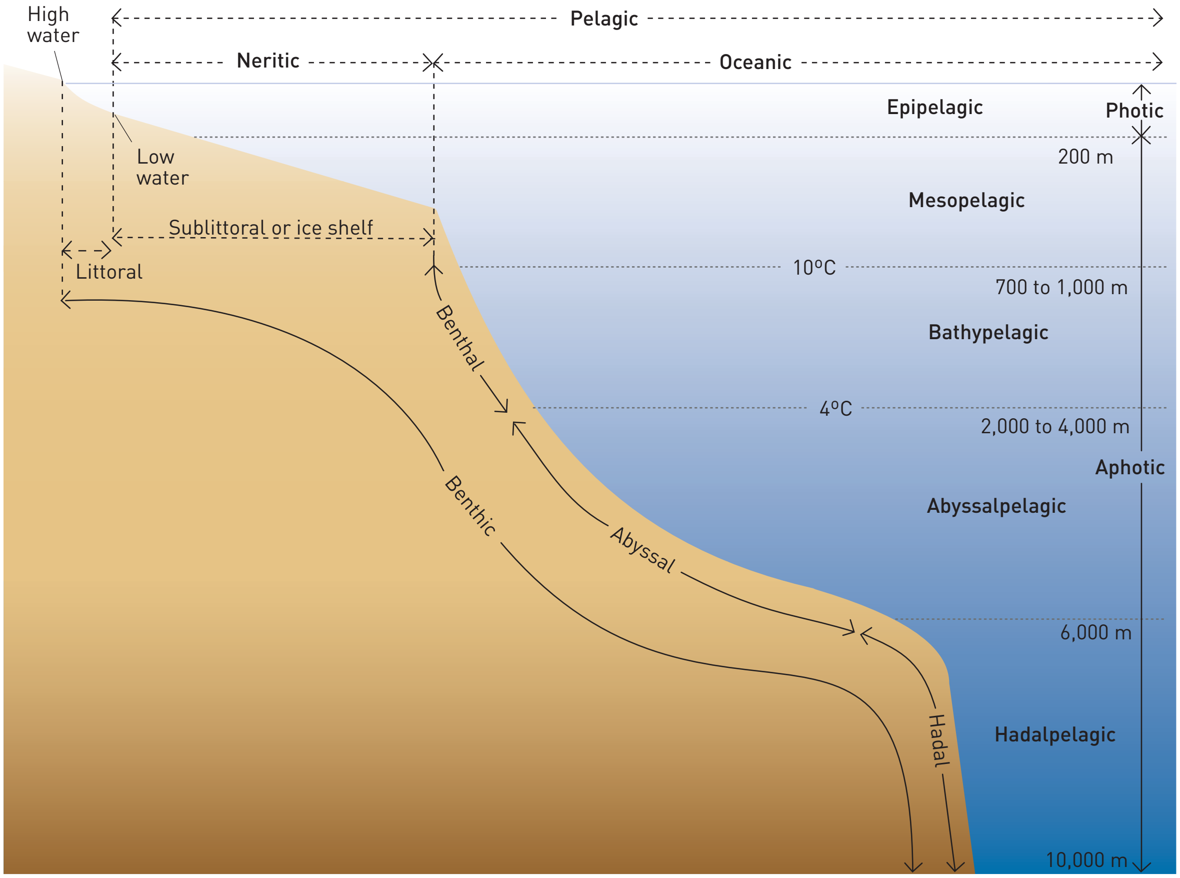


Table 1.1: Main geomorphologic features of the deep sea

Continental shelf	Seaward continuation of continents underwater, typically extending from the coast to depths of up to 150 to 200 metres. Ends at the continental shelf break at an average depth of 130 metres.
Continental slope	Beyond the shelf break, often disrupted by submarine landslides. Steeper slopes frequently cut by canyons.
Continental rise	The gently sloped transitional area between the continental slope and the abyssal plain.
Continental margin	Submerged prolongation of the land mass of a coastal state, consisting of the seabed and subsoil of the shelf, the slope and the rise.
Abyssal plains	Flat areas of seabed extending beyond the base of the continental rise.
Mid-ocean ridges	Underwater mountain range of tectonic origin commonly formed when two major plates spread apart. They often host hydrothermal vents.
Back-arc basins	Submarine basins associated with island arcs and subduction zones, formed where tectonic plates collide.
Dysoxic (anoxic)	Ocean basins in which parts (or all) of the water mass, often near the bottom, is depleted in basins oxygen (for example the Black Sea below 160–200 metres depth).
Submarine canyons	Valleys carved into the continental margin where they incise the continental shelf and slope, often off river estuaries. Act as conduits for transport of sediment from the continent to the deep-ocean floor. Their formation has been related both to subaerial erosion during sea level lowstands and to submarine erosion.
Submarine channels	Wide, deep channels that may continue from canyons and extend hundreds to thousands of kilometres across the ocean floor.
Deep sea trenches and hadal zones	Narrow, deep and steep depressions formed by subduction of one tectonic plate beneath another and reaching depths of 11 kilometres; the deepest parts of the oceans.
Seamounts	Submarine elevations of at least 1 000 metres above the surrounding seafloor, generally conical with a circular, elliptical or more elongate base and a limited extent across the summit. Typically volcanic in origin, seamounts can form chains and sometimes seamounts show vent activity.
Carbonate mounds	Seabed features resulting from the growth of carbonate-producing organisms and (current controlled) sedimentation
Hydrothermal vents	Fissures in the seafloor commonly found near volcanically active places which release geothermally super-heated and mineral-rich water.
Cold seeps	An area of the ocean floor where hydrogen sulphide, methane and other hydrocarbon-rich fluids (with a temperature similar to the surrounding seawater) escape into seawater.
Mud volcanoes	Dome-shaped formations on the seafloor of up to 10 kilometres in diameter and 700 metres in height, created mostly by the release of fluids charged with mud derived from the subseabed. A type of cold seep.

Box 1.1: Biodiversity of the deep sea

Mesopelagic: Biodiversity includes horizontally and vertically actively swimming species (nekton) distributed over large geographic areas and plankton (typically small metazoans, jelly fish and eukaryotic, as well as prokaryotic single cell organisms) living at depths ranging from 200 to 1 000 metres.

Bathypelagic: Biodiversity and biomass inhabiting the water column comprised from 1 000 to 4 000 metres depth. Knowledge of biodiversity in the bathy- and abyssal pelagic zones is limited. Typical life forms include gelatinous animals, crustaceans and a variety of fish.

Benthic: Species on the seabed (epibenthic) and in sediments (endobenthic) are abundant, although not evenly distributed. Complex, 3-dimensional habitats such as seamounts have often a high species richness and a high degree of endemism. Emphasis on the levels of benthic biodiversity, especially in sediments, cannot be overrated since estimates show close to 98 per cent of known marine species live in this environment. Microbial life can extend kilometres into the seafloor (deep biosphere).

parameters on depth (see Box 1.1). In this report we mainly (although not exclusively) focus on deep seabed and benthic biodiversity and ecosystems. Although, in recent years, knowledge about biodiversity in the deep-sea water column has started to increase (Nouvian, 2007; Koslow, 2007) there are still a number of mysteries and myths surrounding deep-sea life. The deep sea was regarded as a vast, desert-like expanse void of life, until the first research expeditions in the mid 19th century proved otherwise (Koslow, 2007). Deep-sea organisms were believed to live in very stable conditions with very little environmental change, relying completely on food sinking down from surface waters. However, we now know that certain biophysical conditions and parameters that govern deep-water and deep-seabed systems are highly dynamic both in spatial and temporal scales, and that there are communities that thrive on minerals and chemicals, rather than energy from the sun and organic matter.

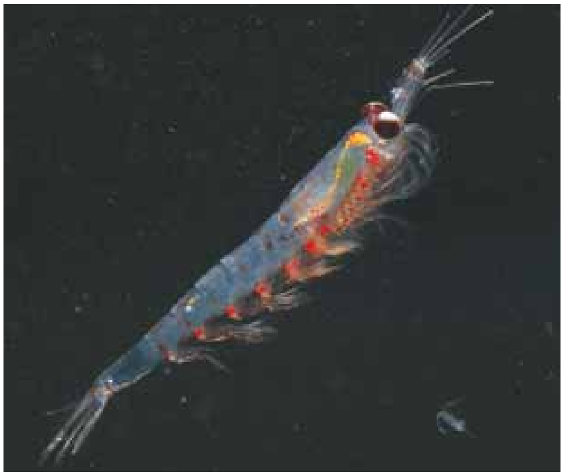
Today, the deep sea is still commonly seen (and addressed, for example, in policy processes) as distinct from shallow coastal marine environments. Research in recent years indicates that the deeper waters and the life therein are horizontally and vertically interconnected with shallow areas, for instance by ocean currents, which carry large amounts of surface water continuously (for example, the Meridional Overturning Circulation in the North Atlantic) or sporadically (by dense shelf water cascading, for example) into the deep sea, and vice versa (upwelling of nutrient-rich deep waters to the surface, for example).

The mesopelagic zone is home to a large number of planktonic micro-organisms as well as a wide variety of macro-organisms, which are widely distributed over large geographic areas and undergo regular horizontal and vertical migrations in search of food. In the bathypelagic zone, the number of species and their biomass appear to decrease rapidly with depth. Very little is known about the organisms living in the deeper bathypelagic waters, and even some of the large animals on Earth such as the giant squid are barely documented.

The study of the deep-seabed life (benthos) has revealed that the fauna is as varied and highly diverse as – and that their diversity is linked to the complexity of – the seafloor it is occupying. Some stretches of seafloor, especially on the abyssal plains, seem to be sparsely populated by interspersed macrobenthos and meiofauna (which account for more than 90 per cent of total faunal abundance), whereas other areas can teem with life. Marine benthic biodiversity is highest from around 1 000 to 2 000 metres water depth. Biodiversity along the continental margins is, per equal number of individuals, in terms of abundance, higher than that of continental shelves. In addition, continental slopes, ridges and seamounts are expected to host most of the undiscovered biodiversity of the globe (Figure 1.2).

Recent results from the HERMES project suggest that in

Planktonic animals like this krill form a vital link in the marine food chain.



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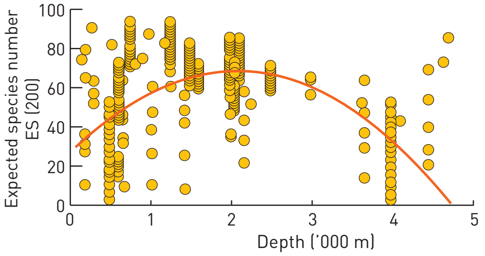


Figure 1.2: Marine biodiversity patterns in relation to water depth. Highest biodiversity values occur from about 1 000 to 2 000 metre depths. *Source Weaver* et al., *2004, compiled from various literature sources*

some areas biodiversity can increase with depth down to the abyssal plains (Figure 1.3).

Despite the heterogeneity and variety of deep-sea life, there are a number of traits that the majority of deep-sea organisms share. Most are adapted to life in environments with relatively low and/or sporadic levels of available energy and food (Koslow *et al.*, 2000; Gage, 1996). Most deep-sea organisms grow slowly and reach sexual maturity very late. Reproduction is often characterized by low fecundancy (that is, number of offspring produced) and recruitment. Some deep-sea organisms can reach astonishing ages: orange roughy, a commercially exploited fish species, can live up to 200 years or more, and gold corals (*Gerardia* spp.) found for example, on seamounts may have been alive for up to 1 800 years, making them the oldest known animals on Earth (Bergquist *et al.*, 2000). However, slow growth is not necessarily consistent even within the same group: the vestimentiferan tube worm *Lamellibrachia* living near cold seeps requires between 170 and 250 years to grow to a length of two metres – which makes these worms the longest-lived non-colonial marine invertebrate known, whereas a close relative, *Riftia pachyptila*, living around hydrothermal vents, reaches maturity and 1.5 metres length in less than two years – which makes these worms the fastest-growing marine invertebrate known (Druffel *et al.*, 1995).

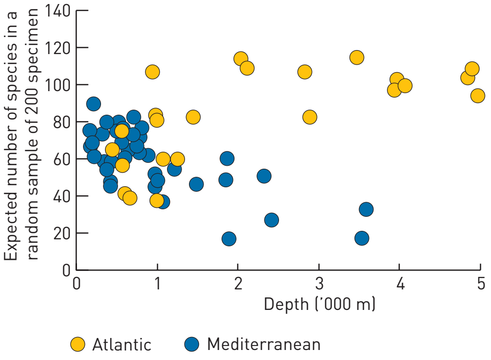


Figure 1.3: Species richness in relation to depth in the Atlantic and the Mediterranean.

Source: preliminary unpublished data from the HERMES project (R. Danovaro, pers. com.)

The majority of deep-sea organisms rely on the input of food and nutrients produced in the epipelagic zone; that is, they depend indirectly on energy from the sun. Where food availability is increased or more stable, such as around seamounts and other seafloor features, organisms and species can aggregate in large numbers, forming biodiversity hotspot communities such as those associated with cold-water coral reefs. Hydrothermal vents and cold seeps are types of ecosystems that are chemotrophic; that is they benefit from non-photosynthetic sources of energy, such as gas, hydrocarbons and reduced fluids as well as minerals transported from the deep subsurface to the seafloor at a wide range of temperatures from 2°C of up to 400°C.

Another frequent characteristic of deep-sea fauna is the high level of endemism (for example, Brandt *et al.*, 2007). Due in part to the unique conditions of deep-sea habitats, and the distances or physical and chemical obstacles that often separate them, in some areas 90 per cent of species are endemic (UN, 2005).

Out of the variety of deep-sea environments, this report focuses on the deep-seabed features and ecosystems described below, which are (or have the potential to be) important from a socio-economic point of view, and for which some information is available, although big gaps of knowledge still exist in most cases.

CONTINENTAL SLOPES

Continental slopes and rises, commonly covering water depths of about 200–3 000 metres, constitute 13 per cent of the Earth's area. They consist of mostly terrigenous sediments angled between 1 and 10 degrees, and are often heavily structured by submarine canyons and sediment slides. These large-scale features, together with ocean currents, create a varied seafloor topography with a wide range of substrates for organisms to settle in or on, including large areas of soft sediments, boulders and exposed rock faces. The geomorphologic diversity of continental slopes, combined with favourable oceanographic and nutrient conditions (for example, through upwelling or cascading-down of nutrient-rich waters from deeper or shallower areas, respectively), create an array of conditions suitable for a great abundance and variety of marine life. Several marine biodiversity "hotspot ecosystems" can be found on continental slopes such as cold-water coral reefs or ecosystems associated with slope features (for example, canyons, seamounts, carbonate mounds or cold seeps).

Vikki Gunn, NOCS

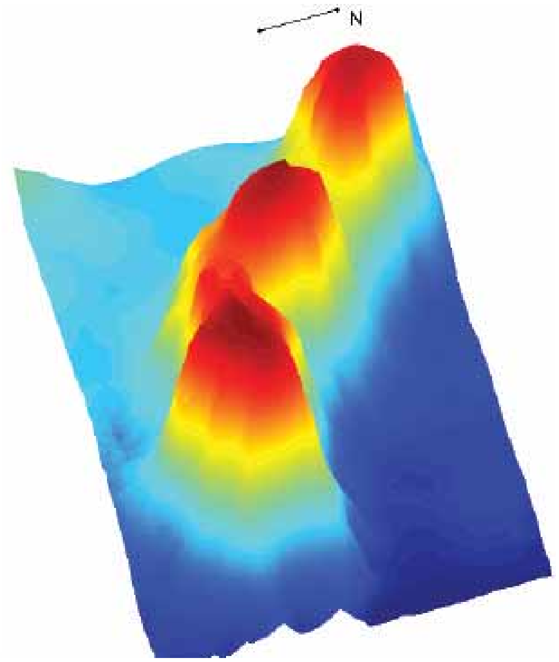
Three-dimensional map of the seafloor off the Atlantic coast of the Iberian Peninsula, showing various submarine canyons cut into the continental shelf.

ABYSSAL PLAINS

Abyssal plains, commonly occurring in water depths of about 3 000–6 000 metres, constitute approximately 40 per cent of the ocean floor and 51 per cent of the Earth's area. They are generally flat or very gently sloping areas formed by new oceanic crust spreading from mid-oceanic ridges at a rate of 20 to 100 millimetres per year. The new volcanic seafloor near these ridges is very rough, but soon becomes covered in most places by layers of fine-grained sediments, predominantly clay, silt and the remains of planktonic organisms, at a rate of appromimately two to three centimetres per thousand years. The main characteristics of abyssal plain ecosystems are (1) low biomass, (2) high species diversity, (3) large habitat extension and (4) wide-scale, sometimes complex topographic and hydrodynamic features. Species consist mostly of small invertebrate organisms living in or burrowing through the seabed (Gage, 1996), as well as an undiscovered plethora of micro-organisms. Given the relative homogeneity of abyssal plains, small organisms (larvae, juveniles and adults) can drift over long distances. The percentage of endemic species found on abyssal plains may therefore not be as high as elsewhere in the deep sea. In certain areas, special conditions are found on the abyssal plains, which support a distinct community of organisms. Cadavers of large marine mammals (for example, whale falls) or fish sinking to the bottom of the abyss attract a succession of specialized organisms that feed on these carcasses over months to years. Polymetallic

Craig Smith, University of Hawaii

For over four years, the bones of this 35-tonne gray whale have rested on the seabed at 1 670 metres depth in the Santa Cruz Basin (Eastern Pacific) and are now covered with thick mats of chemosynthetic bacteria.



Igor Bashmachnikow, IMAR/DoP, University of the Azores

3D map of the Sedlo Seamounts, north of the Azores, Atlantic. Base depth ca. 2 500 metres, minimum summit depth 750 metres.

manganese nodules, found on some abyssal plains, support distinct ecosystems (Wellsbury *et al.*, 1997).

SEAMOUNTS

Seamounts are underwater mountains of generally tectonic and/or volcanic origin, often (but not exclusively) found on the edges of tectonic plates and mid-ocean ridges. Seamounts are prominent and ubiquitous geological features. Based on satellite data, the location of 14 287 large seamounts with summit heights of more than 1 000 metres above the surrounding area has been predicted. This is likely to be an underestimate: there may be up to 100 000 large seamounts worldwide. Seamounts often have a complex topography of terraces, pinnacles, ridges, crevices and craters, and they are subject to, and interact with, the water currents surrounding them. This leads to a variety of living conditions and substrates providing suitable habitat for rich and diverse communities. Although only a few large seamounts have been subject to detailed biological studies (Clark *et al.*, 2006), it appears that seamounts can act as biodiversity hotspots, attracting top pelagic predators and migratory species, such as whales, sharks, tuna or rays, as well as hosting an often-unique bottom fauna with a large number of endemic species (Richer de Forges *et al.*, 2000). The deep-water fish stocks around seamounts have been, and are, increasingly targeted by commercial fisheries. Bottom trawling causes severe impacts on benthic seamount communities, and without sustainable management can deplete fish stocks within a few years ("boom and bust" fisheries). The flanks of some seamounts, especially in the equatorial Pacific, contain cobalt-rich ferromanganese crusts, which are attracting deep-water mining interest. Thus, the commercial fisheries close to seamounts are unlikely to remain the only source of direct human impact on seamounts (ISA, 2004). Moreover, as a consequence of the diversity and uniqueness of species on seamounts, research and bioprospecting programmes may increase, and likewise their associated impacts (Arico and Salpin, 2005).

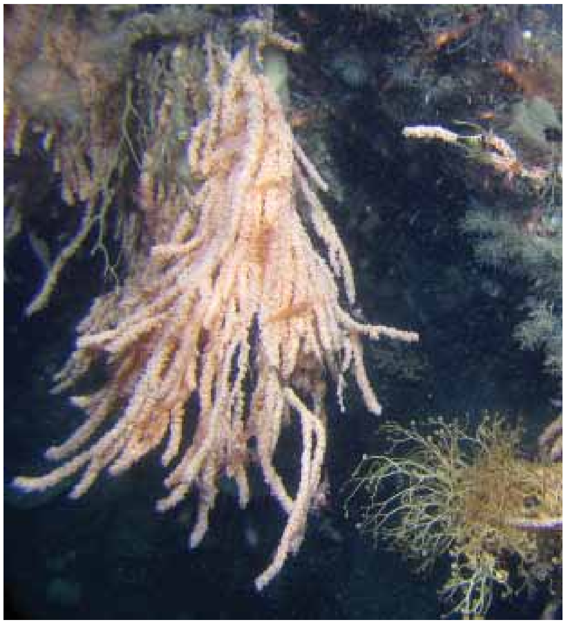
COLD-WATER CORALS

Cold-water corals thrive in the deeper waters of all oceans. Unlike their tropical shallow-water cousins, cold-water corals do not possess symbiotic algae and live instead by feeding on zooplankton and suspended particulate organic matter. Cold-water corals belong to a number of groups including soft corals (for example, sea fans) and stony corals, and are most commonly found on continental shelves, slopes, seamounts and carbonate mounds in depths of 200 to 1 000 metres at temperatures of 4–13ºC (Freiwald *et al.*, 2004). Most cold-water corals grow slowly (*Lophelia pertusa,* 4-25 millimetres per year). Some stony coral species can form large, complex three-dimensional structures on continental shelves, slopes and seamounts. The best-known examples are the cold-water coral reefs in the Northeast Atlantic, which are part of a Lophelia belt stretching on the eastern Atlantic shelf from northern Norway to South Africa. The largest individual reef discovered so far (Røst reef off the coast of Norway) measures 40 kilometres in length and 2–3 kilometres in width. Growing at a rate of 1.3 millimetres a year (Fosså *et al.*, 2002), this reef took about 8 000 years to form. In the deeper waters of the North Pacific, dense and colourful "gardens" of soft corals cover large areas, for example, around the Aleutian Islands. What these cold-water coral reefs or gardens have in common with their tropical counterpart is their ecological role. Cold-water coral ecosystems are among the richest biodiversity hotspots in the deep sea, providing shelter and food for hundreds of associated species, including commercial fish and shellfish. This makes cold-water corals, like seamounts, a prime target for trawling. There is some evidence that some commercially targeted fish are more abundant close to cold-water coral reefs; more detailed studies that demonstrate their role and potential as nursery grounds have yet to be carried out (Freiwald *et al.*, 2004; Clark *et al.*, 2006). Cold-water coral reefs formed by stony corals are also threatened by the indirect impacts of anthropogenic CO_2

emissions. With increasing CO_2 emissions in the atmosphere, large amounts of CO_2 are absorbed by the oceans, which results in a decrease in pH ("ocean acidification") and reduced number of carbonate (CO_3^{2-}) ions available in seawater (see Chapter 3). Scientists predict that, due to this phenomenon, by 2100 around 70 per cent of all cold-water corals will live in waters undersaturated in carbonate, especially in the higher latitudes (Guinotte *et al.*, 2006). The decline in carbonate saturation will not only severely affect cold-water corals – it will also impede and inhibit a wide array of marine organisms and communities (such as shellfish, starfish and sea urchins) with carbonate skeletons and shells.

DEEP-SEA SPONGE FIELDS

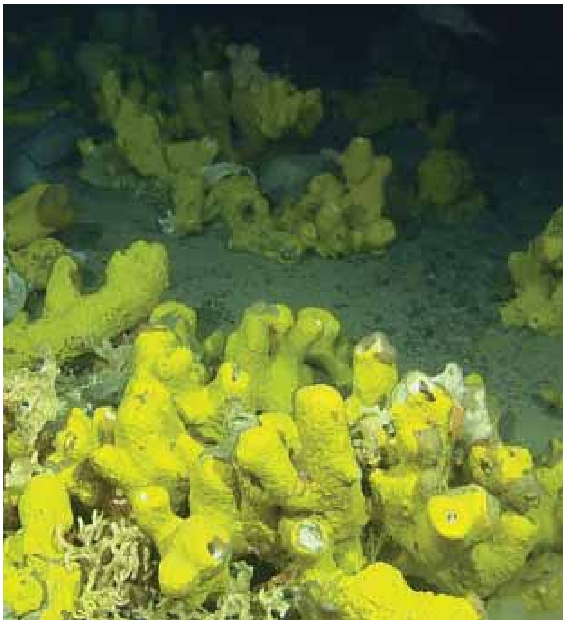
Sponges are primitive, sessile, filter feeding animals with no true tissue, that is, they have no internal organs, muscles and nervous system. Most of the approximately 5 000 sponge species live in the marine environment attached to firm substrate (rocks etc.), but some are able to grow on soft sediment by means of a root-like base. As filter feeders, sponges prefer clear, nutrient-rich waters. Continued, high sediment loads tend to block the pores of sponges, lessening their ability to feed and survive. Under suitable environmental conditions, mass occurrences of large sponges ("sponge fields") have been observed on continental shelves and slopes, for example, around the Faroe Islands, East Greenland, around Iceland, in the Skagerrak off Norway, off the coast of British Columbia, in the Barents Sea and in the Antarctic ocean. Some of these fields originated about 8 500–9 000 years ago. Most deep-water sponges are slow-growing (Fosså and Tendal, undated), and individuals may be more than 100 years old, weighing up to 80 kg (Gjerde, 2006a). Similar to cold-water coral reefs, the presence of large sponges adds a three-dimensional structure to the seafloor, thus increasing habitat complexity and attracting an invertebrate and fish fauna at least twice as rich as that on surrounding gravel or soft bottom substrates. Sponge fields around the Faroe Islands are associated with about 250 species of invertebrates (UN, 2006b), for which the sponges provide shelter and nursery grounds. Most of the approximately 65 sponge species known from sponge fields are characterized by their large size, slow growth rates and weak cementation, which makes them very fragile and vulnerable to the direct physical impact from bottom trawling and to emothering by the sediment blooms this gear causes. Sponges are also a very important marine source of chemicalls and substances with potential pharmaceutical and biotechnological purposes/value. Most of the more than 12 000 marine compounds isolated so far stem from these animals.



T.Lundalv/TMBL

Above: **A colony of the gorgonian coral *Primnoa resedaeformis* at 310m depth in the Skagerrak, off the coast of Sweden.**

Below: **Sponge field dominated by *Aplysilla sulphurea* covering *Stryphnus ponderosus*. Still image from HD video filmed at 271 metres depth in the North East Atlantic off the coast of the Finnmark area, northern Norway.**



J.H. Fosså and P.B. Mortensen, Institute of Marine Research, Norway


Ifremer

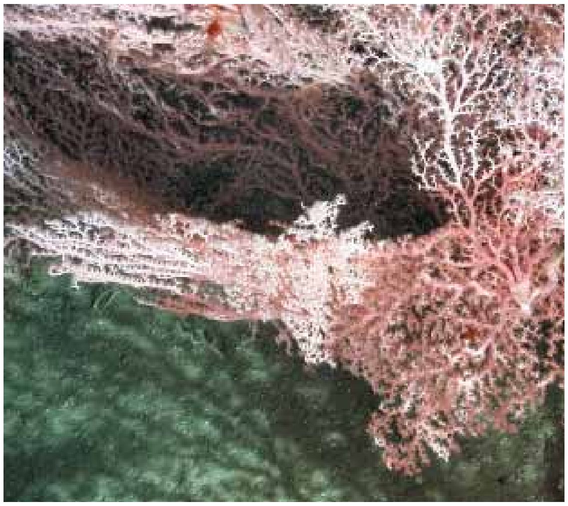
Sampling of hydrothermal vent chimneys in the North East Pacific at 260 metre depth using ROV Victor.

HYDROTHERMAL VENTS

Hydrothermal vents were discovered in 1977 and are commonly found in volcanically active areas of the seafloor (for example, mid-ocean ridges, tectonic plate margins, above magma hotspots in the Earth's crust), where geothermally heated gases and water plumes rich in minerals and chemical energy are released from the seafloor. Vents have been documented in many oceans at depths of 850 to 2 800 metres and deeper, with one of the largest fields at 1 700 metres below sea level off the Azores in the Atlantic (Santos *et al.*, 2003). On contact with the surrounding cold deep-ocean seawater, the minerals in the superheated (up to 400ºC) plumes precipitate and form the characteristic chimneys (which can grow up to 30 centimetres a day and reach heights of up to 60 metres) and polymetallic (copper, iron, zinc, silver) sulphide deposits. Hydrothermal vents host a unique fauna of microbes, invertebrates (for example, mussels and crabs) and fish. The local food chains are based on bacteria converting the sulphur-rich emissions into energy, that is, are independent from the sun as an original source for energy. The chemosynthesis of minerals, and the extreme physical and chemical conditions under which hydrothermal vent ecosystems thrive, may provide further clues on the evolution of life on Earth. Although hydrothermal vent communities are not very diverse in comparison with those in nearby sediments (Tunnicliffe *et al.*, 2003), the biomass around such vents can be 500-1 000 times that of the surrounding deep sea, rivalling values of some of the most productive marine ecosystems. Over 500 vent species have so far been identified (ChEss, 2007). Community composition varies among sites with successional stages observed. Different ages of hydrothermal flows can be distinguished by the associated fauna (Tunnicliffe *et al.*, 2003).

The activity of individual vents might vary over time. The temporary reduction or stop of the water flow, for example,

Gorgonian corals at the Carlos Ribeiro mud volcano in the Gulf of Cadiz, south of the Iberian Peninsula.


NOCS/JC10 cruise

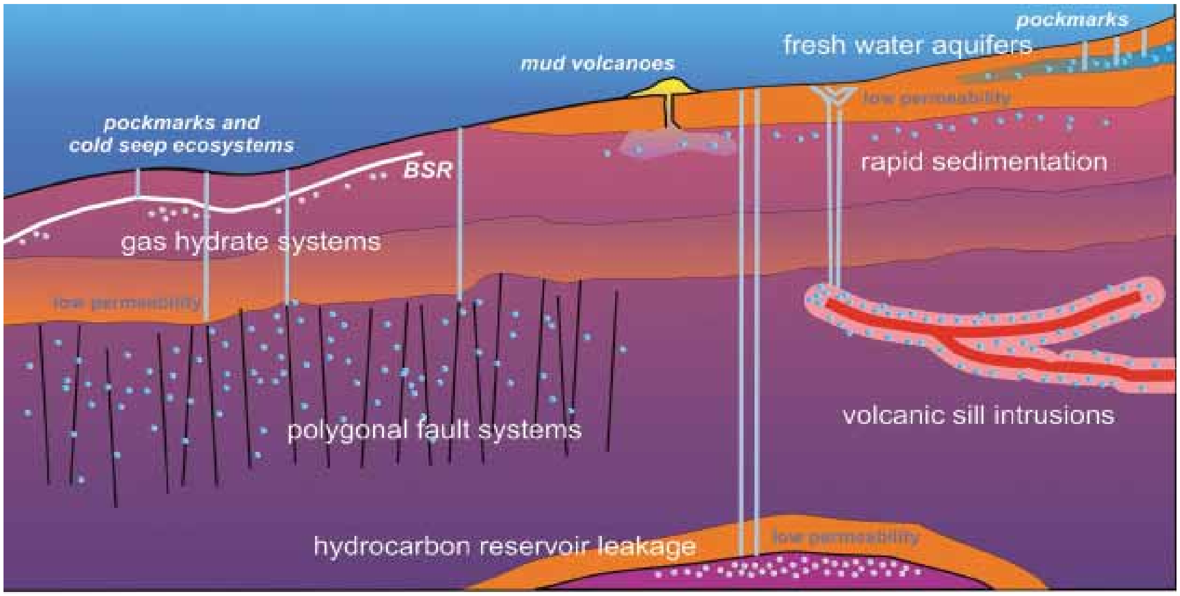
due to its diversion to a new outlet, will also affect the supply of hydrogen sulphide on which the organisms depend. If the flow stops altogether, all non-mobile animals living in the surrounding of the particular chimney will starve and eventually die. The mineral deposits around hydrothermal vents are of potential interest for commercial mining operations, and the "extromophile" fauna of hydrothermal vent ecosystems might become a source of organic compounds (for example, proteins with a wide range of heat resistance) for industrial and medical applications (ISA, 2004). Even when the original vent community becomes extinct, vent chimneys may continue to provide a basis for life – as hard-substrate for a new community of corals and other species to grow.

COLD SEEPS AND GAS HYDRATES

Cold seeps are areas on the ocean floor where water, minerals, hydrogen sulphide, methane, other hydrocarbon-rich fluids, gases and muds are leaking or expelled through sediments and cracks by gravitational forces and/or overpressures in often gas-rich subsurface zones (Figure 1.4). In contrast to hydrothermal vents, these emissions are not geothermally heated and therefore much cooler, often close to surrounding seawater temperature. Cold seeps can form a variety of large to small-scale features on the seafloor, including mud volcanoes, pockmarks, gas chimneys, brine pools and hydrocarbon seeps. As in the case of hydrothermal vents, cold seeps sustain exceptionally rich ecosystems on the basis of microbial chemosynthesis, which makes them prime potential targets for bioprospecting (Arico and Salpin, 2005). Cold seep communities are characterized by a high biomass and a unique and often endemic species composition. Biological communities include large invertebrates living in symbiosis with chemotrophic bacteria using methane and/or hydrogen sulphide as their energy source. The fauna living around cold seeps often display a spatial variability, depending on the distance to the seep. Communities of microbes oxidizing methane thrive around these cold seeps, despite the extreme conditions of pressure and toxicity (Boetius *et al.*, 2000; Niemann *et al.*, 2006). Research recently showed the relevance of such microbes and their genetic makeup in controlling greenhouse gases (GHG) such as methane, which is a much more potent GHG than CO_2 (Krueger *et al.*, 2003).

Cold seeps are often associated with gas hydrates (Figure 1.4), naturally occurring solids (ice) composed of frozen water molecules surrounding a gas molecule, mainly methane. The methane trapped in gas hydrates represents a huge energy reservoir. It is estimated that gas hydrates contain 500-3 000 gigatonnes of methane carbon (WBGU, 2006), over half of the organic carbon on Earth (excluding dispersed organic carbon), and twice as much as all fossil fuels (coal, oil and natural gas) combined (Kenvolden, 1998). However, the utilization of gas hydrates as energy sources poses great technological challenges and bears severe risks and geohazards (see Chapter 3).

Figure 1.4: Schematic showing cold seeps and other focused fluid flow systems/features discussed in the text. (BSR: bottom-simulating reflector) (*Source: Berndt, 2005*)



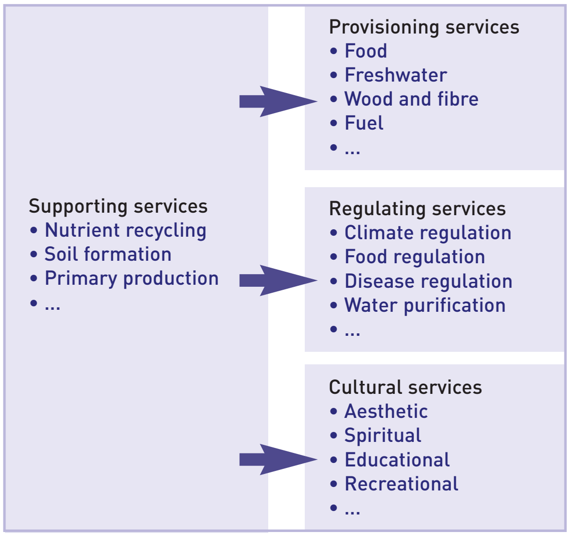
2. Ecosystem functions, goods, services and their valuation

Ecosystem functions are processes, products or outcomes arising from biogeochemical activities taking place within an ecosystem. One may distinguish between three classes of ecosystem functions: stocks of energy and materials (for example, biomass, genes), fluxes of energy or material processing (for example, productivity, decomposition), and the stability of rates or stocks over time (for example, resilience, predictability) (Pacala and Kinzig, 2002).

Ecosystem goods and services are the benefits human populations derive, directly or indirectly, from ecosystem functions (Costanza *et al.*, 1997). This definition includes both tangible and intangible services and was adopted by the Millennium Ecosystem Assessment (MA), which identifies four major categories of services (supporting, provisioning, regulating and cultural) (Figure 2.1). The concepts of ecosystem functions and services are related. Ecosystem functions can be characterized outside any human context. Some (but not all) of these functions also provide ecosystem goods and services that sustain and fulfil human life.

Maintained biodiversity is often essential to the stability of ecosystems. The loss of species can temporarily or permanently move an ecosystem into a different state of biogeochemical conditions. Human societies and economic systems fundamentally depend on the stability of ecosystems and their functions (Srivastava and Vellend, 2005). The provision of ecosystem goods and services is likely to be reduced with biodiversity loss (for example, Worm *et al.*, 2006).

Figure 2.1: Ecosystem services *Source: MA (2005a)*



The notion of ecosystem goods and services has been put forward as a means to demonstrate the importance of biodiversity for society and human well-being, and to trigger political action to address the issue of biodiversity change and loss. The provision of ecosystem goods and services, however, is a sufficient but by no means necessary argument for biodiversity and ecosystem conservation. Other arguments, based on precaution or ethics in particular, are equally legitimate. Hence, the goods and services approach adds value to conservation strategies that argue for conservation on moral or ethical grounds.

VALUATION OF ECOSYSTEMS AND THE GOODS AND SERVICES THEY PROVIDE

The human enterprise depends on ecosystem goods and services in an infinite number of ways, often divided into direct and indirect contributions. Directly, with the provision of goods as essential as food or habitat, and indirectly with multiple services that maintain appropriate biochemical and physical conditions on Earth. Providing value evidence for ecosystem goods and services is important for at least two reasons. First, to measure the human dependence upon ecosystems (Daily, 1997) and second, to better account for the contribution of ecosystems to human life and well-being so that more efficient, effective and/or equitable decisions can be made (DEFRA, 2006). Hence, a key question for the conservation and management of biodiversity and ecosystems is how to value ecosystems themselves and the goods and services they provide, in particular those goods and services that are not (and cannot be) traded in markets.

Different types of values

Valuation of ecosystem goods and services is restrictive in the sense that it caters to humans only. However, as shown in Table 2.1, anthropocentric values are only two of four categories of environmental values. The other two categories cannot be completely accounted for, as by definition it is hard or impossible for humans to comprehend non-anthropocentric values. Focusing on the total economic value only (the top left corner of Table 2.1), in particular through monetary valuation, is often the preferred answer to the question of how to account for ecosystem goods and services in policy and decision making (see, for example, Costanza *et al.*, 1997; Costanza, 1999; Beaumont and Tinch, 2003). There are, however, strong arguments for the use of non-monetary types of valuation in decision-making processes (see section on shortcomings of monetary environmental valuation below).

Several typologies of values exist. Environmental economists often divide **Total Economic Value** (TEV) into various types of (in principle) quantifiable values before adding them up. A major division is between use and non-use values. Use values are further divided into direct and indirect use as well as option-use values, while non-use value includes bequest and existence values (Beaumont and Tinch, 2003). Figure 2.2 summarizes this classification of value.

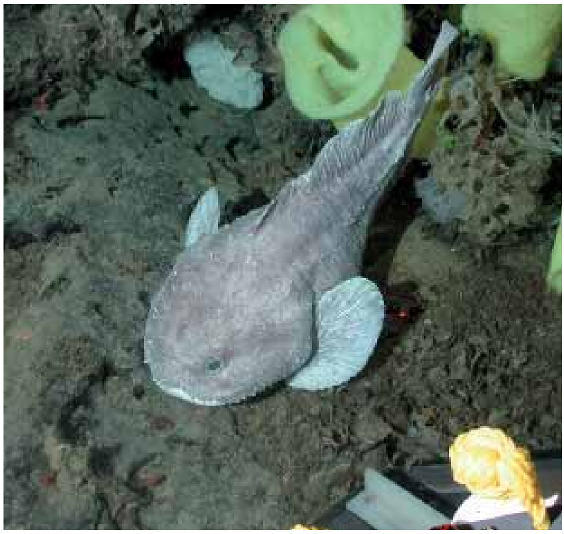
The components of TEV can be defined as follows:

Use values relate to the actual or potential, consumptive or non-consumptive, use of resources:

- Direct-use values come from the exploitation of a resource for both products and services. Sometimes market prices and proxies can be used to estimate such values.
- Indirect-use values are benefits that humans derive from ecosystem services without directly intervening. They correspond to goods and services mostly taken for granted and stem from complex biogeochemical processes, which are often not sufficiently understood to be properly valued.
- Option-use values consist of values attached to possible future uses of natural resources. Future uses are unknown, a reason to want to keep one's options open. As such, option-use values are intrinsically linked with biodiversity. Some species may prove valuable in the future, either as the direct source of goods (for example, the substances they secrete or their genes for pharmaceutical or industrial applications) or as a key component of ecosystem stability.

Non-use values essentially refer to the benefits people attach to certain environmental elements independently of their actual or future use:

- Bequest value is associated with people's satisfaction that (elements of) the natural environment will be passed on to future generations.


NOAA/MBARI

Deep-sea blob sculpin (*Psychrolutes phrictus*); yellow Picasso sponge (*Acanthascus* (*Staurocalyptus*) sp.); and white ruffle sponge (*Farrea* sp.) at 1 317 meters depth on the Davidson Seamount off the coast of California.

Table 2.1: Classification of environmental values

Source: Adapted from DEFRA, 2006

	Anthropocentric	Non-anthropocentric
Instrumental	Total Economic Value (TEV): use and non-use (including value related to others' potential or actual use)/ utilitarian.	The values to other animals, species, ecosystems, etc. (independent of humans). For instance, each species sustains other species (through different types of interactions) and contributes to the evolution and creation of new species (co-evolution).
Intrinsic	"Stewardship" value (unrelated to any human use)/ non-utilitarian.	Value an entity possesses independently of any valuer.

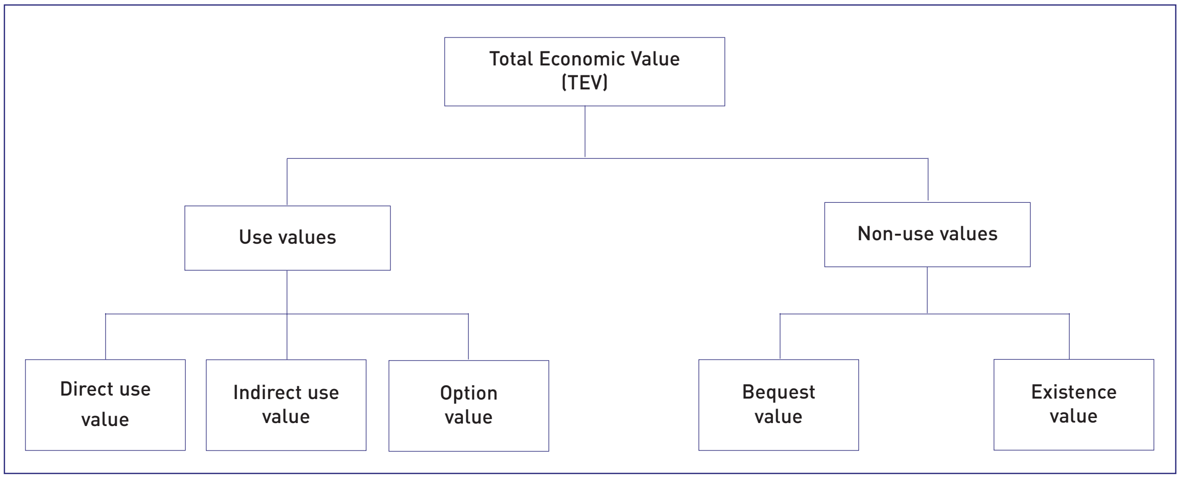


Figure 2.2: Classification under Total Economic Value (Beaumont and Tinch, 2003)

- Existence value is associated with people's satisfaction to know that certain environmental elements exist, regardless of uses made. This includes many cultural, aesthetic and spiritual aspects of humanity as well as, for instance, people's awe at the wonders of nature, such as the deep seas, which may never be witnessed without proxy.

Although TEV represents only a fraction of the overall value of the natural environment, it is a useful notion to signal

Box 2.1: Valuation methods

Source: DEFRA 2006

Monetary valuation methods are based on economic theory and aim to quantify all or parts of the Total Economic Value (TEV). These methods assume that individuals have preferences for or against environmental change, and that these preferences are affected by a number of socio-economic and environmental factors and the different motivations captured in the TEV components. It is also assumed that individuals can make trade-offs, both between different environmental changes and between environmental changes and monetary amounts, and do so in order to maximize their welfare (or happiness, well-being or utility). Several methods can be used to estimate individual preferences in order to monetarize individual values. They are based on individuals' willingness to pay (WTP) for an improvement (or to avoid a degradation) or willingness to accept (WTA) compensation to forgo an improvement (or to tolerate a degradation). Methods include: market price proxies; production function; hedonic property pricing; travel cost method; random utility model; contingent valuation and choice modelling[1].

Non-monetary valuation methods, often called deliberative and participatory methods, also examine the values underlying decisions, but do this by asking people to explain or discuss why they behave in a particular way, or hold a particular view. Often, these methods focus on what people think society should do – not on their personal actions, motivations or values. In this sense, they can be (but are not necessarily) very different from economic methods, which focus on the individual level and apply external value judgments about how individual values should be aggregated to reach a social welfare assessment. Deliberative and participatory methods also focus on the processes of decision making and management, for example in terms of procedures, without necessarily changing the outcomes of management decisions. This represents a move away from the "substantive" framework of standard economic analysis, which focuses on the outcomes of decisions, towards a more procedural rationality, which focuses as much (or more) on the ways in which society reaches decisions. Methods include: survey approaches; focus groups; citizens' juries; health-based approaches; Q Methodology; Delphi surveys and systematic reviews[2].

1 See DEFRA 2006 and Spurgeon 2006 for descriptions of methods. **2** See DEFRA 2006 for descriptions of methods.

Ifremer/Victor 6000/Medeco 2007

An amphipod (Crustacea) found in deep Mediterranean waters.

the need to broaden the horizon of analysis when attempting to capture the value of ecosystem goods and service. Computing total or subtotal dollar figures may not be feasible, or necessarily desirable. Nevertheless, certain values can be estimated in monetary and non-monetary terms, for which a number of methods exist.

Valuation methods

There are two broad categories of valuation methods: monetary methods and non-monetary ones (Box 2.1). While the former attempt at setting a price tag in a single *numéraire* (for example, dollars) on ecosystem goods and services, the latter recognize the inherent incommensurability of different aspects of the value of nature and rather explore how actors value the objects under consideration (See DEFRA, 2006 for a recent inventory of methods).

Whatever the valuation method(s) used, it is important to stress that valuation evidence is to support rather than to make decisions. Decision making is ultimately a political process. As stressed in the MA (MA, 2003, p.34):

> *"the [quantified] ecosystem values in this sense are only one of the bases on which decisions on ecosystem management are and should be made. Many other factors, including notions of intrinsic value and other objectives that society might have (such as equity among different groups or generations), will also feed into the decision framework. Even when decisions are made on other bases, however, estimates of changes in utilitarian value provide invaluable information".*

It is important to note that monetary valuation is not a necessary ingredient of decision making, even though it can be of great use when applicable, available and of good quality. Obviously, many decision makers do act without having a quantitative (monetary) valuation at their disposal, as is often the case for public health issues and the value of human life, for instance.

SHORTCOMINGS OF MONETARY ENVIRONMENTAL VALUATION

Monetary valuation of ecosystems and their goods and services provides a way to evaluate projects on the basis of economic and environmental performance with a single numerical unit (for example, dollars). In other words, when an activity impedes on the provision of ecosystem goods and services, their value could count as a loss to be traded off against the socio-economic benefits of the activity.

As attractive as the idea may be of being able to assign monetary value to all services and goods provided by nature – for it would in principle allow decision makers to "unambiguously" optimize their decisions through cost-benefit analysis – there is no one single best solution for the assignation of monetary values to ecosystem services; in many cases, it is not desirable or simply impossible to do so, for reasons we shall briefly address here.

The monetary valuation approach has a number of caveats. Shortcomings arise in relation to both the very idea of monetary valuation of biodiversity, ecosystems and their goods and services, and the valuation methods per se. Some of the key questions and limitations of monetary valuation

Box 2.2: Some key issues relating to monetary valuation of the environment

- Monetary valuation is more appropriate for valuation of small changes in quality or quantity of well-defined goods or services at a small scale, than to value complex arrays of interlinked ecosystem goods and services on a broad scale.
- Valuation methods such as willingness to pay (WTP) for goods and services, do not determine absolute values. Instead, they establish marginal values; that is the value of having or not having one extra unit of good or service relative to the total current state.
- Nature is composed of highly diverse, complex and interconnected ecosystems. The resultant complexity of many ecosystem goods and services renders it difficult to place boundaries around them to define property rights or to define marginal change for the purpose of monetary valuation (O'Neill and Spash, 2000).
- Valuation methods imply a necessary simplification of the role of ecosystems, which often leads to undervaluation. Monetary methods often do not take into account all environmental benefits of an ecosystem, particularly as some goods and services are unknown and/or unrecognized as such.
- Ecosystem goods and services for human beings and their value, if quantifiable, will only reflect human preferences, which in turn depend on understanding, individual income and/or culture.
- There are significant gaps in knowledge and understanding of the links between environmental service provision and uses. As a consequence, a change in environmental service availability might not necessarily be reflected by changes in price; that is, unlike most markets, a monetary system for valuing the environment might not reflect scarcity issues.
- The assumptions behind monetary valuation methods (Box 2.2) imply that what is valued can be compared, exchanged and compensated for. This is often meaningless for ecosystem goods and services.
- In ecological terms, some ecosystems goods and services can only be given an infinite value, as they are non-substitutable by other forms of capital, goods or services and they are indispensable to support human life on the planet. Some environmental features may also be valued for their "uniqueness" in social, cultural or geographical sense and hence be considered as non-substitutable (Holland *et al.*, 1996).
- Many ecosystem goods and services are public goods, in the sense that they benefit people collectively and are indivisible among individuals. Thus, to value them through methods relying on individual expressions of preferences, such as in contingent valuation methods, for example) may not be appropriate (Wilson and Howarth, 2002).
- People have ethical values that inform their preferences; they have preferences over consequences as well as processes (ethical) and their valuation is always a combination of both (Le Menestrel, 2002). Individuals may have concerns about legitimate procedures and the fairness of the distribution of burdens and benefits beyond mere concerns about maximizing welfare (O'Neill and Spash, 2000).
- The values that inform environmental valuation are plural and incommensurable such that the use of one single unit of measurement (monetary or non-monetary) in view of a cost-benefit analysis cannot capture all the distinct dimensions of environmental choice (O'Neill and Spash, 2000).
- Monetary valuation techniques imply that people have knowledge and/or experience of the ecosystem good or service to value. If they do not, this knowledge can be provided to them in the valuation exercise, but the way it is done will influence their valuation. Moreover, there always remains some extent of unknown about the system to evaluate. For these reasons, combinations of discursive and monetary techniques may be more appropriate.
- Valuing the flow of economic benefits from ecosystem goods and services raises the issue of discounting. In economic cost-benefit analysis, future costs and benefits are converted to current values through a social discount rate. The higher the discount rate, the lower the value of future benefits and costs compared to present ones. Thus, unsustainable resource uses may mean greater profits for now. In the normative context of sustainability, values become atemporal; that is, a tonne of fish today is worth the same as a tonne of fish in 10, 20, or 30 years' time. Discounting the benefits from a flow of non-renewable resources or the depletion of exhaustible stocks must therefore be questioned, and in some cases, rejected (for example Daly, 1996).
- The outcomes of monetary valuations also vary widely according to what is included in the analysis (e.g. which externalities, with what time horizon and discount rate). Hence the importance of making the context and the underlying assumptions explicit in order to avoid ad hoc – or plain misuse – of single "dollar-values".

AWI/Ifremer

Mineral-rich fluid flows and methane gas bubbles seeping from the seabed supports chemosynthetic ecosystems at the Haakon Mosby Mud Volcano on the Norwegian Margin (1 250 metre depth).

are listed in Box 2.2. They suggest subtler and more modest policy roles for monetary valuation and cost-benefit analysis in environment decision making (Holland *et al.*, 1996).

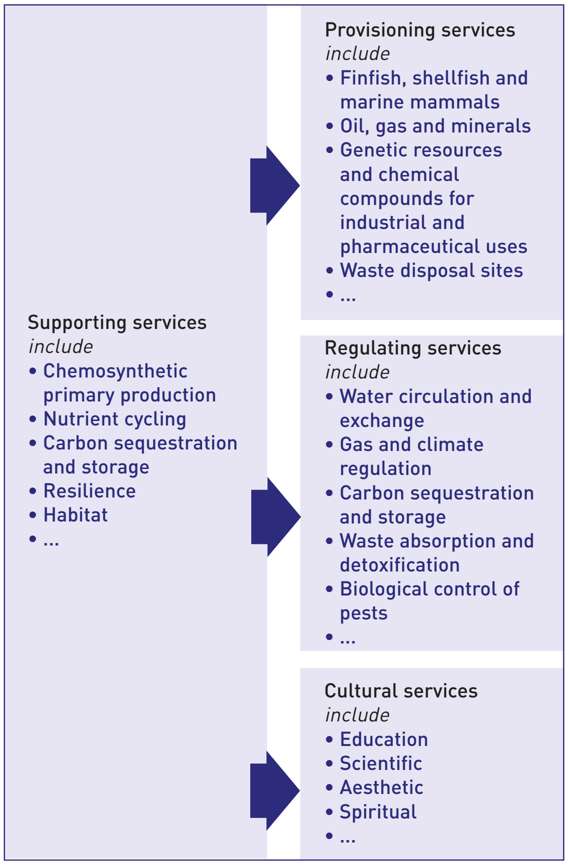
Some defend monetary valuation on the pragmatic grounds that it is better to have an inappropriate (often lower bound) value for ecosystem goods and services than to have no value estimate at all. The argument being that if no value is put forward, there is a risk that these ecosystems and the goods and services they provide will not be taken into account in economic decision-making processes, either because "no value" will be considered to equal zero, or because it is not easy to deal with an infinite value in an economic framework. But this pragmatic defence could well be counter-productive to its own purpose of "taking the environment into account", because continuing reliance upon inappropriate methods could impede the development of alternative methods of environmental value articulation capable of taking living systems into account (Farrell, 2007).

While the shortcomings of monetary valuation, discounting and cost-benefit analysis are well known, in practice, there is still a strong pull to focus on these methods. In the appropriate context (including choice of discount rates and time frames), monetary valuation methods may bring important elements to the decision-making process in those cases where ecosystem goods and services and the underlying ecosystem functions and processes are well understood and mostly small changes in quantity or quality of these services are considered. In particular, the "qualitative insight obtained along the way can sometimes be as valuable as the quantitative estimates themselves" (Holland *et al.*, 1996). In other cases, including most deep-sea ecosystem goods and services, where knowledge is limited, impacts are irreversible, potential thresholds exist, and complexity and interconnectedness of different systems is high, and where knowledge about both the nature of potential outcomes and the probabilities of them is problematic (Table 4.1, p56), other non-monetary analytical methods must be explored and developed. Some already exist – such as Multicriteria Analysis (MCA), indicator-based methods, discourse-based methods or methods building on decision-support tools such as, for instance, life-cycle analysis (LCA) or integrated environmental and social impact assessments – and support decision making in various areas. These methods also aim to take into account the normative and ethical dimensions stressed in Box 2.2 and, in a sense, try to re-establish the role of intuition, common sense and ethics in environmental valuation.

DEEP-SEA GOODS AND SERVICES AND THEIR VALUATION

Deep-sea goods and services

Following the MA's conceptual framework (Figure 2.1), a general and non-exhaustive classification of goods and services for the deep seas, is presented in Figure 2.3. Because the focus of this study is on the deep sea as a whole, including the ecosystems it contains and the human interactions with them, we have included abiotic goods or



Supporting services
include
- Chemosynthetic primary production
- Nutrient cycling
- Carbon sequestration and storage
- Resilience
- Habitat
- …

Provisioning services
include
- Finfish, shellfish and marine mammals
- Oil, gas and minerals
- Genetic resources and chemical compounds for industrial and pharmaceutical uses
- Waste disposal sites
- …

Regulating services
include
- Water circulation and exchange
- Gas and climate regulation
- Carbon sequestration and storage
- Waste absorption and detoxification
- Biological control of pests
- …

Cultural services
include
- Education
- Scientific
- Aesthetic
- Spiritual
- …

Figure 2.3: Examples of deep-sea goods and services

services derived from the deep sea (such as minerals or waste dumps) and goods that are not immediately derived from ecosystems today, although they have depended on biotic elements for their formation (such as oil and gas).

Ecosystems of the deep seas are, as shown in the first chapter, diverse in every sense of the word. The deep oceans and seas are far from the uniform and desert-like plains reported by pioneer expeditions. The oceans are home to 32 of the 33 phyla of plants and animals on Earth, 15 of which are endemic (Beaumont *et al.*, 2006). Thus, the oceans are not just greater in volume than the terrestrial environment, but also in biodiversity. Without deep-sea life, all life on Earth would cease because of the fundamental role of deep sea in global biogeochemical cycles (Cochonat *et al.*, 2007).

In contrast to terrestrial ecosystems, most of the deep-sea ecosystems goods and services have an indirect benefit to human beings. Recent findings support the hypothesis that a large fraction of coastal biodiversity and biomass production is linked to, and supported by, deep-sea ecosystems. Moreover, many commercially exploited marine species recruit in the deep and then move upwards to where they are fished. Such findings substantiate indirect benefits of deep-sea ecosystems functions to human beings, but our knowledge is as yet insufficient to draw well-defined pictures of their overall value. Most goods and services listed in Figure 2.3 are self-explanatory, but some may need a brief description.

Chemosynthetic primary production: There is increasing evidence that chemosynthetic processes in the deep sea are more widespread, which means that the contribution of chemosynthesis to the overall primary production of the oceans may be higher than the original estimates of 0.03 per cent (from hydrothermal vent communities).

Nutrient cycling: Deep-sea organisms (from invertebrates to prokaryotes) are responsible for almost the entire regeneration of nutrients in the oceans. Without these processes, the primary production in the photic zone of the oceans, the basis for most life on Earth, would collapse.

Genetic resources and chemical compounds: Microbial and prokaryote gene richness within the oceans is expected to be orders of magnitude higher than in the rest of the biosphere. Recent findings (Yooseph *et al.*, 2007) reported the discovery of thousands of new genes and proteins (and therefore potentially new functions) in a few litres of water. The deep seas, comprising more than 90 per cent of the biosphere, represent by far the largest reservoir of microbes and potential new discoveries, including ones of major biotechnological interest.

Gas and climate regulation services provided by the deep sea include the maintenance of the chemical composition of the atmosphere and the oceans, for example via the "biological pump", which transports carbon absorbed during photosynthesis into the deep seas (Schubert *et al.*, 2006). Methanotrophic microbes in the ocean floor and waters control almost all of the oceanic methane emission (Reeburgh, 2007). Moreover, if scenarios of deep-sea carbon sequestration and storage became a reality, the deep sea would be of direct service (see pp46 and 51).

Waste absorption and detoxification are important regulating services as marine organisms store, bury and transform many waste materials through assimilation and chemical transformation, either directly or indirectly. Oceans have a unique (though not infinite) ability to clean up sewage, waste material and pollutants. In particular, bioturbation – the biogenic mixing of sediments on the seafloor by burrowing organisms (Solan *et al.*, 2004) – and accumulation regulate the processes of decomposition and/or sequestration (for example, by burial) of organic wastes.

Biological controls of pests: There is evidence that several pathogenic organisms (including pathogenic bacteria) are increasingly spread over the globe (including through ballast waters). Most of these are able to produce cysts and remain

Table 2.2: Knowledge of the contribution of some deep-sea habitats and ecosystems to goods and services

					GOODS and SERVICES				
HABITATS ECOSYSTEMS	Organic matter input/chemo-synthetic primary production	Nutrient cycling	Resil-ience	Habitat	Food, minerals, oil, gas	Micro organ–isms	Climate regulation	Bio-remediation	Educational, scientific, spiritual
Continental shelves	🟩	🟧	🟧	🟩	🟩	🟪	🟪	🟧	🟧
Continental slopes	🟩	🟧	🟪	🟧	🟩	🟪	🟪	🟧	🟧
Abyssal plains	🟩	🟧	🟪	🟧	🟧	🟪	🟪	🟧	🟧
Submarine canyons	🟧	🟧	🟪	🟧	🟧	🟪	🟪	🟧	🟧
Deep-sea trenches	🟧	🟪	🟪	🟧	🟧	🟪	🟪	🟧	🟪
Seamounts	🟩	🟧	🟪	🟩	🟩	🟪	🟪	🟪	🟧
Carbonate mounds	🟧	🟧	🟪	🟧	🟪	🟪	🟪	🟪	🟪
Hydrothermal vents	🟩	🟪	🟪	🟩	🟩	🟩	🟪	🟪	🟩
Cold seeps	🟧	🟧	🟧	🟧	🟩	🟩	🟧	🟧	🟧
Mud volcanoes	🟧	🟧	🟪	🟧	🟧	🟩	🟧	🟪	🟧
Cold-water corals	🟩	🟪	🟧	🟩	🟩	🟪	🟪	🟪	🟩
Deep-sea sponge fields	🟧	🟪	🟪	🟧	🟪	🟪	🟪	🟪	🟧
Whale falls	🟩	🟧	🟧	🟧	🟧	🟧	🟪	🟪	🟪

Key: State of knowledge 🟦 good knowledge 🟩 some knowledge 🟧 little knowledge 🟪 no knowledge

stored within the sediment. Benthic organisms, including those found in deeper waters, contribute to the control of these potential pests by removing them (by ingestion) or averting their outbreak (by competing for available resources). In this sense, a high biodiversity represents a buffer for environmental changes and ecological shifts and this reduces the probability that these invasive forms will develop (Danovaro, personal communication).

Table 2.2 lists some of the deep-sea habitats and ecosystems and the goods and services they provide. It gives an estimation of the level of knowledge about these ecosystems and habitats and their importance for the different goods and services. The major difficulty with a medium as vast and unknown as the deep oceans is tracing the contributions of specific ecosystems. While ecosystem processes support the hypothesis that deep-ocean ecosystems contribute to nutrient cycling, climate regulation services cannot be attributed to one ecosystem in particular. Instead, climate-regulation services are the work of photosynthesis by surface organisms, the great ocean conveyor belt, currents, as well as salinity and the capacity of microorganisms to absorb greenhouse gases.

Valuation of deep-sea goods and services

In view of the problems surrounding monetary valuation of ecosystem goods and services outlined above, the deep sea appears to be possibly the worst case for deriving monetary values. There are several reasons for this, including:

- the limited knowledge of deep-sea ecosystems and the even lesser knowledge of the goods and services they provide; in particular the challenge of linking the results of deep-sea research to the services that people do experience (for example, climate regulation);
- the complexity of the processes going on in the deep sea, as well as the broad time- and space-scales over which they operate;
- the nature of deep-sea ecosystems, especially those

Table 2.3: Total Economic Value components and deep-sea examples

(Source: adapted from Beaumont and Tinch, 2003)

Total Economic Value				
Use values			Non-use values	
Direct-use value	Indirect-use value	Option-use value	Bequest value	Existence value
Examples				
Fish, shellfish, oil, gas and minerals provision, waste dumps, military submarines routes	Nutrient cycling, gas and climate regulation, carbon sequestration, abatement of wastes	Potential drugs, chemicals, and biopolymers for future industrial, pharmaceutical and biotechnological applications	Preserving the deep-sea environment for future generations	Knowing that deep-sea environments exist

with significant option-use values for which it is – by definition – difficult to derive a monetary value;

- that people have practically no first-hand experience of deep-sea ecosystems, so valuation methods based on preferences are likely to be biased or irrelevant.

Deep-sea examples of the components of the Total Economic Value (TEV) presented in the section above is given in Table 2.3.

Certain components of TEV of the deep seas such as oil and gas extracted or fish harvested are relatively straightforward to value through market prices, even though this does not solve the problems associated with incommensurability, discounting, irreversibility, lack of knowledge, uncertainty or externalities presented on pages 23–25. In particular, the majority of deep-water biotic resources have slow growth rates such that their exploitation is much like that of abiotic resources; that is, they should be considered as non-renewable (Roberts, C.M., 2002). We are in a situation where the use of positive discount rates is problematic. Hence methods must be developed to ensure that the valuation process includes sustainable exploitation over the long term as a framing assumption.

Another issue with valuation relates to the fact that habitats and ecosystems of the deep ocean and seas are unevenly distributed across the globe. The total number and distribution of seamounts, for example, is still unknown. Thus, it is difficult, if not impossible, to derive a meaningful pertinent overall value for seamounts and the goods and services they provide globally.

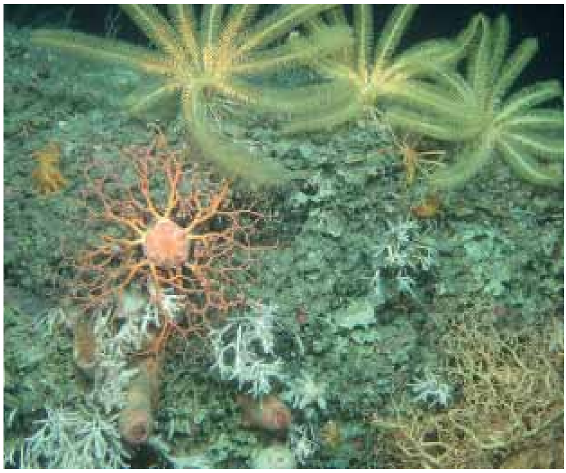
Most of the other goods and services rendered by deep-sea ecosystems and biodiversity are outside the market economy. For instance, establishing estimates of the value of services provided by burrowing organisms on the seafloor with, say, their replacement costs, would be difficult and most likely pointless as replacement costs only make sense when replacement is a viable option.

Our limited knowledge of the deep sea also affects our capacity to put values on its ecosystems and the goods and services they provide. Deep-sea trawling may provide food and employment, but at what environmental costs, and for how long? Were we to have a precise idea of the multiple roles of deep-sea ecosystems and to evaluate them, we might find that deep-sea trawling is highly uneconomical. likewise, before we can value say the supporting services (chemosynthetic primary production) and provisioning services (mineral and biochemical resources) of hydrothermal vents or cold seeps, we need a better understanding of what their role is. Similarly, it is difficult to assess the value of deep-sea bioturbation services without further investigations being carried out. From shallow-water studies, it can be hypothesized that beyond a certain level of biodiversity loss, the rate and depth of bioturbation decreases significantly. This would impact the structure of other marine communities, potentially triggering extinctions and consequent losses in goods and services. Bioremediation of wastes is linked in many ways to bioturbation, but the deep sea cannot assimilate all wastes. Can the costs of disposal on land be used as a proxy for the value of corresponding deep-sea services? This is another example of methodological questions relating to value articulation, which requires further research.

Moreover, as deep-sea biodiversity and ecosystem functions are still largely unknown, any quantitative estimate of option-use value of related goods and services would be highly speculative. Few individuals have "direct" experiences of the deep sea, which in such cases is mediated through manoeuvring a remote-controlled vehicle, a winch on a trawler or a crane on a rig. The rest of the population has only indirect, if any, experience of the deep sea, mediated by the mass media, scientific dissemination, or through the consumption of a deep-sea fish. Valuation methods that rely on surveys for preferences towards the deep sea clearly suffer from a lack of knowledge on the part of both scientists and the public. Thus, a choice of valuation method for deep-sea ecosystem goods and services is not obvious. The way forward is to improve our knowledge of the deep sea and to use knowledge of how deep-sea ecosystem processes link to goods and services as an input to valuation and decision support. This applies to economic and non-economic methods, which equally need to build on the best possible understanding of the roles the deep sea plays in providing ecosystem goods and services.

Another aspect is that, given the nature of the deep sea (similar to other large and wild compartments of the biosphere such as tropical forests, for example), it is likely that with increasing knowledge and awareness, the non-use values become more and more important to the public.

Notwithstanding the issues attached to monetary valuation, some numbers have been put forward for some deep-sea ecosystem goods and services. The benefits from the ocean only restricted to food production, have been valued at almost half a trillion dollars (1994 US$) per year (Costanza *et al.* 1997). In 2005, deep-sea oil and gas wells produced the equivalent of 3.4 millions barrels per day (DWL, 2005). With the price of a barrel averaging US$ 54.5 (BP, 2005) over the year, that amounts to US$ 67.7 billion in 2005, and deep and ultra deep production is expected to double in the next two years (DWL, 2005). With an estimated production value of a US$ 0.25 billion per year, diamond mining off the coast of Namibia is one of the biggest offshore-mining development successes to date (Rona, 2003). Elsewhere, deep-sea mineral resources are still in the exploration phase. The costs of technological alternatives to natural ecosystem processes can sometimes be used as a proxy for the value of ecosystem goods and services. For instance, Costanza *et al.* (1997) valued nutrient cycling from the oceans at US$ 3.9 trillion per year, and gas regulation at approximately US$ 1.3 trillion per year. Yet, it is important to note that, given the remoteness and underexploration of the deep sea, some of its contributions may be completely unknown and out of the human realm. Values beyond human experience simply cannot be estimated, such that any figure will always understate the total value of ecosystem goods and services (Beaumont and Tinch, 2003).


AWI/Ifremer

Fauna living on carbonate crust crust in the Storegga slope area offshore mid-Norway.

One study has attempted to use socio-economic criteria for ranking large marine ecosystems and regional seas, which extend to the deep sea (UNEP/RSP, 2006). A combination of economic rent, calculated as the product of quantities of goods and services and market values, and Human Development Index (HDI) gives a measure of the intensity of human activities. In turn, this might represent the level of exploitation and degradation of large marine ecosystems. Exploitation of the deep sea would, however, fall under another category since access requires large capital expenditures available only to rich countries and big corporations. The resulting classification, however, might help prioritize international conservation efforts and direct management resources where needed.

Another issue linked to deep-sea valuation lies in the problem of ownership of values as property rights are loosely, or not at all, defined in the high seas (see Chapter 4 for more details).

RESEARCH NEEDS

Today, we still do not have the knowledge basis to be able to list all the goods and services and other benefits provided by the deep sea and its ecosystems, nor to provide estimates of their values in support of decision making. In the next chapter, some human activities and their impacts on the deep sea will be described. By doing so, we also further illustrate some of the benefits provided by the deep-sea environment.

The above discussion highlights the question of the (im)possibility of providing pertinent TEVs (in monetary terms) for deep-sea ecosystem goods and services and the importance of developing research on alternative methods

Ifremer/Victor 6000/Medeco2007

A skate ray near the Napoli mud volcano in the deep Mediterranean.

for taking the value of ecosystem goods and services into account in decision-making processes. Obviously, this is a challenge for most ecosystems, but because of its characteristics, the deep sea provides a potentially highly fertile area for developing and testing alternative methods of value articulation and their potential to support decision making for governance and sustainable management.

To value ecosystems and their goods and service, one requires knowledge about ecosystems, their structure, function, global and regional importance, rarity, sensitivity (resistance and resilience), ecological significance, spatial and temporal distribution of impacts, and status of health, decline or recovery. Hence, the importance of developing simultaneously and cooperatively our knowledge of ecosystems, their goods and services and the corresponding values to human well-being. This further highlights the need for interdisciplinary natural and social science research. The latter should consist in an integrated socio-economic research effort to improve understanding of the social, cultural, economic and political aspects of the deep sea, including the relevant actors and institutions (for example, Spurgeon, 2006).

As expressed by the 'no knowledge' cells in Table 2.2, relations between deep-sea ecosystems and the provision of goods and services need more systematic research. While evidence exists of the substantial contribution of deep-sea ecosystems and biodiversity to human livelihood and well-being, more research should allow better estimates of the costs imposed to society and the environment associated with the unsustainable use of deep-sea resources.

More research is also needed on both monetary and non-monetary valuation techniques and on how to use available valuation evidence in decision-making processes for the deep sea. It is also essential to develop decision-support tools for combining different types of value evidence with a view to present as much information as possible. This involves, in particular, the exploration of interfaces and combinations of monetary and non-monetary methods while keeping in mind the inevitability of imperfect assessment with the methods currently – and likely to be in the medium term – at our disposal (Tinch, 2007).

3 Human activities and impacts on the deep sea

Any human interaction with an ecosystem has potentially destabilizing effects and may result in losses of biodiversity and ecosystem integrity or resilience, and consequent losses in goods and services. Such impacts of human activities have to be contrasted with the benefits obtained from the exploitation of goods and services. In general, the issue as to when a positive benefit becomes a negative impact is difficult to grasp and requires more holistic, ecosystemic and long-term thinking.

An increasing number of human activities target resources found in the deeper marine waters and seabed. Deep-sea organisms and ecosystems are particularly vulnerable given their often slow growth and low productivity. Fisheries are a case in point as overexploitation on an industrial scale has already severely decimated some deep-sea fish stocks, maybe even beyond the point of recovery. Bottom trawling, in particular, destroys large portions of the deep seafloor at a time (Gianni, 2004).

Technological advances in the last decades have opened access to the deep seas to industrial and scientific ventures (Gianni, 2004); these two spheres of activity are not completely independent of one another. Marine research, both applied and for purely scientific purposes, is crucial to our understanding of the deep-sea environment and its role in the global biogeophysical cycles. It is also of key importance for our understanding of climate change. Results of scientific research may be used by industry to prospect for new biological or mineral resources and to develop exploitation strategies, for example, it can lead to the development of new fisheries and/or help to regulate existing fisheries. Research can also help to better assess and limit the impacts of industrial activities on marine ecosystems and biodiversity, while industry data and exploration tools (ROVs, for example) can be valuable for the deep-sea scientific community or as tools for educational and public outreach purposes. The latter is illustrated, for instance, by the SERPENT collaborative project (Scientific and Environmental ROV Partnership using Existing iNdustrial Technology). It brings together key players in the oil and gas industry and the deep-sea scientific community to make cutting-edge ROV technology and data more accessible to the world's science community, share knowledge and progress deep-sea research. (www. serpentproject.com).

Industrial exploitation may, however, permanently alter deep-sea habitats, and thereby impede scientific efforts to conduct inventories, baseline and long-term studies. Thus, understanding of biodiversity or community structure, especially in the vast deep sea areas that have not yet been studied, may be foregone by rapid direct and indirect human impacts on habitats and ecosystems. In the following sections we describe some of those impacts and the activities that are causing them.

DIRECT IMPACTS ON DEEP-SEA BIODIVERSITY AND ECOSYSTEMS

Several human activities can cause acute or potential direct impacts on deep-sea ecosystems. Table 3.1 summarizes those that potentially affect deep-sea ecosystems directly, according to the nature of the interactions (extraction, pollution, noise, infrastructure, for example), the deep-sea areas or habitats targeted by the activity, the frequency, geographic area/extent of threat or impact, the current stage of development and the foreseeable development in the coming decades (increasing, decreasing or stable level of activity).

Oil tanker.

Henry Wolcott 2005/Marine Photobank

Table 3.1: List of the main human activities directly threatening or impacting the deep sea

Activity	Nature of interaction	Deep-sea area/habitat	Frequency	Area and extent of threat/impact	Stage of development	Foreseeable development
Deep-sea fishing	Resource extraction/ pollution	Continental margins seamounts, currently down to 1 500 m depth	Repeated	Regional, large	Widespread	↑
Hydrocarbon exploration and extraction	Resource extraction/ infrastructure pollution/noise	Continental margins	Continuous	Local to regional small to medium	Limited	↑
Pipeline laying	Infrastructure/ pollution	Continental margins	Sporadic (Installation) Continuous (operation)	Local/regional small	Limited	↑
Deep-sea mining	Resource extraction/ pollution	Continental margins, abyssal plains, hydro-thermal vents, cold seeps, seamounts	Continuous	Local/regional small	Anticipated (pilot projects)/ tests (carried out)	↑
Waste disposal and litter	Pollution	All	Variable	Local/regional medium	Limited (waste disposal) Widespread (litter, illegal dumping)	→
Marine scientific research and surveys	Noise/ infrastructure/ resource extraction	All	Repeated	Local, small (research) medium (surveys)	Widespread	↑
Bioprospecting	Resource extraction	Biodiversity hotspots (for example, cold-water coral reefs, cold seeps, hydrothermal vents)	Sporadic	Local, Small (except if organisms are harvested	Limited	↑
Submarine cable laying	Infrastructure	All	Sporadic (installation, repair)	Local small	Widespread	→
Gas hydrates exploration and extraction	Resource extraction/ infrastructure/ pollution	Continental margins down to 2 000 metres depth	Continuous	Local/regional medium	Anticipated (pilot projects/ tests carried out)	↑
Surveillance (e.g. military activities. high-intensity sonar)	Noise/ pollution	All	Repeated or continuous	Global medium	Widespread	↑
Carbon sequestration and storage	Pollution/ changes in environmental conditions	All	Sporadic	Local small (except if accidental releases: large)	Anticipated (pilot projects/ tests carried out)	↑
Shipping	Pollution/ noise	All	Continuous	Global Large	Widespread	↑
Pollution from land-based activities	Pollution	All	Continuous	Global large	Widespread	↑

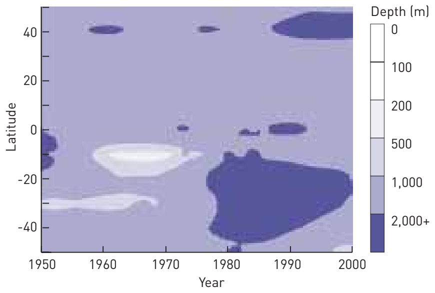
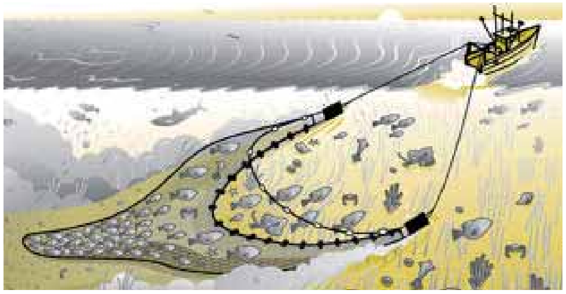


Figure 3.1: Mean depth of global fisheries landings by latitude, from 1950 to 2000 *Source: Pauly* et al.*, 2005*



Schematic cartoon showing the principle of bottom trawling.

The exploration and prospecting stages of most deep-sea activities involve hydrographical, geological and/or geophysical profiling via acoustic or optical methods. Thus, at this stage of the activities, their associated threats or impacts are similar, even if the subsequent operations have very different impacts. Some operations interact with the deep-sea environment in similar ways, causing comparable impacts, albeit often at very different temporal and spatial scales. The burial of submarine cables/ pipelines (commonly done on the continental shelves of 1 500 m to prevent accidental damage to the cable) and bottom trawling can, in principle, have the same kind of impact on the seafloor by disturbing habitats and ecosystems. The extent of impacts, however, is quite different due to the nature of the activity and the size of the areas involved. Trawling for instance is a repetitive operation, whereas the placement of submarine cables is generally a one-off activity (barring repairs). Trawling affects thousands to tens of thousands of square kilometres per tow (Gianni, 2004), whereas the area taken up by all submarine cables ever deployed is several orders of magnitude smaller. Some activities also involve risks of accidental impacts (for example, pollution from a burst or leaking submarine pipeline).

Some of the human activities listed in Table 3.1 are still in the early testing or planning stages. Table 3.2 lists the most developed human activities in the deep sea and the main habitats/ecosystems that are threatened and/or affected by them. In the following subsections, we address in more detail those activities that are most important from a socio-economic and environmental perspective and/or which currently represent the greatest actual or potential impact on the deep seas.

Deep-sea fishing

Context

Deep-sea fisheries became commercially feasible and attractive for two main reasons: (i) the depletion and

Table 3.2: Most developed human activities in the deep sea and main habitats/ecosystems affected

Activity	Main direct impacts on:
Deep-sea fishing	Continental shelves and slopes Seamount ecosystems Cold-water coral ecosystems Deep-sea sponge fields
Hydrocarbon extraction	Seamount ecosystems Cold-water coral ecosystems Deep-sea sponge fields
Deep-sea mining	Continental shelves and abyssal plains Seamount ecosystems Cold-water coral ecosystems Deep-sea sponge fields Hydrothermal vents
Waste disposal and pollution	All marine habitats and ecosystems
Cables	All marine habitats and ecosystems
Pipelines	All marine habitats and ecosystems, especially on continental shelves and slopes
Surveys/ Marine Scientific Research	All marine habitats and ecosystems
Bioprospecting	Seamount ecosystems Continental shelves and abyssal plains Cold-water coral ecosystems Deep-sea sponge fields Hydrothermal vents Cold seeps and mud volcanoes

increasing control/regulation of the traditional fish stocks in shallower, coastal areas under national jurisdiction and (ii) technological developments that provided the tools and gear necessary to fish effectively in deeper waters. Figure 3.1 shows the trend towards deeper catches, especially in the southern and northern oceans. It is estimated that 40 per cent of all marine trawling grounds are now deeper than the continental shelf (Roberts, C.M., 2002). Deep-sea fisheries are dominated by bottom trawling, which provided some 80 per cent of the deep-sea catch in 2001 (Gianni, 2004). The main target species are prawn, orange roughy, redfish, oreos, alfonsinos and grenadiers (Pauly *et al.*, 2003). Patagonian toothfish is a target of longliners in the Southern Ocean, while bottom gillnets fisheries target monkfish and deep-water sharks. Compared to coastal fisheries, a high percentage of deep-water fishing is carried out illegally, unreported and unregulated (IUU).

The characteristics and life traits of most deep-sea organisms and ecosystems (see Chapter 1) such as slow growth, late maturity, slow reproduction, exceptional longevity and low productivity apply also to deep-sea fish species. Orange roughy, for example, live up to 200 years or more, and only start to reproduce at around 20 years old (Gjerde, 2006a; Koslow *et al.*, 2000). This has considerable implications for the approach to be taken in the conservation, protection and sustainable management/use of deep-sea fish stocks.

Nature

Heavy-duty bottom trawls are the dominant deep sea fishing gear used to catch fish and shrimps living on or near the seafloor. To avoid losing or damaging gear, fishers sometimes drag chains and heavy equipment to level the seafloor before they trawl with their nets. The trawls are towed for short periods of time, at speeds averaging 4 knots, usually by one or two large vessels with engines of several thousand horsepower. Bottom trawling for commercially valuable deep-sea species now takes place at depths from approximately 250 to 1 500 metres, depending on the targeted species (Clark *et al.*, 2006).

Scope

Bottom trawling in the high seas constitutes a small fraction of the world's fisheries in both quantitative and monetary terms (Gianni, 2004), but the ecological impacts of this activity are disproportionately large. The Northwest Atlantic (Grand Banks and Flemish Cap) accounts for approximately two thirds of the high seas bottom trawl catch, of which European trawlers (the majority Spanish vessels) take approximately two thirds (Gianni, 2004). Other countries with significant deep-sea trawling activity are: Russia, Portugal, Norway, Estonia, Denmark/Faroe Islands, Japan, Lithuania, Iceland, New Zealand and Latvia. In general, deep-water bottom trawling requires large and powerful ocean-going vessels, often owned/operated by big commercial enterprises. Without government incentives and subsidies (for example, for building new vessels or on fuel tax), deep-water and high seas bottom trawling would in most cases not be economically attractive. Over the 1990s, government subsidies (estimated at US$ 15–20 billion per year) accounted for nearly 20 per cent of revenues of all fishing industry worldwide (Milazzo, 1998). A more recent figure estimates the sum of fuel and non-fuel subsidies to be between US$ 30–34 billion per year for the period from 1995 to 2005 (Sumaila and Pauly, 2006). The global amount of subsidies paid to bottom trawl fleets operating in the high seas is estimated to be at least US$ 152 million per year, that is 25 per cent of the total landed value of the fleet. If, as suggested by economic data for bottom trawlers, the profit achieved by this vessel group is normally not more than 10 per cent of landed value, the implication is that, without subsidies, the bulk of the world's bottom trawl fleet fishing in the high seas would operate at a loss. This could be a factor in reducing the current threat to deep-sea and high seas fish stocks (Sumaila *et al*. 2006).

Although deep-sea fish stocks have been exploited only since the late 1960s, several species have already declined so much that they can be categorized as "endangered", some of them practically unknown to marine and biological sciences (Devine *et al.*, 2006). Armourhead and alfonsino fisheries along the Hawaiian and Emperor Seamount chains and the northern mid-Atlantic ridge respectively, have not shown much sign of recovery since their collapse in the mid 1970s after a decade of intensive fishing (Gianni, 2004). Without sustainable management, many deep-water and high seas fisheries follow a "boom and bust" cycle of rapid development and decline, such as the recent fisheries in the Southwest Indian Ocean, which collapsed after only four years in the late 1990s (Clark *et al.*, 2006).

Impact

The impact of deep-water demersal trawling has been compared to that of forest clear-cutting or resource mining, given rapid depletion and unlikely recovery of resources (Beaumont and Tinch, 2003; Roberts, C.M., 2002). Some areas of the southern North Sea may be trawled more than 10 times a year (Beaumont and Tinch, 2003), while deeper and more sensitive waters may only be trawled once a year to allow for minimal recovery. Any type of gear dragged on the seafloor has considerable impact, classified into eight categories: scraping, penetration, pressure, sediment suspension, habitat destruction, burying, pollution by ripped nets and mortality in the benthos (Linnane *et al.*, 2000).

Trawls level the seabed, reducing habitat complexity

Greenpeace/Virginia Lee Hunter

Bottom trawling for deep sea red fish (*Sebastes marinus*) at depths of 650 metres in the North Atlantic Ocean.

Jan Helge Fosså/IMR

Malcolm Pullman/Greenpeace

Top: **Trawl scars across a destroyed coral reef, offshore Norway.**
Bottom: **A giant piece of 500-year-old gorgonian coral being hoisted out of a trawl net.**

and leaving ground for opportunistic species such as scavengers. The removal of ecosystem-building species such as corals might lead to a temporal or permanent change in fauna composition. In general, the impact depends on four factors: the type of gear (weight and size), the towing speed and length of the line, the nature of the seabed substrate (sand, sediments, rocks) and tidal conditions or currents (Linnane *et al.*, 2000). Depending on local conditions, sediments suspended by the trawl may impact neighbouring ecosystems over considerable distances. Water column species are also affected by the cloud of suspended particles churned up by the bottom gear.

While most deep-sea ecosystems are threatened by demersal trawling, the risk is particularly acute for seamounts and cold-water coral reef communities. The benthic biomass from unfished seamounts has been measured at 106 per cent more than that of fished ones (Koslow *et al.*, 2001). Suspension feeders such as cold-water corals and deep-sea sponge fields are particularly at risk from physical impact and smothering by sediments. Evidence of impact on cold-water corals from bottom trawling includes images of devastated reefs and large amounts of coral bycatch (both reef-forming and solitary species). Thirty to fifty per cent of cold-water corals in Norwegian waters are severely damaged or dead, and their extremely slow growth threatens recovery (Fosså *et al.*, 2002). In 1999, Norway was the first country to protect and conserve cold-water coral reefs within its Exclusive Economic Zone (EEZ) under the Norwegian Nature Conservation Act (Armstrong and van den Hove, 2007). The state of cold-water corals on the Darwin mounds in the North East Atlantic prompted authorities to adopt protective measures (Commission Regulation (EC) No.1475/2003) (De Santo and Jones, 2007). In October 2007, the European Commission proposed a ban on fishing with active or passive gears in four areas (Belgica Mound, Hovland Mound and Northwest and Southwest Porcupine) off the Atlantic coast of Ireland hosting extensive cold-water coral reefs (Belgica Mound, Hovland Mound and Northwest and Southwest Porcupine). Together, these areas cover a total of around 2 500 square kilometers. In the first year of the orange roughy fishery on the south Tasman rise, an estimated 10 tonnes of coral was caught per tow, or approximately 10 000 tonnes of coral for 4 000 tonnes of fish (Gianni, 2004).

Box 3.1: Deep-sea fishing gear

Source: UN, 2006a

There are essentially four types of gear used in deep-sea fisheries. These are listed below in decreasing order of importance and in increasing order of so -called ghost fishing potential.

Trawls are by far the most common. They consist of large nets with openings of up to 55 metres length and 12 metres width, large enough for a double-decker bus. Two otter boards on the side of the net opening, weighing up to six tonnes each, act like ploughs on the seafloor and keep the net apart. The head line or upper lip of the net opening is fitted with buoys, and the foot rope or lower lip is weighted with rollers, cables, chains, bobbins and "rock hopper gear", depending on the roughness of the seafloor. The mesh size of the net is determined by the targeted species. Bycatch of non-target or unwanted organisms can be very high. Bottom trawls are being dragged, and are in constant contact, with the seafloor. Apart from the direct physical impact, they create large sediment plumes which can smoother nearby communities.

Long lines are thin lines/cables with several thousands of baited hooks attached. The lines are lowered to the seafloor with weights, most often near or in deep-sea biodiversity hotspots. While long lines are a static fishing gear, bycatch of seabirds (hooked when the lines are being deployed), marine turtles and mammals is a significant problem. Bycatch Reduction Devices (BRDs) do exist, but are not yet applied by all long liners.

Gillnets are similar to drift nets except that they are anchored on the seafloor. The bottom of the net is weighted and buoys or floats are attached to the top. Up to 3 metres in height, these nets can stretch for 1 000 metres. They are widely used in all oceans.

Traps are mostly used on seamounts to catch crustaceans, sometimes around cold-water corals.

Bycatch from trawlers is a significant problem in both shallow and deep waters. Mortality among undesirable species or immature specimens of target species tends to increase with depth and as fisheries progress. In the southern North Sea for instance, for every kilogram of market fish, an average of 4–5 kilograms of invertebrates and 2 kilograms of fish are thrown out by beam trawlers (Linnane *et al.*, 2000). Trawls can be equipped with bycatch-reduction devices (BRDs), however, these can only reduce the magnitude of the problem.

Demersal long-line fishing has a considerable impact on seabirds such as albatross, which take the bait and drown during the deployment (Dunn, 2007), and also has some of the highest bycatch and discard rates (Maguire *et al.*, 2006). Octocorals and other invertebrates are routinely entangled or caught by deep long-line fisheries (Alex Rogers, pers. comm.), but no scientific studies of this impact have been carried out to date.

The physical impact of other fishing gear is moderate and mostly limited to the damage caused by weights or anchors (UN, 2006a). Fishing gear lost or dumped at sea continues to attract and ensnare fish for several years – so-called ghost fishing (Hareide *et al.*, 2005). Remains of fishing gear are commonly observed on cold-water coral reefs in the northeast Atlantic (Jan-Helge Fosså, pers. comm.). They were also recently documented in submarine canyons off the coasts of Portugal in depths of more than 1 000 metres during a HERMES cruise (JC10, June 2007) with the research vessel RSS James Cook. It is estimated that such abandoned fishing gear represents 30 per cent of sea-based marine litter (UN, 2006a). Deep-sea environments are more exposed to ghost fishing than shallow waters, where nets are quickly overgrown by algae or ripped by storms and currents. However, the recovery of lost long lines and gillnets that snagged cold-water coral reefs or sponge fields can also have a large environmental impact (ICES, 2005).

Future

Given the state of fisheries and the serious decline in fish stocks worldwide, the pressure to develop new fisheries and/or target new stocks and species is stronger than ever, with exploration mainly taking place in deeper waters both within and beyond national jurisdiction. Large seamounts in the southern Indian Ocean, the southern portions of the Mid-Atlantic Ridge in the South Atlantic and in some regions of the southern-central Pacific Ocean could become targets for the future commercial exploration and exploitation of alfonsino and orange roughy, threatening the as yet undiscovered ecosystems and communities that might live on these seamounts (Clark *et al.*, 2006). Rapid (and unsustainable) development of deep-sea fisheries is bound to go on with greater impact on biodiversity and ecosystems and continued decline of global catch (Pauly *et al.*, 2003). Nevertheless, deep-sea fisheries, and bottom trawling in particular, rely heavily on cheap and abundant fossil fuels, which means they would be the first to be hit by peak oil and high oil prices (Pauly *et al.*, 2003). Captains of large trawlers have already refused to go to sea knowing the ex-vessel value of the catch would not cover fuel costs, despite subsidies (Clavreul, 2006). Pauly *et al.* (2003) suggest that areas of the high seas could become "quasi-marine reserves" as deep-sea fisheries become cost-prohibitive for large trawlers. Restrictions on trawling gear, such as the diameters of bobbins and rollers or the use of chains for levelling the seabed, could also prevent fishing in some vulnerable and coarse areas (UN, 2006a).

The long-term effects of bottom trawling are increasingly visible and habitat destruction will potentially lead to the collapse of more fisheries. Assessing the impact of these fisheries on biodiversity and ecosystems at all trophic levels is an urgent task for the scientific community. Further economic studies of the deep-sea fishing sector – including assessment of externalities and of market distortions due to subsidies – are needed to support sustainable use and management of the deep-sea resources. Such studies must be linked to the issue of sustainable use of shallow-water fisheries, which have a greater potential for resilience than deep-sea ones.

Offshore oil and gas operations

Context

Most submarine oil and gas reserves occur on the continental shelfs and slopes (sometimes at considerable depth), where continental crust is present. These oil and gas resources were formed by the degradation of organic matter that accumulated over millennia in sedimentary basins on the bottom of the ocean. Buried by sediments in an anaerobic environment, the organic matter was subjected to gradual decay through bacterial and chemical action while sediments continued to accumulate above. The resulting conditions of pressure and temperature led to the breaking down of complex biological molecules into simpler hydrocarbon chains. The resulting oil and gas migrated upwards through the rock layers in which they were enclosed until they reached an impermeable surface, which concentrated them into an exploitable accumulation.

The depletion of shallow-water offshore hydrocarbon reserves (DWL, 2005), rising oil prices, and the development of new drilling and sub-sea technologies, has made the exploration and exploitation of oil and gas reserves in deep (500–1 500 metres) and ultra deep (deeper than 1 500 metres) waters increasingly interesting and commercially viable. The "golden triangle" of the continental slopes off western Africa, the Campos Basin in Brazil and the US Gulf of Mexico, concentrates at present most of the investment. Sixty per cent of the golden triangle's output now comes from deep-water wells. This ratio reaches 65 per cent for the Gulf of Mexico (French *et al.*, 2006). In some deep-water areas, such as for instance the Gulf of Mexico, favourable tax regulations (in this case from the US government) provide an additional incentive to oil companies to be more active.


Norsk Hydro

The Ormen Lange gas field off Norway.

Nature

Systematic seismic surveys by oil and gas companies, combined with "ground-truthing" data from drilling programmes (for example, Deep Sea Drilling Project, Ocean Drilling Program, Integrated Ocean Drilling Program and other private endeavours) have yielded considerable information on continental margins and the nature of the ocean's subsoil. These results are obviously valuable to both science and industry exploration and production in the deep sea (Katz, 2003).

The development of deep and ultra-deep water fields has continuously provided new technological challenges. At present, semi-submersible, submersible and tender platforms account for roughly 20 per cent of all oil and gas rigs worldwide. It is now possible to lower up to a thousand tonnes economically to depths of 3 000 metres (for further information see www.rigzone.com) and to install sub-sea production systems with processing hubs and tie-backs linking more wells to an equal number of surface platforms. Deep and ultra-deep fields are often developed with fewer, high-productivity and horizontal or highly deviated wells drilled into poorly consolidated reservoirs, which require large volumes of injected and produced water (Bruhn, 2005).

Chevron broke a number of records in 2003, drilling in 3 051 metres of water at its Toledo prospect in the Gulf of Mexico. Transocean drilled a well to 10 411 metres in 2005 at the Chevron/Unocal's Knotty Head discovery. In 2006, on the Walker Ridge, a well sustained a flow of 6 000 barrels of crude per day during tests and is believed to be one of the largest fields in the Gulf of Mexico. Despite these results, a peak in deep-water drilling activities was observed in 2001

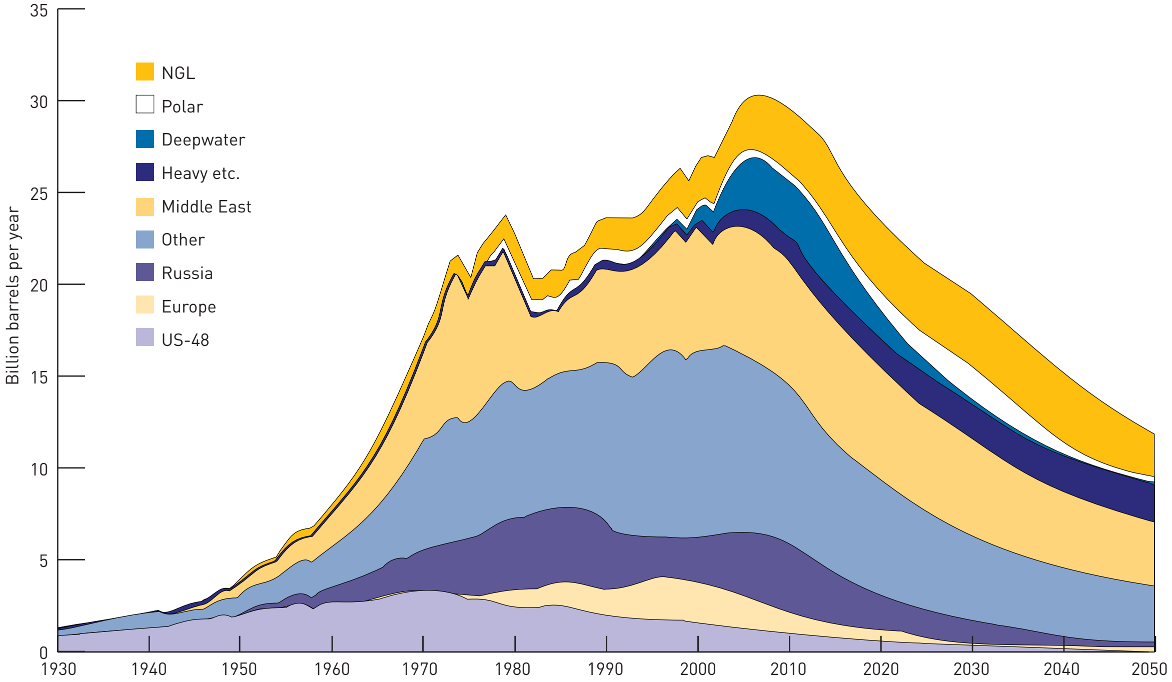


Figure 3.2: Oil and gas production scenario per type and region *Source: Campbell, 2004*

and fewer exploratory and development wells have been drilled in all but one year between 2001 and 2006 (French *et al*., 2006; Robertson *et al*., 2006). Expenditures continue to rise however, as activities such as drilling and floating platforms become increasingly expensive and form the main component of deep-water development (Robertson *et al*., 2006). A recent development is the coming on stream of the Total-operated Dalia project offshore Angola. It operates at 1 200 to 1 500 metres depth, with 71 subsea wells and 160 kilometres of pipelines and umbilicals to transfer the oil to the Floating Production Storage and Offloading vessel.

Various potential geohazards may affect the development of deep-water oil and gas fields. These include large prehistoric submarine landslides and gas/liquid seepage features like pockmarks and gas chimneys, active faulting and earthquakes, mud volcanoes, diapirs, gas hydrates and very soft and brittle ooze-type sediments. In addition to these natural features and processes, human activities related to drilling of exploration and production wells, anchoring and pipeline installation might trigger large-scale instabilities of the seabed (NGI, 2007). Hence, geohazard analysis is an important component of the studies required before going ahead with the development of hydrocarbon fields in the deep seas. An example is the Ormen Lange gas field off Norway, on the upper section of the giant Storegga slide. The fact that hydrocarbon extraction could eventually trigger seafloor and subseafloor destabilization has resulted in extensive geohazard studies of the area (for example, Bryn *et al*., 2007). Impacts of hurricanes are another important component to take into account in business risk assessments prior to deep-sea operations.

Scope

Deep-water oil and gas accounted for 10 and 7 per cent respectively of global offshore oil and gas production in 2004 (DWL, 2005), which amounts to roughly 3 and 1 per cent of world oil and gas extraction, respectively. Determining the amount of deep-water hydrocarbon resources and reserves is an intricate process, involving data on:

1. Estimates of hydrocarbon resources by geoscientists;
2. Discoveries by scientists and oil and gas corporations;
3. Estimates of recoverable reserves from well development;
4. Proven hydrocarbon reserves once fields go into production.

The results are subject to both inaccuracies and uncertainties due to several factors, including limited geological knowledge of the oceans, the difficulties in sampling as well as the use of different statistical methods, and technological change for recoverable reserves. For instance, of the 99 gigatonnes of oil equivalent estimated to be in deep waters, the known oil and gas reserves account for a mere 2.9 to 3.4 per cent (ISA, 2000). If the estimated amounts of hydrocarbon resources in the deep water are proven and recoverable reserves, then the growth potential of deep-water oil and gas is significant.

The oil and gas production scenario per type and region (see Figure 3.2) shows that even though deep-water oil and gas extraction will remain limited compared to overall global production, relative to other sources, the projected increase in deep-water production comes only second to the projected production of natural gas liquids (NGL).

Impact

The environmental threats and impacts resulting from such activities in deeper waters can be estimated based on experiences and analyses of shallow-water oil and gas operations. Direct physical impacts are relatively low. Other potential impacts consist essentially in chemical pollution (for example, from operational releases of chemicals and drilling muds and/or accidental, sudden spills) that may occur during the drilling process. Drill cutting piles that surround oil and gas wells are often contaminated with hydrocarbons and drilling fluids. Leaking of, and chronic exposure to, these contaminants can have serious effects on nearby ecosystems, especially sessile organisms. The volume of contaminated drill cuttings from oil and gas platforms in the United Kingdom and Norwegian sectors of the North Sea is approximately 2 million cubic metres (Grant and Briggs, 2002). While this is mostly in shallow waters, it illustrates what deep-sea environments may face. Given the relative lack of current and tidal motion in the deep sea, the dispersion and degradation of contaminants and pollutants such as polycyclic aromatic hydrocarbons (PAHs), may be slower than at shallower depths where no significant levels of contamination from a rig may be detected among fish (King *et al.*, 2005). In some places this is debatable, however, as processes such as dense shelf water cascading could be extremely efficient in carrying pollutants to the deep sea (Canals *et al.*, 2006).

The deeper waters in the northern North Sea, the Norwegian shelf, off northwest Scotland and in the Atlantic "golden triangle" are all regions where deep-water oil and gas exploration and extraction might take place close to vulnerable deep-sea ecosystems, such as deep-sea sponge fields or cold-water corals. The effects are potentially acute on the latter in particular (Freiwald *et al.*, 2004), albeit varying between coral species. But implications regarding environmental sensitivity of cold-water corals, such as *Lophelia pertusa*, near offshore oil and gas drilling platforms are unclear as the amount of exposure to drill discharges is often unknown. Moreover, corals may use platforms for settlement as they provide a hard substrate in an area where naturally ocurring hard substrate is sparse (Roberts, J.M., 2002).


Total

The Dalia Project: oil extraction in the deep waters offshore Angola.

The presence, or formation, of reefs around installations where trawling is prohibited, may indicate that the environmental impacts of deep-water oil and gas operations are less damaging in the short run compared to bottom trawling. Nevertheless, more detailed studies of the (short- and long-term) physical and chemical effects of drilling waste discharges on ecosystems are needed to have a more precise assessment of environmental impacts (Patin, 1999).

Another potential impact of oil and gas activities in the deep sea is the spread of invasive species as slow-moving and frequently moored vessels, such as drilling platforms serve as large artificial reefs and therefore pose a risk of alien species transmission when (and if) they are brought to shore for maintenance (Galil, 2006).

Future

Figure 3.3 shows the forecasted production of deep-water hydrocarbons to 2009. Between 2005 and 2009, deep-water oil and gas operations are expected to rise from 17 per cent to 24 per cent of global offshore expenditures. As new development projects come online, the share of deep-water oil output is likely to increase by 2015 to 25 per cent of all offshore extraction (Robertson *et al.*, 2006). The contribution of deep-water oil and gas is expected to account for most future offshore growth. Not all deep-sea provinces are suitable for holding hydrocarbon reservoirs because of their geological nature and evolution. There are still many uncertainties and most deep continental basins and margins, including the polar ones, are still poorly explored.

Deep-water hydrocarbons are considered an unconventional source of hydrocarbons. Exploiting oil and gas in harsh environments such as the deep sea at high

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Gas hydrate is found in subsurface sediments where physical and chemical conditions permit. When brought to the surface, the hydrate dissociates, releasing the (flammable) methane gas.

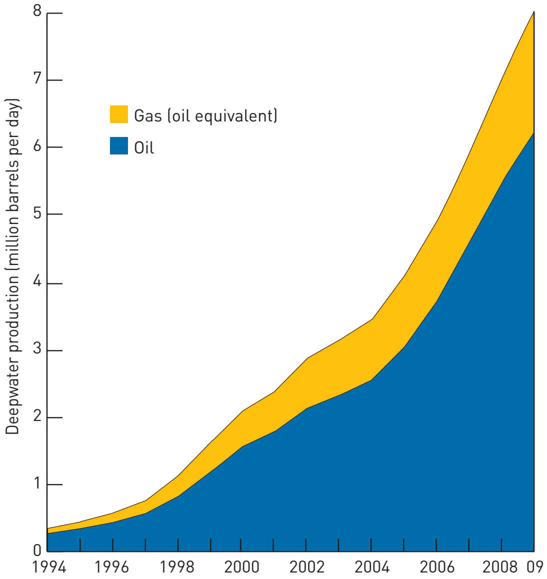
pressures and low temperatures relies on technological breakthroughs and sustained oil prices. It is accordingly more vulnerable and accident-prone than operations in shallow waters and on land. Furthermore, under current cost/benefit (that is, energy return to energy investment) ratios, deep-water oil remains a marginal source of energy, however, should the combination of world demand and peak oil lead to significantly increased oil prices, the story could be completely different.

To ensure minimum impacts of deep-sea hydrocarbon exploration and production, the industry needs to better understand, assess, predict, monitor and consequently manage the potential short, medium and long-term impacts that its activities may have on the surrounding environment. To that purpose, more knowledge on deep-sea ecosystems and their environments is needed, as well as improved strategic environmental assessments, environmental impact assessments, indicators and monitoring.

Ultimately, even if the cumulative adverse effects of hydrocarbon extraction continue to pressure deep-sea biodiversity, the indirect impacts from the combustion of fossil fuel – in particular, climate change and ocean acidification – remain a far more daunting threat.

Figure 3.3: Deep-water oil and gas production

Source: DWL, 2005



Deep-sea gas hydrates

Context

The increasing worldwide demand for energy (and the shortcomings associated with satisfying this demand with fossil fuels, nuclear power or renewable energies) has triggered over the last decade a search for other unconventional energy resources. Gas hydrates, naturally occurring solids (ice) composed of frozen water molecules surrounding a gas (mostly methane) molecule, are known to represent an immense energy reservoir. It is estimated that gas hydrates contain between 500 and 3 000 gigatonnes of methane carbon (WBGU, 2006), over half of the organic carbon on Earth (excluding dispersed organic carbon), and twice as much as all fossils fuels (coal, oil and natural gas) combined (Kenvolden, 1998).

Nature

Gas hydrates are metastable; that is, their existence is controlled by the prevailing pressure, temperature, water chemistry, gas composition and gas concentration (Lüdmann *et al.*, 2004). Suitable conditions for gas hydrate formation are found in polar areas and in sediment layers on the outer continental margins in 500 to 2 000 metres water depth. Changes in these conditions, due to a rise in water temperatures near the deep-sea bottom, for example, can cause the gas hydrates to dissociate into gas (methane) and water (liquid or frozen). The volume of methane captured in gas hydrates is large, with 1 m^3 of gas hydrate equalling 164 m^3 of methane at standard temperature and pressure.

The utilization of gas hydrates as energy sources poses great technological challenges and bears severe risks and geohazards. The destabilization of gas hydrates can cause large parts of the seafloor on the continental margins to become instable and slump or slide into deeper areas, triggering earthquakes and tsunamis. An example is the Storegga Slides off the Norwegian coast, which count among the largest submarine sediment slides in history (the latest incident occurred around 6100 BC). Here, a 290-kilometre stretch of coastal shelf suddenly collapsed, displacing some 3 500 cubic kilometres of material. This caused a large tsunami, which affected all coastal states and islands in the North Atlantic. In Scotland, the effects of this tsunami can be traced up to 80 kilometres inland. In addition, destabilized gas hydrates may also affect the climate and increase atmospheric concentrations of greenhouse gases through the release of large amounts of methane, more than 20 times as potent a greenhouse gas as CO_2.

Scope

Research into submarine gas hydrates has so far concentrated on the identification of the distribution and extent of gas hydrate reservoirs. Apart from some experimental pilot projects to recover small amounts of gas hydrates, the challenges and risks involved have so far prevented operations on a commercial scale. Whether the exploitation of gas hydrates could become reality in the near future is still disputed among experts. Firstly, technologies would have to be developed to cope with the physical conditions (pressure and temperature, for example) under which gas hydrates would have to be extracted. Secondly, gas hydrates commonly occur in numerous but small forms of ice interspersed within sediments; that is, they do not form "clean" and easily minable concentrations or horizons. This means that large amounts of sediments would have to be extracted with considerable environmental impacts, including the removal of large quantities of fauna and wide-ranging increase in turbidity and sediment suspension.

Future

It is still uncertain if and when it will be feasible and economically viable to exploit gas hydrates as an energy resource

Box 3.2: Main potential sources of non-fuel minerals in the deep sea *Source: adapted from ISA, 2004)*

Polymetallic manganese nodules are rock concretions containing metals such as cobalt, copper, iron, lead, manganese, nickel and zinc. They lie partially buried on the surface of sediments that cover the abyssal plains (typical water depth 5 000 metres) and mostly range in size from that of a golf-ball to a tennis ball. It generally takes millions of years to form a manganese nodule. The metals concentrated in these nodules come from two sources. The primary source is considered to be metals that are dissolved from rocks on land as part of the weathering process and transported to the ocean by rivers. The secondary source is metal-rich solutions that discharge as warm and hot springs at ocean ridges. The upper portion of the nodules accumulates metals that are precipitated from seawater, while the lower portion of the nodules accumulates metals from pore-water in the underlying sediments.

Massive polymetallic sulphides containing copper, lead, zinc, silver, gold and other trace metals are forming in the deep ocean around submarine volcanic arcs, where hydrothermal vents exhale sulphide-rich mineralizing fluids into the ocean. Their mineralization process requires tens of thousands of years.

Cobalt-rich ferromanganese crusts are precipitations of metals such as iron, manganese, cobalt, nickel, platinum and others that are dissolved in seawater. The metals are derived from a combination of sources comprising dissolution from continental rocks and transport into the ocean by rivers, and discharge of metal-rich hot springs in the deep ocean. Instead of accumulating as nodules on the sediment surface of abyssal plains in the deep ocean, cobalt-rich-ferromanganese crusts accumulate as extensive layers directly on volcanic rock that forms submerged volcanic seamounts and volcanic mountain ranges.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Hydrothermal vents, such as this black smoker at the Logachev hydrothermal vent site on the Mid-Atlantic Ridge, and their underlying mineralization system are the source of rich polymetallic sulphide deposits at and just below the seafloor.

on a commercial scale. If it were an option, consequent GHG emissions would only exacerbate the problem of climate change. The occurrence and distribution of gas hydrates is also of special interest to other industrial developments taking place in the deep sea, such as oil and gas operations. In relevant areas, gas hydrates could become one of the major risks for these activities, as their disturbance can dramatically modify the character and engineering response of the seabed and subsoil and may lead to large and explosive gas releases.

Deep-sea mining

Context

Both continental margins and ocean basins contain potentially valuable non-fuel mineral resources. Some of these minerals have a terrigenous origin; that is, they come from land erosion and were transported to the sea mainly by rivers and glaciers. Margins and ocean ridges, however, are host to other sources and processes (for example, volcanic) that form different types of mineral deposits (see ISA, 2004 for a detailed description). The main potentially exploitable sources of deep-sea minerals lie in polymetallic manganese nodules, polymetallic sulphides, and cobalt-rich ferromanganese crusts (see Box 3.2).

The potential for deep-sea mining operations is significant. Submarine cobalt-rich ferromanganese crusts of 0.6 to 1 per cent grades would be enough to provide up to 20 per cent of global cobalt demand, but cost-effective mining methods still need to be developed (Rona, 2003). Similarly, the high recovery cost of manganese nodules on abyssal plains and hydrothermal vent polymetallic sulphides has prevented any significant development so far.

Nature

Commercial interest in deep-sea mining concentrates at present on polymetallic sulphides around hydrothermal vents (for example, around Papua New Guinea) and manganese nodules. The latter are mainly found in the Clarion-Clipperton fracture zone of the Pacific, the so-called "manganese nodule belt".

Scope

Mining activities in the deep sea are still largely prospective. Since 1987, the International Seabed Authority (ISA) has signed eight exploration contracts, which allow contractors to prospect and explore for nodules in specified areas beyond national jurisdiction. Exploration contracts require contractors to report their activities to ISA on an annual basis, and contractors are bound to prevent, reduce and control pollution and other hazards to the marine environment arising from their activities. Seven of these contracts are for areas in the J31manganese nodule belt, including the most recent with the German Federal Institute for Geosciences and Natural Resources. At stake for this 15-year claim are 50 million tonnes of copper, nickel and cobalt in depths of at 4 000 to 5 000 metres.

Prospecting for massive polymetallic sulphide deposits containing deposits of gold, silver, copper and zinc from hydrothermal vents and seamount areas respectively, currently takes place in the Exclusive Economic Zones (EEZs) of Papua New Guinea and New Zealand by two companies. Nautilus Minerals is operating at 1 600 metres water depth, whereas Neptune Mineral's concession ranges from 120 down to 1 800 metres (for further information see www. neptuneminerals.com and www. nautilusminerals.com). Industry has recently invested several million dollars in marine mining. The chief executive of Nautilus Minerals compares the costs of underwater mines to those of the Pascua Lama gold mine project in Chile, stressing that mining sulphides in 1 600 metres of water may represent lower capital costs than drilling for gold under a glacier 4 500 metres above sea level (see media article "Nautilus Minerals looking to ocean floor" on www.nautilusminerals. com).

Independently of environmental considerations, several economic factors affect the feasibility of deep-sea mining. They include the price of metals, the availability and costs of different technology options, as well as the energy costs. As regards technology, depth is not the only constraint. The more complex the geometry of the deposit and the structure of the seafloor, the more sophisticated (and therefore potentially less reliable) the collecting devices need to be. The different deposits can be classified from relatively easy (nodules) to moderately difficult (Cobalt-crusts) and more difficult (sulphides) to mine (Lenoble, 2004).

Table 3.3: Summary of the princial types of mineral resources in the oceans

Source: Cochonat et al., 2007

Type	Location	Commodity	Depth	Mining status	Economic interest
Salt	Coastal	Salt	Shore	Operational	Moderate
Sand and gravels	Beach, shallow water	Aggregates	Shallow	Operational	High
Marine placers	Beach shallow water	Tin, gold, chromium zirconium Rare Earth Elements, titanium	Shallow	Operational	Moderate
Diamonds	Coastal	Diamonds	<250m	Operational	High
Phosphates	Shallow water and seamounts	Phosphate	Shallow to medium depths	Non-operational	Low
Nodules	Deep ocean	Copper, cobalt, nickel	4 500m - 5 500m	Potential resources	Moderate
Manganese crusts	Intraplate seamounts	Copper, cobalt, platinum	1 000m - 2 500m	Potential resources	Moderate
Deep-sea sulphides	Volcanic ridges	Copper, zinc, silver, gold, cobalt, lead	1 000m - 4 000m	Potential resources	High

Impact

The potential environmental impact of deep-sea mining still needs to be further investigated, including the recovery of deep-sea ecosystems after mining has taken place. Earlier impact studies by German and US scientists, and biodiversity studies by French scientists (Tilot, 2006) have shown a unique fauna associated with nodule fields, which would be endangered in case of large-scale mining (Thiel, 2001). However, experiments would have to be carried out over large spatial and temporal scales, something the mining companies may not wait for. Very little is known about the community structure of deep-sea organisms and, by the same token, their resilience to large disturbances.

Given the presence of macrofauna primarily in the top sediment layers of the deep-sea bed, scooping up polymetallic nodules and subsoil operations would wipe out biodiversity (Smith, 1999). Recolonization rates on abyssal plains are expected to be extremely low. Moreover, the occurrence of endemic species would seriously limit the options for conservation in one area to compensate for biodiversity loss in another. The impact from resuspension of sediments would also be considerable. For instance, one calculation estimates that to be economically feasible, it would be necessary to mine on the order of 0.5 square kilometres per day, which would resuspend about 7 400 tonnes of sediment per day. Surface deposit feeders in a radius of over one kilometre would find themselves buried under millimetres to centimetres of sediments (Smith, 1999). An estimate of how thick a layer of sediment might entomb burrowing organisms would help to quantify potential losses of biodiversity. The actual removal of sediments, that is, habitat to the majority of organisms on abyssal plains, would sacrifice the fauna. Needless to say, resuspension and removal would occur repeatedly during operations.

Similarly, mining massive sulphides is likely to affect the unique fauna around hydrothermal vents, either by direct killing of organisms by mining machinery or by altering the fluid flows on which these organisms depend. Individuals surviving these disturbances would be subject to a radical change in habitat conditions. Because of the high degree of uniqueness and high endemism of vent communities, impacts of mining on biodiversity are likely to be significant as species might not be able to recolonize easily once mining operations cease. The vents of some seafloor polymetallic sulphide deposits can become naturally inactive and stop providing habitat for the specialized chemosynthetic vent fauna. Once this occurs, these inactive areas can be colonized by neighbouring deep-sea organisms. Before concluding that mining in such inactive areas would pose little threat to biodiversity, more extensive sampling is required to establish the nature of their fauna, as mining would eliminate habitats (Juniper, 2004).

Ecosystems and biodiversity in areas rich in ferromanganese crusts would be seriously affected by mining activities. Especially around seamounts, these operations would affect vulnerable communities and associated species – some of which with commercial value – in a similar way to trawling. Before mining for crusts on seamounts becomes the underwater equivalent of mountain top removal, thorough environmental impact assessments must be conducted (Koslow, 2004).

Nevertheless, some argue that deep-sea mining is less damaging than terrestrial excavation. Picking up nodules and sulphides from the seafloor appears less intrusive than, say, open pit mines (Scott, 2006). In the end, impact largely depends on the scale at which deep-sea mining operations would take place. Further research would be necessary to assess the scale factor relative to the size and vulnerability of deep-sea ecosystems and biodiversity hotspots.

Future

Today, most operational ocean mining takes place in shallow water, however, recent advances in industrial capability have increased the potential economic interest in deep-sea ores (see Table 3.3). With the technology developed for submarine oil and gas production facilities and the rising prices of minerals, deep-ocean mining might become feasible and commercially attractive in the near future. Due to their generally higher metal contents, lesser water depths, and proximity to land within the 200-nautical mile zone, the polymetallic massive sulphide deposits at convergent plate boundaries associated with the coastal states of the volcanic island chains, especially in the Western Pacific, are likely to be developed sooner than more remote and deeper sites on the submerged volcanic mountain range associated with divergent plate boundaries in the international seabed area of the oceans (ISA, 2004). Underwater mining potentially offers the same prospects pioneer miners had when land-based industries first started.

Waste disposal and pollution

Context

Despite their vastness and depth, the deep seas are no longer a pristine environment. Eventually, many pollutants end up in the sea from either point or diffuse sources. Pollution, wastes and litter are running off from land, are intentionally dumped at sea (including toxic chemicals, oil, disused weapons and radioactive materials), are lost (such as oil, fishing gear), or are discarded (such as plastic bags, damaged fishing nets), with no consideration for the resulting environmental effects. The threats to biodiversity from waste disposal and pollution include ghost fishing, death from ingestion of plastics and chemical compounds, and extinction from changes in biochemical conditions that might disrupt entire food chains. In addition, it is most likely that the oceans will also become a critical target and component of attempts to mitigate climate change. However, the "dilution is the solution to pollution" maxim, the utmost misconception of environmental engineering, proves to be as wrong in the oceans and seas as in the atmosphere or on land. In addition, ocean currents such as the Gulf Stream have no concept of political and legal borders, which makes pollution across these boundaries difficult to manage.

Nature and scope

Some 80 per cent of the pollution load in the oceans originates from diffuse land-based activities. This includes municipal, industrial and agricultural wastes and run-off, as well as atmospheric deposition (see www.gpa.unep.org for further information). Untreated sewage, sewage sludge, fertilizer, pesticide residues, persistent chemicals and heavy metals all reach the marine environment through natural and man-made channels. Rivers, estuaries and their prolongation in the form of submarine canyons carved in continental slopes carry large amounts of sediments to the deep sea (Canals *et al.*, 2006). Also, around 80 to 90 per cent of the material in weight deliberately dumped at sea results from dredging, currently amounting to hundreds of millions of tonnes per year. Disposal of dredged material in deep seas represents about 20 to 22 per cent of the total dredged, while the rest ends up in shallow waters and on land (see www.oceanatlas.org for further information). Approximately one tenth of all dredged sediments are contaminated with anything from anti-fouling paints and heavy metals to sewage and land runoff. It is therefore a matter of time before toxic chemicals from land-based sources are transported to the deep sea.

The nuclear and military industries are sources of some of the most dangerous wastes intentionally dumped at sea. Because of the difficulty to access data from both civil and military sources, the quantities of radioactive wastes dumped in ocean trenches off the British Isles by the United Kingdom and other European nations, or of submarines reactors dumped by the Soviet Union, can barely be estimated. Nuclear (re)processing plants continue to discharge low levels of radioactive waters into the sea. However, atmospheric nuclear tests are responsible for more than 2 000 times the levels of radioactivity observed in the oceans, compared to solid wastes (IMO, 1997). The oceans are not safe, secure garbage cans either: nuclear wastes in shallow waters off Somalia were recently washed ashore by the 2004 Tsunami, causing serious health and environmental problems (see www.unep.org/tsunami_rpt.asp for further information).

The oil and gas industry is also a source of pollutants. Radioactive radon and lead isotopes are released in the seas while pumping oil and gas out of continental crusts (Dutton *et al.*, 2002). Decommissioning of oil and gas rigs, as the 1995 Brent Spar case showed, will become a critical issue and strategies need to be put in place to manage the end of life of such equipments, especially in the deep sea. Even if pipelines and platforms can be towed to shore, chances are that some equipment will be left in place on the seafloor and the potential contaminants contained in such structures will become a key issue. The toppling of disused offshore installations is equivalent to dumping according to the OSPAR Convention and therefore illegal in the North Sea, unlike in the Gulf of Mexico. The bulk of the oil and gas industry's wastes, however, will come from another indirect source: the deep sea is bound to be at the end of the economy's largest waste stream, CO_2 emissions.

Pollution from ships tends to be less controlled away from the coasts. Further out at sea, tanks are often cleaned, and oil and chemical residues deliberately discharged overboard. Such operations represent the largest sources of pollution from ships (UN, 2007). Moreover, the regulation of effluents from ships remains difficult to enforce, especially if discharges take place in remote offshore areas or international waters. Spurred by a boom in tourism at sea, cruise ships are increasingly threatening vulnerable areas with their wastes. Seabed litter studies in the Mediterranean found that the most common litter were paint chips (44 per cent) and plastics (36 per cent), with probably most of this seabed debris being ship-based. Moreover, vessel-generated refuse remains a major source of marine litter, even after the entry into force of regulations that prohibit disposal of all litter except food (Galil, 2006).

MARUM Research Centre Ocean Margins www.marum.de

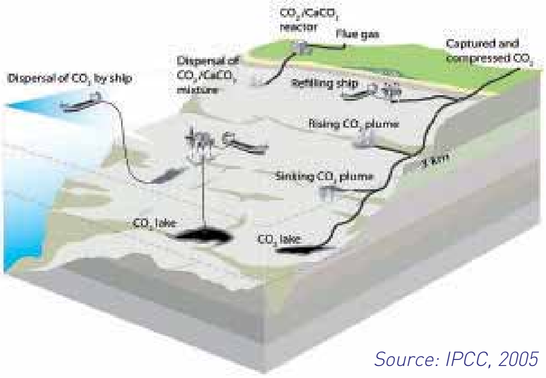
Plastic rubbish caught on Madrepora coral colonies in the central Mediterranean.

As mentioned above, some 30 per cent of marine debris is fishing gear, either lost or dumped. In addition, a rough estimate of lost merchant freight at sea is 1.3 million tonnes per year. Over seven million tonnes of British merchant vessels were sunk during the First World War and more than 21 million tonnes of allied merchant cargo during the Second (Angel and Rice, 1996). Numerous types of non-degradable plastics litter the ocean floor, and even buoyant plastics might eventually sink due to their long persistence. Recent deep-sea dives to the Eastern Mediterranean observed a piece of plastic litter every 10–100 m^2 (HERMES expeditions RV METEOR M70). The proportion of plastics in marine litter varies between 60 and 80 per cent (Derraik, 2002).

Another type of pollution impacting on the deep sea is acoustic pollution. Maritime transportation around the globe is increasing and so is the number of boats and vessels at sea. The acoustic impact of the low frequency sounds produced by vessels is not confined to coastal waters, but penetrates into the deep portions of the oceans. It is not yet clear what impact this type of pollution can have on cetaceans (such as sperm whales, for example) that spend a large part of their life in the deep sea and use sound to communicate, navigate, feed and sense their environment (Galil, 2006). Ships can also kill mammals by accident when they surface to breathe. Most lethal or severe injuries are caused by ships 80 metres or longer travelling at 14 knots or faster. Ship strikes can significantly affect small populations of whales (Laist *et al.*, 2001).

Impact

Bioaccumulation of toxic chemicals increasingly affects deep-sea biodiversity. Some deep-sea fish are seriously contaminated by heavy metal and polychlorinated



Source: IPCC, 2005

Figure 3.4: Methods of CO_2 storage in the oceans

biphenyl (PCB) concentrations that led to consumer warnings about fish consumption. Even fish reared in aquaculture farms might be contaminated by fishmeal made of deep-sea fish (Storelli *et al.*, 2004). Canyons on continental slopes seem to carry contaminants from coastal to deep waters where they accumulate. As well as the risks they present to humans consuming deep-sea fish or fish fed with deep-sea fishmeal, PCBs are known to behave like enzymes and hormones and to disrupt biological functions, especially reproduction in many organisms (for example, Koppe and Keys, 2001).

Among the most toxic materials introduced into the sea are tributyltin compounds (TBT) (Galil, 2006). These substances were (and in some places still are) commonly used as antifouling agents in ship paints as they effectively and economically prevent the accumulation of fouling communities on vessels and man-made structures at sea (Santillo *et al.*, 2001). TBT and its degradation products impact notably on the immune system of marine mammals and on the reproductive system of molluscs. TBT compounds may reach great depth and have been found in deep-sea crustaceans, cephalopods, echinoderms, gastropods and fishes (Takahashi *et al.*, 1997; Borghi and Porte, 2002). The substances bioaccumulate and move up the food chain to end up in high concentrations in top predators such as dolphins, tuna and sharks (Galil, 2006). As legislations develop and restrictions are put in place on the use of TBTs, alternative antifouling compounds are used more widely, but there is still very little available data on the toxicity and environmental impacts of the herbicides and pesticides they contain (ibid.).

The risks and impacts associated with exotic species transported in ballast water are largely unknown for the deep seas (Gjerde, 2006a).

On the seafloor, plastics form a barrier to gas and nutrient exchange and benthic organisms. Plastics also pose a great threat to marine mammals, turtles and seabirds via ingestion, suffocation, entanglement and ensuing death. As victims die, persistent plastics are freed again to be picked up by subsequent victims.

Oceans naturally absorb some two gigatonnes of carbon per year (Brewer *et al.*, 1999). Moreover, as a carbon reservoir, the oceans have unparalleled capacity in the biosphere, 44 teratonnes (44×10^{12} tonnes) compared to 750 gigatonnes (750×10^{9} tonnes) for the atmosphere (Johnston and Santillo, 2003). Storage of CO_2 emissions in the oceans is now technically feasible, with various techniques being proposed and considered (see Figure 3.4). Economically, some claim that the ocean storage of CO_2 would increase the cost of electricity generation by 50 per cent on average, but estimates vary widely, depending on the choice of capture technology, the type of (power) plant, transportation and place of injection (IEA, 2002; IPCC, 2005). The solubility of CO_2 increases with pressure and decreases with temperature, such that beyond 2 600 metres water depth, sinking plumes of pure CO_2 can be formed (Brewer *et al.*, 2000). Injection of liquefied gases at such depths is technically difficult and, in general, injection technology plays an important role in overall storage efficiency. Geological formations under the seabed might provide a safer place for the storage of CO_2. The potential impacts of sub-seabed storage are disturbance on the seafloor due to well drilling and operations and accidental leaks or sudden release of CO_2 from the geological reservoir.

The increased concentrations of CO_2 in the areas of injection will change the pH of seawater (acidification) with adverse consequences for biodiversity such as changes in oxygen supply, and metabolic rates of primary producers. Pools of liquefied CO_2 in the water column or on the seafloor would create chemical barriers for pelagic and benthic organisms, disrupting vertical migrations and food provisions. Moreover, CO_2 from industrial sources is likely to be impure and contaminated with, for example, sulphur and nitrogen oxides as well as heavy metals. In addition, the disposal of CO_2 in the deep oceans would not permanently remove it from the global carbon cycle. Taking into account global ocean circulation and water exchange patterns, CO_2 stored in the deep sea would, on average, come into contact with the atmosphere again in around 1 000 years. The only long-term sequestration of CO_2 could be achieved by injection into geological formations underneath the seabed, where the CO_2 could be stored for millions of years, provided no leakages or sudden releases occur. The disposal of CO_2 in the deep sea and/or in geological formations under the seabed can postpone the consequences of climate change, however, they may also result in slowing down the emergence of better alternatives to fossil fuels (Schubert *et al.*, 2006).

Future

Past disposal of wastes in the deep sea is certainly no argument for future environmentally harmful ocean disposals, but hazardous chemicals and radioactive elements continue to make their way to the ocean depths. As for carbon storage, before large quantities of CO_2 are injected in the deep sea or beneath the deep sea floor, many factors must be studied in greater detail. While the oceans naturally absorb large quantities of CO_2, the same is not true for other more potent greenhouse gases. Although parties to the London Convention approved storage of CO_2 in geological formations under the ocean floor and seabed, the economic and environmental soundness of such a scheme over the long term must still be demonstrated. In any case, even if technically and economically feasible, these methods would only apply to point sources of CO_2 emissions, not the large quantities of diffuse CO_2 emissions released, for instance, by the transportation sector.

Cable laying

Context

Ever since Professor Samuel Morse thought of the transatlantic cable idea, cables have been laid on the ocean floor. The placement of submarine cables is historically the first human activity to directly affect and take place in the deep sea, with the first transatlantic cable laid in 1858 between Great Britain and Newfoundland. It is estimated that 100 000 kilometres of cables are being laid on the seafloor each year (Vierros *et al.*, 2006). As an important part of modern infrastructure, submarine cables literally wire and connect the world. Nowadays, fibre-optic cables carry hundreds of gigabytes of information per second, with the transatlantic routes concentrating a large part of total traffic (see www.atlantic-cable.com). Ninety five per cent of the voice and data traffic between continents is being carried by submarine cables, which remain a cheaper and quicker option than via satellites.

Nature, scope and impact

Telecommunications cables are designed to meet various seabed conditions. In shallow water zones of high current and wave action or rough seabed, cables are armoured with steel wire and can reach a maximum diameter of 50 millimetres. In contrast, deep-sea cables are typically unarmoured and have a diameter of 17–21 millimetres. The main threat to submarine cables is bottom trawling, which accounts for approximatively 70 per cent of faults caused by external aggression. Cables often give way when snagged by trawl doors or rollers and tension may disturb the seabed at length along the cable. In order to avoid accidental damage, cables are regularly buried 1–3 metres below the seabed for protection on the continental shelf and slope in water depths of up to 1 400 metres, a depth, which, until a few years ago was the limit of deep-sea trawling (Shapiro *et al.*, 1997). Another risk for cables comes from earthquakes and submarine landslides. One of the Internet's most recent and largest breakdowns was caused by a powerful earthquake and resultant submarine landslide which damaged undersea cables in the Luzon Strait between Taiwan and the Philippines.

TeleGeography Research

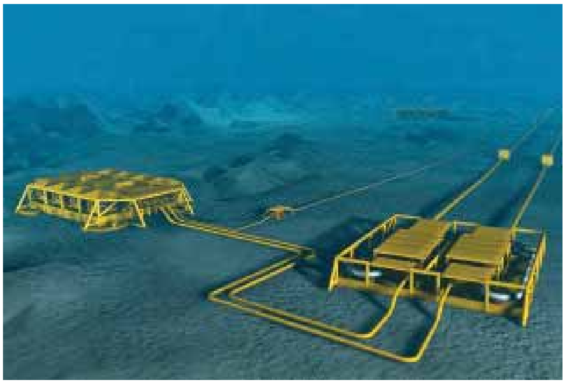
The vast majority of international telephone and internet traffic travels through underwater cables. This map shows the submarine cables in use in 2007 and gives an indication of where traffic is heaviest.

See http://www.telegeography.com/products/map_cable for a wall poster of Submarine Cable Map

Burial of cables in the sediment is by a plough-like device, which slices a narrow furrow into which the cable is inserted before the furrow is closed/covered again. Remotely operated vehicles may also be used to jet a narrow trench in the seabed into which the cable is inserted. This technique is most commonly used for cable reburial after repairs. Depending on sediment composition and currents, jetting can create large plumes of sediment. In contrast to the shelf and upper slope, the unarmoured deep-water cables are laid on the seabed surface guided there by computer-based systems that control the ship's position, speed, location relative to the seabed and the cable-laying machinery.

Future

Optic fibres were a revolution in the submarine cable industry, but the real boom came in the mid to late 1990s. The surge in Internet use, especially from Europe and North America, accelerated growth until eventually the e-business bubble burst in 2001. Cable overcapacity meant new cable-laying activities levelled off. Two recent trends include investment shifts into the cable upgrade market, and a geographical shift in new laying operations from the North Atlantic to the Indian and Pacific oceans (Ruddy, 2006). The



Norsk Hydro

Artist's view of the Ormen Lange field subsea installations off Norway. The templates will be at depths of around 800 – 1 100 metres.

former trend presumes a considerable reduction of impact, eliminating route surveys and new furrows. Technological progress also shortens the lifespan of cables. However, and with a roughly 150-year history, many cables lie abandoned on the seafloor, except in shelf and upper slope environments where older cables are often recovered to clear routes for new cables. The question of recovery and corresponding impact must be asked.

With the increase in deep-sea research, more cabled observatory projects will be built in the near future, which means placing cables in areas sometimes more sensitive than for communication purposes. However, this should be balanced against the benefits of such projects in terms of better understanding and monitoring the deep sea and managing anthropogenic activities (Cochonat *et al.*, 2007). Moreover, these observatories are subject to the same environmental assessment requirements as commercial systems so that impacts are assessed and regulated.

Pipeline laying

Context

Legally, the placement of cables and pipelines is often treated similarly, and both activities belong to the list of freedoms established in the UNCLOS (see Chapter 4, p62). However, the difference in size between pipelines and cables is noteworthy: deep-ocean cables are typically of 20–50 millimetres, while submarine oil or gas pipes reach 900 millimetres diameter. In addition, the laying, operations and maintenance of pipelines have different characteristics from that of submarine cables.

Nature, scope and impact

Pipelines require more construction work than submarine cables. They may be laid on the seabed rather than buried. Construction, maintenance and repair have an impact on the seafloor. The submarine cables, over time the greatest risks come from bottom trawling, earthquakes, landslides, and rust, which may cause leaks. Depending on the nature of the product, temperature and pressure, an oil or gas leak could have serious impact on benthic biodiversity, and upper trophic levels.

Future

To date, few pipelines have been laid in the deep sea and most of them serve as tie-backs between oil and gas wells and the surface where tankers take over transportation. Several major projects are underway. For instance, a consortium led by Norsk Hydro is currently building the world's longest sub-sea gas pipeline, stretching for 1 200 kilometres from the Ormen Lange gas field in Norway to England at depths of 800 to 1 100 metres (see www.hydro.com/ormenlange/en). Another example is the Medgaz natural gas pipeline between Algeria and Spain and whose construction started in 2007. With a length of 210 kilometres and a diameter of 60 centimetres, its maximum depth will be 2 160 metres (see www.medgaz.com). Other ambitious projects are being discussed across the globe (for example, in the Caspian and Baltic seas).

The development of sub-sea oil and gas production systems tying back wells to a central hub and up to a surface platform means many kilometres of pipelines have been – and will still be – added. Over the next five years, some 13 000 kilometres of pipeline might be needed by the oil and gas industry to complete planned deep-water projects (Robertson *et al.*, 2006).

Surveys and marine scientific research

Context

Surveying and mapping the deep ocean is a prerequisite to many civilian and military activities. Surveys are essential tools for, *inter alia*, submarine cable and pipeline routes, deep-sea oil, gas and mineral developments, installation of any other equipment in the deep sea, as well as production of navigational charts. Surveys are also used in marine scientific research (MSR). In terms of impact and growth potential, MSR and non-research surveying jobs share similar characteristics, although not always on the same spatial and temporal scale.

Nature

The main methods used to survey the deep sea are sonars of varying frequency, seismic air guns, drilling and sampling. The first two – used by scientists, industry and the military – allow both mapping of seabed topography and profiling of geological formations under the seabed. Arrays of air guns producing intense pulses are coupled with large computing capacity to process the echoes. The sounds of seismic air guns penetrate the ocean crust and can profile the subsoil down to 10 kilometres below the seafloor (Weilgart, 2004). Scientists also use sediment cores and small-scale dredges and trawls for benthic sampling.

The high costs of deep-sea MSR encourage public-private partnerships. In particular, scientists may benefit from industry's surveys just as industry may benefit from scientific surveys. In some cases, scientific institutions may also benefit from data acquired by military organizations, and researchers are embedded within military organizations like hydrographical institutes.

Scope and impact

Different types of surveys have different impacts. Industrial (for example, for hydrocarbon exploration) and military surveys are often much more intense and cause more damage than scientific surveys. Research activities involve a low-level and small-scale use of sound. Oil industry activities involve much higher levels, but the areas covered are relatively small and mitigation measures are often in place. Military activities involve high-level uses of sound over broad areas, but it is extremely difficult to access relevant data.

There are still many open questions and controversies around the effects of multibeam and seismic sources on marine fauna, in particular, mammals. Seismic surveys usually cover large areas, with high-intensity and high-frequency pulses sent from slow-moving vessels over long time periods. The sound signals become amplified with depth. The resulting impact from intensity and repetitiveness could especially affect deep-sea organisms. Compared to military sonar, commercial and scientific seismic surveys operate in a broader range of frequencies (10 Hz – 3 kHz) depending on the depth under investigation. However, despite possible mitigation measures – for example, visual detection of animals, time/area planning of surveys to avoid marine mammals (Weir *et al.*, 2006) – seismic surveys have been linked to mass stranding of cetaceans (see Engle *et al.*, 2004, for example). Accumulating evidence suggests that acoustic factors may provoke behavioural changes particularly among deep-diving species, which are sent rapidly to the surface, and become victims of decompression sickness (Jepson *et al.*, 2003). The damage to organic tissues is lethal, but other effects may eventually be lethal as well. Air guns and sonar may interfere with cetaceans' own sonar, disorienting them on their migration course, hunt for food or hazard detection. Military mid-frequency tactical sonar has been linked to the increasing number of whale strandings and the increased military use of low frequency sonar during the past decade has been shown to affect animals hundreds of kilometres away (Jepson *et al.*, 2003; Reynolds and Jasny, 2006).

Scientific surveys and deep-sea scientific research have both positive and negative impacts. On the positive side, they are essential for increasing our knowledge of the deep-sea environment and ecosystems, to understanding the value of deep-sea ecosystems goods and services and of other abiotic resources, and to underpin appropriate governance, management and exploitation schemes. On the other side, marine scientific research may cause local physical impacts due to equipment, cables and their operations. But scientific research programmes normally strive to cause the least amount of disruption in order to make accurate observations, as well as for conservation and deontological reasons. There is obviously a big difference between the scale of potential impacts of scientific research compared to that of industry or military activities. For instance, the impact of scientific trawls is minuscule compared to that of fishing trawlers. As a further step in limiting the impact of MSR, codes of conduct for MSR are currently being discussed internationally, for example, in the framework of the OSPAR Convention, to ensure that scientific research and monitoring is carried out with minimum impacts.

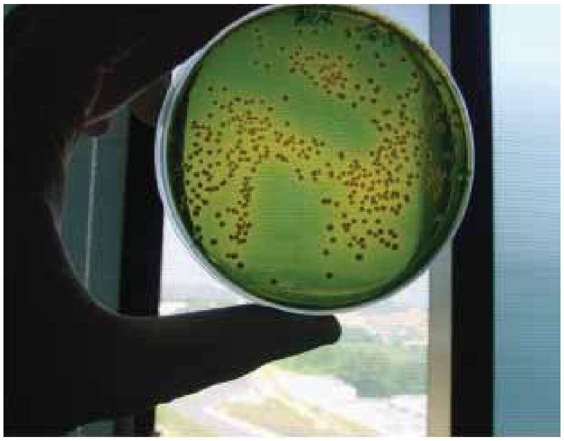
Future

In the future, sonar exercises and seismic surveys are likely to continue on a broad scale. This is driven by both the lack of knowledge and the differences between civilian and military interests. Hence surveys of the deep sea will continue at various levels, if only for natural resource extraction. Sharing data across the scientific and industrial sectors would bring synergies and contribute to diminishing impacts. Studying the effects of acoustic devices on deep-sea organisms might help geosciences corporations to explore alternative technologies and processes.

The development of long-term deep-sea cabled observatories such as the Monterey Accelerated Research System (see www.mbari.org/mars) and other deep-sea obs-

The UK research ship RRS James Cook.

NOCS


Roberto Danovaro/DiSMar

Bacterial colonies (orange dots) growing on a nutritional substrate (green background). These bacteria are isolated from the deep sea and used in biotechnology for the production of new bioactive molecules .

ervatory programmes such as the European Seafloor Observatory Network (ESONET, see www.oceanlab.abdn.ac.uk/research/esonet.php) in Europe will also have both positive and negative impacts on deep-sea ecosystems and biodiversity. The proposed ESONET for instance would comprise 5 000 kilometres of fibre-optic sub-sea cables linking observatories to the land via seafloor junction box terminals.

Bioprospecting

Context

Bioprospecting is generally defined as the search for substances or genetic materials for commercial or industrial purposes (Arico and Salpin, 2005). Marine genetic resources include a broad range of macro- and micro-organisms. The latter, which include bacteria, archae, fungi, yeasts, and viruses, are the world's most genetically diverse organisms (UN, 2007).

Present legislation does not distinguish between marine scientific research and bioprospecting. With current technological means, samples of deep-sea species can be taken practically anywhere. Both UNCLOS and CBD established the sovereign rights of nations over biodiversity within their jurisdictions, but in the Area of the High Seas there is a regulatory vacuum for bioprospecting, as the International Seabed Authority addresses and manages only abiotic resources (see Chapter 4, p63).

The CBD stresses the societal benefits of biodiversity and therefore the need to ensure its conservation and sustainable use as well as equitable sharing of benefits, however, whether and how these principles are also applicable to the high seas is still debated.

Nature and scope

Because of the high biodiversity and richness of deep-sea faunas and the extreme conditions of pressure and temperature in which deep sea species thrive, deep-sea ecosystems and their genetic resources offer great opportunities in terms of bioprospecting for industrial and medical applications. Developments in molecular technology and bioinformatics are facilitating the gathering of information on the diversity of existing bacteria and their potential (UN, 2007). Meanwhile, new technologies enable access to remote and new deep-sea areas. The frontier between scientific investigation and bioprospecting is sometimes unclear since genetic resources are often collected and analysed as part of scientific research projects, in the context of partnerships between public research institutes and biotechnology companies (UN, 2007).

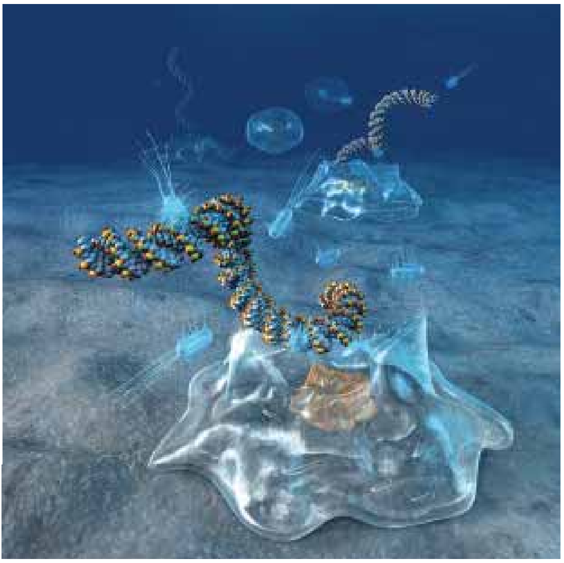
Successful industrial and medical screening of deep-sea organisms in search of biological anti-fouling compounds, anti-freeze, anti-coagulant, food conservatives, anti-oxidant, as well as drugs and genes of all sorts and functions might return great profits. Most of the larger international pharmaceutical and chemical corporations are involved in developing products from marine biodiversity, although not always from the deep sea. Companies have been running clinical trials with anti-tumour drugs containing active ingredients from deep-sea sponges, for instance (Fenical W. *et al*., 1999). The Diversa Corporation holds a number of patents from isolating compounds of deep-sea origin with potential industrial uses, which are often subsequently licensed to larger corporations. Deep-sea substances have also been introduced into sunscreen lotions for higher UV and heat protection (Arico and Salpin, 2005). Cytotoxins from deep-water sponges found on the Chatham Rise 400 kilometers off the New Zealand coast are under investigation. Other examples of work in progress include cold-adapted enzymes from deep-sea microbial extremophiles in the Southern Ocean and deep-sea extreme environments such as hydrothermal vents; and genes for "anti-freeze" proteins from fishes found in the Southern Ocean (FAO, 2003).

Impacts

Because of the difficulty and high costs of access to deep-sea ecosystems, it is unlikely that harvesting will be applied to deep-sea species. The industry will rather aim at retrieval of a small number of specimens for screening and testing, with subsequent culture of organisms and/or synthesis of compounds of interest. If this is the case, the physical impact of deep-sea bioprospecting is likely to remain limited.

Future

Bioprospecting activities are likely to increase in the future


Tangherlini and Danovaro/DiSMar

Deep-sea sediments host huge amount of DNA and genes that can be released by dead cells or remain in the living biomass. This enormous amount of genes and their functions are the main resource explored by bioprospecting. The drawing shows a cell releasing the DNA and some bacteria that swim around it searching for nutritional sources.

as marine scientific deep-sea research shifts from geophysical aspects to a more biological focus (Arico and Salpin, 2005). To lower the costs, the number of public-private partnerships between science and industry will also increase. The establishment of regulations, especially as regards bioprospecting in deep-water areas beyond national jurisdiction will therefore become a critical issue. Options range from voluntary measures such as a code of conduct for bioprospecting to legal frameworks that guarantee access but also conservation and benefit sharing.

Recent international discussions on bioprospecting and marine genetic resources, such as those held under the auspices of CBD and at the eighth (2007) meeting of the United Nations Informal Consultative Process on Oceans and the Law of the Sea (UNICPOLOS), identified a need for comprehensive information about the scope of present, and potential for future, bioprospecting activities in the deep sea, including market studies and maps of key actors in the field.

Ocean fertilization

The challenges associated with global environmental change have triggered a vast array of ideas and responses, including technological and geo-engineering proposals for artificially "enhancing" natural processes on land and in the oceans. Frequently, these solutions are presented by commercial operators as the panacea to combat global climate change, but unfortunately, many lack proper scientific assessment of their environmental impacts and effectiveness (see Box 3.3). One of the technological fixes which has been put forward to tackle the increasing concentration of CO_2 in the atmosphere is the fertilization of ocean areas with iron. In some areas of the World's oceans, primary production is low, despite sufficient levels of nutrients ("High Nutrient/Low Chlorophyll areas"), indicating that certain factors and conditions are limiting the growth of phytoplankton, such as the availability of iron. The idea of ocean fertilization is to artificially enrich such areas with iron in order to trigger phytoplankton blooms (Martin *et al.*, 1994). According to the theory, the increased phytoplankton mass would absorb large quantities of CO_2, which, following the plankton bloom would sink to the deep ocean, where the carbon would remain for many decades (Myers, 2006).

Since 1993, 11 major iron enrichment experiments were conducted around the world. There are, however, several unknowns regarding the process of iron fertilization, its effectiveness in trapping carbon and its ecological consequences. These include: effects of iron fertilization through the food web; influences on species composition of the phytoplankton community and productivity of the ecosystem; genetic, behavioural or ecological responses of phytoplankton communities; impacts on the nitrogen cycle; fate of the excess organic matter; actual amount of carbon transported to the deep sea; effects on deep-sea ecosystems; risk of formation of extended anoxic zones due to increased decomposition of organic matter in deep-ocean waters; uncertainties about end-product of decomposition (methane or carbon dioxide) and potential increase in ocean acidification (IPCC, 2007; Myers, 2006; Torda, 2007). Hence, before such large-scale technological and/or geo-engineering solutions are put into practice, long-term, interdisciplinary, holistic *in-situ* studies are needed to

Box 3.3: IPCC on geo-engineering

Source: IPCC, 2007, pp.78–79

Geo-engineering solutions to the enhanced greenhouse effect have been proposed. Options to remove CO_2 directly from the air, for example, by iron fertilization of the oceans, or to block sunlight, remain largely speculative and may have a risk of unknown side effects. Detailed cost estimates for these options have not been published and they are without a clear institutional framework for implementation.

Table 3.4: Estimated anthropogenic impacts on key habitats and ecosystems of the deep sea

	Key deep-sea habitats and ecosystems						
Human activities	Continental shelves and slopes	Abyssal plains	Seamounts	Cold-water coral reefs	Deep-sea sponge fields	Hydro-thermal vents	Cold seeps and mud volcanoes
Deep-sea fishing	🟥	🟩	🟥	🟥	🟥	◇	◇
Hydrocarbon extraction	🟦	◇	◇	🟦	🟦	◇	◇
Deep-sea mining	🟦	🟦	🟦	🟦	🟦	🟦	◇
Waste disposal and pollution	🟩	🟩	🟩	🟦	🟦	◇	◇
Cable laying	🟩	🟩	🟩	🟩	🟩	🟩	◇
Pipeline laying	🟦	◇	◇	🟦	🟦	◇	◇
Research and bioprospecting	🟩	🟩	🟩	🟩	🟩	🟩	🟩

Impact: 🟥 high 🟦 medium 🟩 low ◇ unknown

answer those questions. There is also a need to ensure that proper regulations are in place before any such operations are being carried out on in the high seas.

INDIRECT IMPACTS ON DEEP-SEA BIODIVERSITY AND ECOSYSTEMS

In addition to direct impact, human activities result in global environmental changes that also affect the oceans. Climate change and ocean acidification are consequences of anthropogenic greenhouse gas emissions, while ozone depletion results from anthropogenic emissions of freons and halons. The impacts of climate change on the deep sea are still hard to predict, but changes in water chemistry and temperature alone may threaten a number of vulnerable ecosystems (such as cold-water coral reefs) and lead to great shifts in biodiversity, especially (and starting) in sensitive zones such as the polar areas. Many marine organisms, in particular those inhabiting the deep waters, tend to live within narrow temperature ranges and sudden changes may not provide enough time for them to adapt (Schubert *et al.*, 2006). We still know very little about potential impacts of climate changes on deep-sea currents, on salinity and on water densities and movements of subsurface currents and the consequent impacts on ecosystems. Although surface waters are prone to quicker changes than the deep sea, the formation of cold water in the North Atlantic, which is driving the global ocean current conveyor belt, already sends signals of anthropogenic interference deep under the surface. A drop in primary production as a result of climate change would also diminish nutrients sinking to the seafloor, an essential source of food for deep-sea organisms. Conversely, a decrease in bio-diversity could have implications for climate change; lower productivity of surface waters implies lower carbon dioxide absorption, a positive feedback loop on indirect impacts.

Close up-of a *Lophelia pertusa* cold water coral. Collected in the Cap de Creus Canyon (northwestern Mediterranean) at 250 metres depth.

Andrea Gori & Cova Orejas/ICM.CSIC

Carbon dioxide emissions dramatically alter ocean chemistry. As more atmospheric carbon is absorbed and dissolved in the slightly alkaline seawater, carbonic acid is produced, which progressively acidifies the ocean (Royal Society, 2005). Carbonic acid separates in hydrogen and carbonate ions, which in turn lowers concentrations of calcium carbonate. Most marine organisms are adapted to narrow pH ranges and would face dire consequences from the slightest changes in pH (Knutzen, 1981). The pH of the oceans has been lowered by 0.1 units (which equates to a 30 per cent increase in the concentration of hydrogen ions) since the beginning of the industrial age (Orr *et al.*, 2005). Coupled with the decrease in pH is a reduction of calcium carbonate concentrations, which poses severe risks to all organisms with calcareous skeletons and shells, ranging from major plankton groups at the bottom of the food chain to corals, mollusks, shellfish and echinoderms. The calcification rates of some of these organisms could drop by 60 per cent during this century (Kleypas *et al.*, 2006).

Research shows that the impacts of ocean acidification will be particularly acute in the deep seas and polar regions (Orr *et al.*, 2005), although in certain areas, the slow dissolution of carbonate sediments on the seabed might partly reduce, or slow the effects of acidification (Schubert *et al.*, 2006).

It is as yet unknown whether acidification of the oceans will lead to massive extinctions and changes in marine ecosystems and foodchains, but with the ocean chemistry currently changing at least 100 times more rapidly than it has changed during the last 650 000 years, it is unlikely that marine organisms and systems affected by these changes will be able to adapt. Assessment of the potential impact of ocean acidification on biodiversity hotspots may partly respond to this lack of knowledge.

The emissions of ozone-depleting gases, mainly chlorofluorocarbons and bromofluorocarbons, weaken the protective ozone layer in the atmosphere and leave some regions of the world under intense radiation from the sun. According to NASA, the ozone "hole" over the south polar region was the biggest ever recorded in September 2006, almost twice the size of Antarctica. That too could have considerable impact on primary production, especially in the southern ocean, with knock-on effects for other ocean areas and deeper waters.

RESEARCH NEEDS

Table 3.4 summarizes the direct and indirect impacts of the main human activities upon key deep-sea habitats and ecosystems. It should be noted that these impacts can occur synergistically with potentially cumulative effects, with indirect impacts (such as those induced by climate change) causing extra stress on the systems. However, much more research is needed to qualify and quantify total impact.


UK Department of Trade and Industry

These beautiful feather stars were found living amongst live and dead coral on the Hatton Bank in the Northeast Atlantic. Bryozoans and anemones, squat lobsters and sponges are just some of the fauna that lives in amongst the coral.

In light of the the high uncertainties and the lack of knowledge about the deep-sea environment, the importance of prior environmental impact assessments to any type of human activity that might affect the deep sea must be emphasized. Furthermore, there is a need for monitoring once activities commence. This requires the adaptation of existing methodologies, or the development and testing of new techniques of, suitable for the deep-sea conditions and environment.

ICES defines "sensitive habitats" as those habitats that are easily adversely affected by a human activity, and/or those where an affected area is expected to recover only over a very long period, or not at all (ICES, 2005). In order to identify and define sensitive deep-sea habitats with a view to developing effective governance of human activities that may affect these habitats, we need to gain a better understanding of the scope of these activities and have scenarios for their future development.

Key research needs on human activities in the deep sea include mapping of activities, impacts, stakeholders, and potential conflicts between activities as well as the development of plausible scenarios of future trends in economic activities. Studies are also needed on how various direct and indirect impacts may interact and combine. This, together with studies of effects of these impacts on the provision of ecosystem goods and services from deep-sea ecosystems, including their socio-economic valuation (see Chapter 2), would allow a better assessment of threats and to prioritize areas for policy action, depending on ecosystem vulnerability and fragility, the extent of activities, and their associated impacts.

4 Governance and management issues

Designing and implementing effective governance and management strategies is critical to address the challenges posed by the increasing impacts of human activities on deep-sea biodiversity and ecosystems and to ensure conservation and sustainable use of deep-sea living and non-living resources. Governance is:

> *the sum of the many ways individuals and institutions, public and private, manage their common affairs. It is a continuing process through which conflicting or diverse interests may be accommodated and cooperative action may be taken. It includes formal institutions and regimes empowered to enforce compliance, as well as informal arrangements that people and institutions either have agreed to or perceive to be in their interest.*
>
> (Commission on Global Governance, 1995)

It may sometimes be difficult to articulate the distinction between governance and management. In this study, we follow the distinction proposed by Olsen *et al.* (2006: 5) whereby governance "probes the fundamental goals and the institutional processes and structures that are the basis for planning and decision making," while "management, in contrast, is the process by which human and material resources are harnessed to achieve a known goal within a known institutional structure." This is a useful if imperfect division as the distinction between "governance" and "management" is not clear-cut in many real-life situations, for management does create its own institutions that are embedded in governance institutions. Other authors see governance as providing the vision and direction for sustainability, while management is the operationalization of this vision (Boyle *et al.*, 2001, quoted in Folke *et al.*, 2005).

Today, we are confronted with an ever-rising environmental crisis that spans across spatial and temporal scales to encompass local, regional and global, short- and long-term, reversible and irreversible destabilization of ecosystems and as a consequence affects the indispensable life-support functions they provide. Both natural and human systems are complex non-equilibrium and self-organizing systems that are in co-evolution (Kay *et al.*, 1999). Traditional forms of environmental governance, based on sectoral approaches to problems, have shown their limits to address such complex systems and a shift towards ecosystem-based adaptive management and governance is taking place (for example, Dietz *et al.*, 2003; Folke *et al.*, 2005). T*he Handbook on Governance and Socioeconomics of Large Marine Ecosystems* (Olsen *et al.*, 2006), which is aimed primarily at practitioners ("innovators in governance" as the authors call them), offers practical insights on how governance and socio-economic science can support the ecosystem approach to marine resource management.

Before turning to the specific challenges of deep-sea governance, we briefly review some important and necessary elements for integrated environmental governance and management.

Crinoids (sea lilies) living at 2 500 metres water depth in the Whittard Canyon, North East Atlantic.

NOCS/JC10 cruise

Two squat lobsters (galatheid crustaceans) on the Var Canyon seafloor, North West Mediterranean.

Ifremer/Victor 6000/Medeco

Box 4.1: Risk, uncertainty, ambiguity and ignorance *Sources: Stirling, 2007; Stirling and Gee, 2002; Harremoës* et al., *2001*

Risk is a function of two variables: likelihood of an impact and magnitude. It is a condition under which the possible outcomes are known in advance and their relative likelihood can be adequately expressed as probabilities. When knowledge about either likelihood or outcomes are problematic, there are three possible states of incomplete knowledge: uncertainty, ambiguity and ignorance.

- Under the condition of **uncertainty**, possible outcomes can be characterized, but the adequate empirical or theoretical basis for assigning probabilities to outcomes does not exist. This may be because of the novelty of the activities concerned, or because of complexity or variability in their contexts.
- Under the condition of **ambiguity**, it is not the probabilities but the outcomes themselves that are problematic. This might be the case for events that are certain or have occurred already (probablility = 1). Ambiguity stems in particular from the multidimensionality, complexity and scope of environmental issues and from the different ways of framing them.
- The condition of **ignorance** is when neither probabilities nor outcomes can be fully characterized. It differs from uncertainty, which focuses on agreed, known parameters such as carcinogenicity or flood damage. It also differs from ambiguity in that the parameters are not only contestable but also – at least in part – unknown. Ignorance refers to the prospect of unknown unknowns. It is an acknowledgement of the possibility of surprise.

For each of these conditions, different types of methodological responses can be called upon, as shown in Table 4.1.

KEY ELEMENTS FOR ENVIRONMENTAL GOVERNANCE AND MANAGEMENT

Implementing an ecosystem approach

Governing and managing complex environmental systems, (which, by definition, include the socio-economic and cultural human systems that are at the root of many pressures bearing on ecosystems) requires a "paradigm shift" (Olsen *et al.*, 2006) towards a systemic approach. This is evidenced today by efforts at all levels to move towards ecosystem approaches to environmental governance and management.

The ecosystem approach strives to account for the interconnectedness of ecosystem processes and socio-economic processes. Following the 2002 World Summit on Sustainable Development, many multilateral environmental agreements and governance institutions now include provisions for the ecosystem approach. However, there are still many discussions about what such approach entails and how it should be implemented in practice. According to the CBD, the ecosystem approach is:

> *a strategy for the integrated management of land, water and living resources that promotes conservation and sustainable use in an equitable way. [...] It is based on the application of appropriate scientific methodologies focused on levels of biological organization, which encompass the essential processes, functions and interactions among organisms and their environment. It recognizes that humans, with their cultural diversity, are an integral component of ecosystems.*
>
> (CBD website: http://www.biodiv.org/programmes/cross-cutting/ecosystem/description.asp [accessed April 2007])

Hence, this approach stresses the importance of integrating socio-economic dimensions in the governance and management of ecosystems. Unlike sector-specific management regimes, the ecosystem approach is integrative and recognizes the need to tackle the expanding human footprint on biodiversity and ecosystems in a comprehensive manner. It also recognizes that while conservation areas are a vital tool, a more holistic approach that includes ecosystem health as a common goal in all sectoral activities is essential. At the same time, the ecosystem approach acknowledges (and strives to address) from the outset the existence of value conflicts between different social groups and between different users.

Addressing uncertainties, ignorance and irreversibility

A precautionary approach

Ecological systems are complex, non-equilibrium and self-organizing systems characterized by properties of emergence, non-linear internal causality and indeterminacy. Hence, complete knowledge and understanding of ecosystems and full prediction of their evolution will never be achieved (van den Hove, 2007). Models and paradigms underpinning environmental governance and management must embrace risk, uncertainty, ambiguity and ignorance (see Box 4.1) and lead to appropriate methodological responses.

This condition, combined with the potential irreversibility of environmental change and the magnitude of actual and potential threats and impacts calls for precaution, as articulated in the precautionary principle and precautionary appraisal (see Box 4.2), to be a central element of environmental

Table 4.1: Different forms of incertitude and possible methodological responses

Source: Adapted from Stirling, 2007 and Stirling and Gee, 2002

	Knowledge about outcomes	
Knowledge about likelihood	**Outcomes well defined**	**Outcomes poorly defined**
Some basis for probabilities	**Risk** Risk assessment Multi-attribute utility theory Decision analysis Cost-benefit analysis Monte Carlo modelling Bayesian techniques Statistical errors, levels of proof	**Ambiguity** Participatory deliberation Stakeholder negotiation Q-method, repertory grid Scenario workshops Multi-criteria mapping Interactive modelling
No basis for probabilities	**Uncertainty** Uncertainty heuristics Sensitivity analysis Scenario analysis Interval analysis Onus of persuasion Decision heuristics	**Ignorance** Targeted research and horizon scanning Transdisciplinary and institutional learning Open-ended surveillance and monitoring Evidentiary presumptions, ubiquity, mobility, persistence Bio-accumulation Adaptive management: flexibility, diversity, resilience

governance and management. Precaution implies that measures may need to be taken even when some cause-and-effect relationships are not fully established scientifically.

Adaptive governance and management

Characteristics of environmental issues also imply that both governance systems and management schemes must be adaptive to deal with the complexity and dynamics – hence the constant change – of ecosystems and of human systems, to respond to uncertainties and to allow for continuous learning, feedbacks and adjustments to new situations and knowledge (see Box 4.3). The concept of adaptive governance is used to enlarge the focus from adaptive management of ecosystems to address the broader social contexts that enable ecosystem-based management (Dietz *et al.* 2003; Folke *et al.*, 2005).

Small spider crab among black corals (antipatharians).

Ifremer/Victor 6000/Medeco 2007

Multi-level governance

The anthropogenic causes of the current environmental crisis are of an inherently global dimension and at the same time deeply rooted in local contexts. Focusing on a single scale is not sufficient, as many local interactions are caused by trends and interactions at higher levels, which they in turn influence. The most important contemporary environmental challenges require governance at levels from the global all the way down to the local (Dietz *et al.*, 2003). Hence, institutional governance and management arrangements must be complex, redundant, and nested in many layers.

"Simple strategies for governing the world's resources that rely exclusively on imposed markets or one-level, centralized command and control and that eliminate apparent redundancies in the name of efficiency have been tried and have failed" (Dietz *et al.*, 2003). The challenge is to design, implement and constantly revise multilevel governance systems, crossing local and global dimensions of both the issue at hand and the institutions addressing it, and building on a complex multilayered network of actors, institutions and interactions. This is further complicated by the fact that the linked cross-scale social-ecological systems at hand are dynamic. These systems change over time, which creates fundamental problems for establishing

Box 4.2: The Precautionary Principle and Precautionary Appraisal

Sources: adapted from O'Riordan and Cameron, 1994; Stirling, 2007 and Harremoës et al., *2001*

The **Precautionary Principle** states that:

> *"Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation."*
>
> Principle 15 of the Rio Declaration on Environment and Development (UN 1992)

The precautionary principle includes elements such as:

- Preventive anticipation;
- Research and monitoring for the early detection of hazards;
- Duty of care;
- Need to allow natural processes to function in such a manner as to maintain the essential support for all life on Earth;
- Burden of proof of no harm on those who induce potential damage or propose technological change;
- Action to reduce risks before full "proof" of harm is available if impacts could be serious or irreversible;
- Proportionality principle, where the costs of actions to prevent hazards are shown not to be unduly costly;
- Going beyond short-term benefits and accounting for long-term benefits of precautionary action;
- Cooperative approaches between stakeholders to solving common problems;
- Polluter-pays principle and historical responsibility.

The **Precautionary Appraisal** of risk implies a new vision and manner of approaching risk, whereby:

- the scope of appraisal is broadened to include more scientific disciplines, more types of information and knowledge;
- transdisciplinary learning takes place;
- more humility is shown in the practice and the use of science;
- research is active and interactive;
- alternative options are explored;
- the appraisal is based on deliberate arguments where different publics and stakeholders are engaged.

and adopting a division of responsibility between centralized and decentralized agents (Folke *et al*., 2005).

Governance mechanisms and institutional variety

As shown in Figure 4.1 there are three key mechanisms by which the processes of governance are expressed: markets, governments and the institutions and arrangements of civil society. These three mechanisms of governance interact with one another through complex and dynamic interrelationships, and individually and collectively affect how

Table 4.2: Some major governance mechanisms and tools *Source: adapted from Olsen* et al., *2006 and Dietz* et al., *2003*

Government	Market Place	Institutions and organizations of civil society
Laws and regulations	Profit seeking (production of and/or trade in goods, services, permits)	Socialization processes
Taxation, subsidies, incentives and spending policies	Ecosystem service valuation	Constituency roles and "issue framing"
Property rights, permits, quotas	Eco-labelling and green products	Co-management
Area-based management measures	Voluntary schemes	Information, education and outreach
Sanctions, compliance arrangements	Lobbying	Campaigning, lobbying
Information, education and outreach		Community self-governance

humans use and otherwise interact with ecosystems. These mechanisms can alter patterns of behaviour through tools such as those identified in Table 4.2 and induce changes in social organizations and attitudes, which in turn have an impact on the effectiveness of governance and management schemes. Socio-economic and governance analyses can be applied to understand and explain how these mechanisms function, and how they interact with one another (see illustration in Olsen *et al.* (2006), Part III).

The Millennium Ecosystem Assessment (MA) proposes a typology to classify the wide range of responses societies have devised to regulate their use of ecosystem services and the human activities that affect ecosystems.

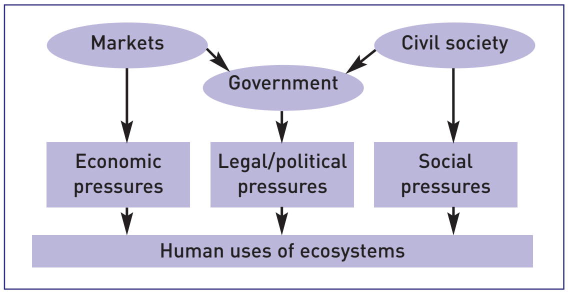


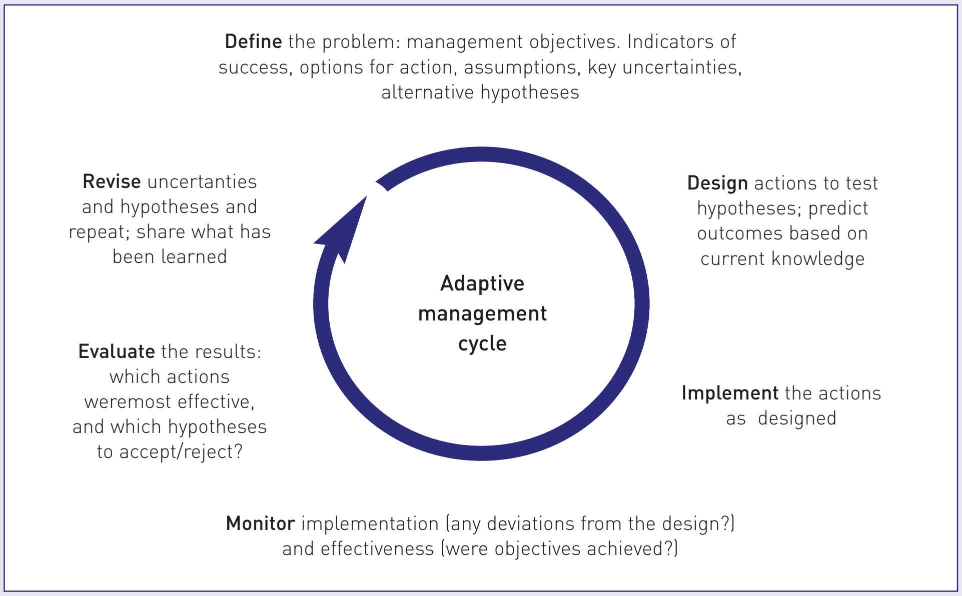
Figure 4.1: Three key governance mechanisms

Source: Adapted from Olsen et al., 2006

Box 4.3: Adaptive Management

“Adaptive Management is a systematic approach for improving environmental management and building knowledge by learning from management outcomes. Contrary to common belief, adaptive management is much more than simply “adapting as you go”. It involves exploring alternative ways to meet management objectives, predicting the outcomes of each alternative based on the current state of knowledge, implementing one or more of these alternatives, monitoring to learn which alternative best meets the management objectives (and testing predictions), and then using these results to update knowledge and adjust management actions.

Adaptive management differs from traditional management approaches in that it allows management activities to proceed despite uncertainty regarding how best to achieve desired outcomes, and despite inevitable changes and surprises. In fact, it specifically targets such uncertainty: it compels ecosystem managers to be open and explicit regarding what is not known about how best to achieve conservation and management objectives, and provides a science-based learning process characterized by using outcomes for evaluation and adjustment (“closing the loop”) [...].” Murray and Marmorek (2003, 2004)



Source: Murray and Marmorek (2003, 2004)

Table 4.3: The Relationship between the Responses and the Actors *Source: adapted from MA (2005b)*

RESPONSE			ACTORS		
	Government	Private sector	Local communities	NGOs	Scientists
Legal					
Treaties	5/5				
International soft law	2/5				
International customary law	3/5				
International agreement legislation outside the environment sector	5/5				
Domestic environmental regulations	5/5				
Domestic administrative law	3/5				
Domestic constitutional law	4/5				
Domestic legislation outside the environmental sector	4/5				
Economic					
Command and control interventions	5/5				
Incentive-based	5/5	5/5	2/3	2/4	
Voluntarism-based	3/5	4/5	4/5	4/4	
Financial/monetary measures	5/5	5/4	3/3	3/3	
International trade polices	4/5				
Social and behavioural					
Population policies	5/4	3/4	4/3	3/4	
Public education and awareness	5/3	4/5	4/5	4/5	
Policy-maker education and awareness	4/3	3/3	4/3	5/4	5/4
Empowering youth	3/5	4/5	4/5	4/5	
Empowering communities	3/5	4/3	5/5	5/5	
Empowering women	3/5	4/3	5/5	5/5	
Civil society protest and disobedience			1/5	1/5	
Lobbying		5/5	4/3	5/4	4/4
Technological					
Incentives for innovation R&D	5/4	5/5	5/4	5/4	
Cognitive					
Legitimization of traditional knowledge	5/2		5/5	5/5	
Knowledge acquisition and acceptances	5/3	4/3	3/2	4/4	

The first number in a pair is the availability of the response to the actor. The second number shows the effectiveness the actor has in using the response. Blank cells mean the response is not applicable to the actor. Elements in red have been added by the authors.

These responses are human actions to address specific issues, needs, opportunities or problems in ecosystem governance and management. They encompass policies, strategies, measures and interventions that are established to change ecosystem status and processes directly, and those that modify direct or indirect drivers that shape ecosystem status and processes. The typology is organized according to the dominant mechanism through which specific responses are intended to change human behaviour or ecosystems characteristics. It distinguishes

Box 4.4: Information and knowledge needs for environmental governance

- Ecosystem function, structure
- Status and trends of ecosystems
- Natural drivers and evolution of ecosystems
- Geographical occurrence and abundance
- Direct human interactions with ecosystems (anthropogenic pressures)
- Indirect human influence on ecosystems (anthropogenic drivers)
- Existing institutional framework and its potential for evolution
- Actors and power distribution
- Uncertainties and scientific disagreements
- Individual and social values and value conflicts
- Effects of decisions on valued outcomes

legal, economic, social and behavioural, technological and cognitive responses (MA, 2005b). Responses are not equally available to and/or used by all actors (Table 4.3).

Governance is more likely to be effective if it employs a mixture of mechanisms and responses that constitute different strategies to change incentives, increase information, monitor use of resources and impacts, and induce compliance (Dietz *et al.*, 2003; National Research Council, 2002). Hence, notwithstanding the current enthusiasm in many national and international policy and economic circles for the creation of markets and market-based instruments (for example, biodiversity offsets, auctioning, tradable permits) for biodiversity conservation and the sustainable use of ecosystem services, these should not be seen as the panacea. Rather they should be considered as one subset of tools and approaches in a wider mix, applicable to some (but not all) ecosystem services and situations. When designed and implemented, market based instruments necessitate solid framing by the other two types of governance mechanisms (government and civil society institutions) to ensure that externalities are properly internalized, that equity aspects are accounted for, and that they do not end up displacing the problems (as many examples have shown, for example, in the fisheries sector) or being plainly counterproductive (Duraiappah, 2007).

Box 4.5: Some key governance principles for sustainability

- **Decision making:** democracy; subsidiarity; participation; transparency; international cooperation; holistic approaches; policy coordination and integration; internalization of environmental and social costs.
- **Precaution:** decision making under uncertainty, indeterminacy, irreversibility; adaptive approaches.
- **Responsibility:** polluter pays; responsibility for generating knowledge; burden of proof; common but differentiated responsibilities; liability; accountability.
- **Management:** prevention; rectification of pollution at source; adaptability; (eco)systemic approaches; partnerships.
- **Distribution:** intra-generational and inter-generational equity; capacity-building.

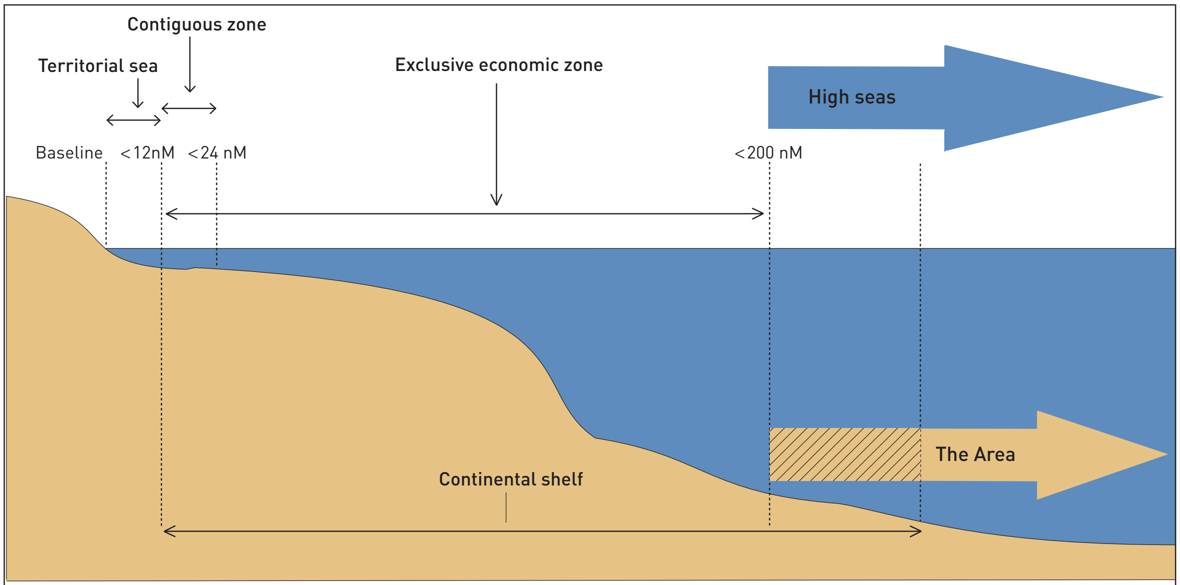
Information and knowledge

To ensure effective environmental governance, a whole array of information and knowledge will need to be called upon (see Box 4.4). Governance requires factual information about the ecosystems being governed, in particular about their function, structure, state and natural evolution. It requires knowledge of geographical occurrence and abundance of ecosystems as well as information on how human actions affect these ecosystems (drivers and pressures). It needs information about uncertainties and values as well as information about scientific and value disagreements and about the effect of decisions on various valued outcomes (Dietz *et al.*, 2003: 1908). It also requires knowledge about the existing institutional framework and its potential for evolution. In other words, knowledge is needed on the natural and the social, economic, legal and political processes (including on the interactions between them), and on actors and power distribution. This knowledge is necessary to devise governance schemes and management strategies, to monitor implementation and effectiveness of policies and measures, to support enforcement, and to underpin an adaptive and dynamic approach to governance and management based on self-evaluation and learning.

Equity as a cornerstone of environmental governance

Underlying the development and evolution of environmental governance are a number of principles that are frequently called upon as a normative basis for governance and management (see Box 4.5).

Effectiveness of environmental governance and institutions can be gauged against multiple evaluation criteria. These typically include economic efficiency, ecological integrity, sustainability and equity, but also other



▨ The Area starts at 200 nautical miles (nm) from the baseline when the legal continental shelf (as defined in UNCLOS, Article 76) does not extend beyond that limit.

Source: Adapted from IUCN, 2007

Figure 4.2: Marine zones under the UN Convention on the Law of the Sea, 1982 (UNCLOS).

criteria that link more or less directly to the underlying principles listed in Box 4.5.

Equity is a central criterion of sustainability. In particular, elements such as equitable sharing of burdens and benefits, capacity-building in developing countries and the rights of future generations need to be taken into account in designing and assessing governance institutions and management schemes. Nevertheless, although concerns of equity and sustainability of the resource may be more important to those directly affected by policy proposals, economic efficiency frequently dominates the policy debate (National Research Council, 2002), which often results in placing lower priority on equity aspects. As Dietz *et al.* (2002: 26) emphasize: "no institutional arrangement is likely to perform well on all evaluative criteria at all times. Thus, in practice, some trade-off among performance criteria is usually involved". The key point here is to ensure that those trade-offs are explicit and open to debate.

KEY ISSUES FOR DEEP-SEA GOVERNANCE

Deep-sea governance

As noted previously, the deep seas are defined as the waters and seafloor beyond the reach of sunlight, most commonly below 200 metres depth. Legal boundaries in the oceans and seas, however, are vertical limits, extraneous to habitats and ecosystems. Figure 4.2 illustrates this difference and how human-defined limits as set out in international law by UNCLOS add to the complexity of the situation.

Of particular importance to deep-sea governance are Exclusive Economic Zones (EEZ) out to 200 nautical miles (nm) seaward; the High Seas water column beyond the EEZ (or territorial sea where no EEZ has been declared); the "legal continental shelf" which extends to 200 nm, or to the outer edge of the continental margin when this lies beyond 200 nm; and the Area – the seabed and oceanfloor as well as subsoil beyond the legal continental shelf. In the EEZ, states have sovereign rights for exploration, exploitation, conservation and management of all natural resources and

Serpulid worm.

Ifremer/MEDECO2007/Matthieu Bruneaux

Greenpeace

Orange Roughy catch landed by a deep-sea trawler.

NOAA/MBARI

Mystery mollusk (Order Nudibranchia) in 1498 meters depth above the Davidson Seamount, located 120 kilometers to the southwest of Monterey, California (US).

over other economic activities, while on the legal continental shelf, states have sovereign rights for exploration and exploitation of non-living (for example, mineral) resources and sedentary seabed organisms. The High Seas and Area (that is, the waters, seabed and subseafloor beyond national jurisdiction) are explained in greater detail below. All states and all areas are subject to the duty to protect and preserve the marine environment (UNCLOS, Art. 192).

UNCLOS provides the main framework agreement which governs rights, duties and activities throughout the oceans. In addition to UNCLOS, there are a number of other global and regional agreements that supplement UNCLOS regarding specific activities or regions (see Gjerde (2006a) for a more extensive review of the evolving international and policy regime for the deep sea). At the global level, key instruments include: the 1995 UN Fish Stocks Agreement (UNFSA) and the Convention on Biological Diversity (CBD). At the regional level, the UNEP Regional Seas Programme (see http://www.unep.org/regionalseas) and other regional marine environmental programmes include multilateral agreements that generally apply to deep seas out to the limits of national jurisdiction. Four agreements, however, include areas beyond national jurisdiction: the OSPAR Convention for the Protection of the Marine Environment of the northeast Atlantic, the Barcelona Convention for the Protection of the Marine Environment and the Coastal Region of the Mediterranean, the Noumea Convention for the Protection of the Natural Resources and Environment of the South Pacific Region (SPREP), and the Antarctic Treaty and related agreements. In certain regions of the world's oceans these regional environmental agreements are complemented by Regional Fisheries Management Organizations (RFMOs), established for the development of conservation and management measures for fisheries. Currently, twelve of these RFMOs have full responsibility to agree on binding measures that cover marine areas beyond national jurisdiction.

The right of coastal states to enforce these agreements depends on where the violation takes place, and sometimes on its potential impact on coastal state interests. Coastal states may enforce these agreements as well as associated national regulations over vessels within their ports and over their citizens, corporations and nationally registered vessels wherever they are located (flagstate responsibilities). With respect to the conservation of living resources, states may enforce their laws over vessels within their territorial seas and EEZs (UNCLOS, Art. 73, 213–222), whereas the right to enforce pollution control laws in the territorial sea and EEZ depends on the severity of the pollution and its impact on coastal interests (UNCLOS, Art. 220). Enforcement on the high seas may only take place under certain very limited conditions (for example, stateless vessels). But states can also agree to mutual boarding and inspection procedures to enforce fisheries and other regulations on the high seas (for example, UNFSA, Art. 21–22). To date, only a few regions have enacted such mutual high seas enforcement schemes for high seas fisheries.

For areas beyond national jurisdiction, UNCLOS defines a series of rights and duties. Unlike the high seas, the deep seabed Area and its non-living resources have been designated by UNCLOS as the "common heritage of mankind", which means they are free from national claims and subject to a different governance regime. High seas rights include freedom to fish, navigate, lay submarine cables and pipelines, conduct marine scientific research, conduct peaceful military activities and authorize vessels to fly national flags. Duties include conserving living marine resources, protecting and preserving the marine environment, cooperating, controlling vessels and citizens and not interfering with the rights and interests of others. The laws that do exist beyond the EEZ are often very basic and as noted above, difficult to enforce. Nations have been very good at taking advantage of their rights, but many have not yet fully implemented their duties to protect, conserve and cooperate. The high seas freedoms create a challenge as they assume all states and all people will behave responsibly. There are rich resources and some actors adopt opportunistic strategies, depleting resources in one place and then moving on to another (Berkes *et al.* 2006). Until recently, law makers have not paid much attention to what goes on in the high seas beyond pelagic fishing activities (Gjerde, 2006b).

Mineral resources within the Area are regulated by the International Seabed Authority (ISA) established under UNCLOS. These include solid, liquid and gaseous mineral deposits. Abiotic seabed exploitation is subject to the rules of benefit sharing as well as protection of the marine environment. ISA oversees mining-related activities, develops environmental rules, and promotes marine scientific research. Rules to protect the marine environment are to be in place before any mining can begin (Gjerde, 2006b).

Living resources in the Area and in the High Seas are either unregulated or, as in the case of fisheries, managed by species or on a regional basis by Regional Fisheries Management Organisations (RFMOs). The UN Fish Stocks Agreement supplements and implements the provisions of UNCLOS with respect to the conservation and governance duties of states for highly migratory and straddling fish stocks, but does not cover deep-sea fish stocks in the high seas. Thus, deep-sea bottom fishing and its related habitat impacts are not addressed by a specific treaty at present. It should be noted, however, that the United Nations General Assembly in 2006 called for targeted and time specific action by states and RFMOs to bring high seas bottom fisheries and their impacts under control (UNGA resolution 61/105, paras. 80–91).

Overall, the deep-sea governance context forms what Gjerde (2006a: 37) calls a "web of obligations for states regarding biodiversity". However, Gjerde stresses that "there are inadequacies, both with respect to the implementation of existing legal requirements ("implementation gap"), as well as in the coverage of the existing conventions and organizations ("governance gap") (*ibid.*). For example, as of May 2007, China, the world's largest fishing nation, had not yet ratified the UN Fish Stocks Agreement. And until recently, following a vast global effort by NGOs and scientists, deep-sea vents and coral reefs were more strictly protected from potential mining activities than from deep-sea fishing impacts. The UNGA resolution 61/105 fills that gap somewhat, but will need significant follow-up to ensure that such protection is effectively implemented wherever deep-sea fishing on the high seas occurs.

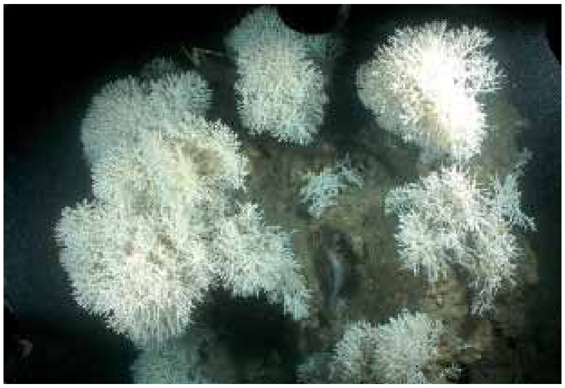

NOCS/JC10 cruise

Deep-sea ecosystem in the Setubal canyon in the North East Atlantic, 1 444 metre depth.

Implementing an ecosystem approach in the deep sea

The fragmentation of management regimes, per species, issues, or region is a major obstacle for the implementation of an ecosystem approach for the deep sea. In the case of fisheries, the present governance structure has been unable to prevent overfishing and collapses of deep-sea fish stocks in both areas of national jurisdiction and in the high seas. Even if the sectoral approach to deep-sea governance and management still dominates, a shift (at least in texts) towards the ecosystem approach is noticeable in different fora. This is illustrated for instance by the 2006 UNGA resolution on sustainable fisheries, which repeatedly calls for the implementation of the precautionary approach and an ecosystem approach to fisheries management, even though it maintains the sectoral approach (UNGA Res. 61/105, 2006). As far as fisheries are concerned, implementation of the ecosystem approach appears as a necessary condition to the maintenance of fisheries in the long term (Garcia *et al.*, 2003). The non-binding FAO code for responsible fisheries in tandem with the UN Fish Stocks Agreement provide a good basis for an ecosystem approach (FAO, 1995), but are in need of more effective implementation.

The paradigm shift towards ecosystem-based governance and management is necessary to achieve conservation and sustainable-use objectives in the deep sea. The ecosystem approach recognizes that some challenges related to conservation and sustainable use of ecosystems cannot be solved with protected areas (see below). This obviously applies to marine protected areas (MPAs), which constitute a necessary (but in itself not sufficient) tool to ensure sustainable management of the deep sea. This does



JAGO-Team, IFM-GEOMAR

A highly diverse ecosystem around cold water coral *Madrepora oculata* in the Cap de Creus canyon (Western Mediterranean) at 200 metres depth, photographed through front window of manned submersible JAGO, HERMES IV_CORAL8 cruise on board RV García del Cid.

in no way reduce the importance of MPAs, as their relevance as tools in the framework of an ecosystem approach is increasingly recognized.

When considering the implementation of holistic and integrated approaches for the deep sea, specific additional problems arise. In areas under national jurisdiction, difficulties arise because of the lack of awareness and/or interest that many countries show towards their deeper EEZ waters. Many states, especially developing countries and small developing island states, do not have the necessary capacities, technical means and financial resources, and therefore have a tendency to focus more on their coastal waters. As for the high seas, there is not yet an international body or organization formally designated to be in charge of such programmes. One way to overcome this and to allow for the paradigm shift to take place would be the development of an UNCLOS Implementation Agreement on the High Seas (as proposed by the European Community and some other countries during recent UN General Assembly consultations). Such an agreement could provide a framework for a holistic, integrated and coherent ocean governance and management approach for the areas beyond national jurisdiction.

In practice, a first necessary step in the ecosystem approach consists of mapping out stakeholders and their interests (Vierros *et al.*, 2006). An inventory of human activities in the deep sea as those described in Section 3 allow for identification of the immediate circle of actors and stakeholders. This circle then needs to be enlarged, for example, to include those who value the deep sea for cultural purposes, who stand for the voiceless species and ecosystems, and for future generations. A comprehensive map also presents potential conflicts between stakeholders themselves as well as conflicts between human activities and ecosystem health.

Governance mechanisms in the deep sea

Deep-sea ecosystems provide a unique and challenging case for applying the main governance mechanisms set out in Figure 4.1 and Table 4.2. Currently, the governance of commercial activities such as fishing, oil and gas exploration and production, takes place through sector-based regulations in areas under national jurisdiction. Legal and political pressures by governments are barely in place and/or not working when it comes to the deep seas. A number of countries have adopted some legislative measures for the deeper waters of their EEZs (including for example, the USA, Canada, Australia, New Zealand, Norway, Iceland and various EU member states). Also some small island developing states (SIDS) are starting to take action on deeper waters. For instance, several island states in the South Pacific are very aware of their deeper waters, and were among the first to call for an international ban on bottom trawling. Nevertheless, most developing countries and SIDS have not yet the capacity to manage activities in their deeper waters, hence leaving their governance mostly to markets.

In areas beyond national jurisdiction (high seas and the Area) there are only a few sectoral or activity-based regulations. The principles of High Seas Freedoms embedded in UNCLOS can leave the door wide open for markets to move in and act without effective control. Many commercial activities primarily take place in relatively unregulated markets. Resources from the high seas are currently common pool resources, which may lead unsustainable exploitation (the so-called "tragedy of the commons" (Hardin, 1968)).

Meanwhile, social pressures from civil society (including international environmental NGOs and the research community) to regulate human impacts on deep-sea ecosystems are starting to build as more information emerges about these ecosystems, their importance, and their vulnerability. However, taking into account the current lack of knowledge and awareness of the general public about the deep sea, as well as the remotness of the deep-sea environment, these social pressures may never be as great as they are for other environments and ecosystems, to which people can more closely relate (for example, terrestrial systems, coastal marine systems such as coral reefs). In any case, these pressures will depend on the quality of dissemination, education and outreach efforts by the scientific and NGO communities.

The process of regulating the oceans and seas follows the general pattern of regulating the commons: management measures are proposed first to fix burning problems and the governance framework only comes next. When fish stocks started to collapse for instance, management was called upon to control both the stocks and the flow of economic benefits from fisheries resources. Unfortunately, to date, most instruments have failed to improve either the socio-economic conditions of fishing communities or the conservation of fish stocks (Ben-Yami, 2004).

As seen in Chapter 3, overcapitalization is a chronic problem in fisheries. Fishery subsidies are immense and distributed across several categories. Both capital and variable costs are sometimes subsidized with special subsidies to access foreign EEZs. Subsidies can lead to overcapacity, overfishing and encourage IUU fishing. Decommissioning subsidies or buybacks can also have perverse effects, since retiring old vessels does not necessarily reduce the capacity of the fishing fleet as fishermen include future rounds of buybacks in their investment strategies (Clark *et al.*, 2005). Larger and more powerful fleets do not necessarily yield more fish any more, but powerful vessels are able to fish the high and deep seas, should traditional shallow-water fishing ground become depleted or too regulated. Market- and regulatory-based instruments such as licenses, Total Allowable Catch (TAC), Individual Transferable Quotas (ITQ), have been put in place to limit the collapse of stocks and hopefully help their recovery. Nevertheless, such management tools often fail to ensure sustainable use, in particular due to information and enforcement problems (Dietz *et al.*, 2003). No simple solutions exist to the problems of conservation and overcapacity, even though they have been central issues in fisheries management for some time. The key seems to lie in an ecosystem approach to fisheries and more holistic forms of management.

The governance of the deep sea and management of goods and services human beings derive from deep-sea ecosystems need to take two very important characteristics into account. First, the deep sea is the largest ecosystem on Earth, making monitoring and enforcement very difficult. Second, stocks of biotic deep-sea resources can in general be considered as non-renewable (Roberts C.M., 2002). The majority of biotic resouces deep under the surface have slow growth rates such that their exploitation is often more akin to mining mineral resources and impacts may not be reversible in our lifespans, if ever. Hence timely and effective enforcement is difficult but also of vital importance. As a result of these two factors, the deep-sea governance system will need to develop processes that encourage actors to comply willingly as well as processes that enable real-time monitoring, tracking and surveillance to enable effective policing.

These two characteristics also mean that for governance and management purposes the deep sea is completely different from other habitats and ecosystems on Earth. One should therefore expect that many conventional practices carried out in shallow waters are not, or only with limitations, applicable to the deep sea as they can be incompatible with either the natural or the human context. This is something that has not yet been sufficiently recognized by many policy makers.


NOAA

Deep-sea octocorals at the top of an inactive sulfide chimney, off the coast of western North America.

Area-based management, marine protected areas and spatial planning

The need for precautionary, integrated and multi-level governance of marine ecosystems was acknowledged 15 years ago in the Agenda 21 adopted at the 1992 Rio UN Conference on Environment and Development. The text stresses that the protection and sustainable development of the marine and coastal environment and its resources requires new approaches for management and development of these areas, at national, subregional, regional and global levels, approaches that are integrated in content and are precautionary and anticipatory in ambit (Agenda 21, §17.1). The Plan of Implementation of the World Summit on Sustainable Development (Johannesburg 2002) invites nations to:

> *Develop and facilitate the use of diverse approaches and tools, including the ecosystem approach, the elimination of destructive fishing practices, the establishment of marine protected areas consistent with international law and based on scientific information, including representative networks by 2012 and time/area closures for the protection of nursery grounds and periods, proper coastal land use and watershed planning and the integration of marine and coastal areas management into key sectors.*
>
> (WSSD Plan of Implementation, Art. 32(c))

Important to the integrated governance of the deep sea is the development of comprehensive systems of spatial planning. These must be developed in cooperation with stakeholders and linked to management tools such as extensive spatial data and geographic information systems, environmental impact assessments and marine protected areas. Marine spatial planning and zoning is already taking place in a number of countries that have developed overarching marine policies (for example, Australia, Canada) whereby areas are protected first and activities are built up, taking the protection framework into account.

Management of the oceans and deep seas takes many different forms. Area-based management measures are an important subset of these. They include geographical and temporal closures to fishing and/or other activities, technical measures such as fishing gear restrictions in a given area, multipurpose protected areas or networks of protected areas. Area-based management measures are widely viewed as key tools to improve integrated conservation and sustainable use of marine biological diversity (Gjerde, 2007), and to bring current sectoral authorities and tools together. This requires "compatibility of governance in marine areas within and outside national jurisdiction, a cooperative rather than competitive agenda and states acting uniformly in different international fora" (UN, 2006b).

According to the World Conservation Union (IUCN) definition, a protected area is "an area of land and/or sea especially dedicated to the protection and maintenance of biological diversity, and of natural and associated cultural resources, and managed through legal or other effective means." Protected areas can have different management objectives, including: protection for scientific research, for wildlife protection, for ecosystem protection, for recreation, for conservation of specific natural features, for conservation through management intervention, for landscape/seascape protection and recreation, and for the sustainable use of natural ecosystems (IUCN, 1994). A Marine Protected Area (MPA) is "any area of the intertidal or subtidal terrain, together with its overlying water and associated flora, fauna, historical and cultural features, which has been reserved by law or other effective means to protect part or all of the enclosed environment" (Kelleher, 1999).

MPAs will tend to address one or more of the objectives listed above by protecting species and habitats from direct human impacts, but this need not necessarily imply that all human activities have to be prohibited in these areas. A significant strength of MPAs is their potential to go beyond traditional sectoral management practices by allowing a more holistic take on management needs and promoting improved coordination between – and cooperation with – existing sectoral regimes (Laffoley, 2005).

As noted in the report of the FAO Expert Consultation on Deep-sea Fisheries in the High Seas:

> *Spatial and temporal management tools such as MPAs, spawning closures and seasonal closures are particularly useful in data-poor situations such as encountered in the deep seas. These tools could contribute to management using a precautionary approach and, if appropriately implemented, provide some level of protection for biodiversity, habitats and fish stocks.*
>
> (FAO 2007: 18)

Nevertheless, the establishment and management of MPAs (or networks of them) in the deep sea raise a series of specific problems. Some of these problems relate to all deep-sea areas, whether under national jurisdiction or in the High Seas, others are specific to the latter. Issues concerning all deep-sea areas stem primarily from the lack of knowledge of the deep-sea environment. It is difficult to ensure that MPA designation is ecologically sound in the sense that the widest possible range of ecosystems and habitats would be under sufficient protection. There is a risk that arguments for protection are biased towards those ecosystems and habitats already known to science. This suggests a need to develop alternative ways to accommodate the precautionary principle in MPA selection when the very nature of the ecosystems is barely known and where protection is needed before the damage is too severe or irreversible. The lack of knowledge also renders the development of ecosystem-based management more challenging. Moreover, as stressed by Gjerde, "many marine experts suggest that MPAs need to be vastly scaled up in number and size to protect deep-sea biodiversity at ecosystem, species and genetic levels" (2007:2). This implies a need for improved cooperation between all actors: governments, regional fisheries and marine environmental bodies, intergovernmental and non-governmental organizations, the research community, the deep-sea fishing industry and other industries operating in the deep sea (*ibid.*). In the case of the High Seas, additional challenges relate to their global commons nature and to the need to frame actions in the context of international law (Gjerde and Kelleher, 2005, 2007; Foster *et al.*, 2005). Hence issues arise of how to legislate MPA development in the high seas, how to enforce MPAs and how to finance their establishment, administration, monitoring and enforcement (Morling, 2005).

Just as protected areas on land, MPAs are more effective if integrated in a network protecting vulnerable areas of biological and ecological significance as well as areas representative of the full range of regional biological diversity, even when their full ecological or societal significance has not yet been assessed. Biodiversity and ecosystems require a certain level of connectivity, which could be translated into a combination of spacing, number and coverage of MPAs. The diversity and endemism of species found over the deep sea mean the scale and scope

NOCS

Equipment such as remotely operated vehicles (ROVs) are essential tools in the advancement of our knowledge of the deep ocean environment.

of protected areas may need to be much larger than in nearshore waters (Laffoley, 2005).

Deep-sea MPAs could be enforced through measures already at hand for the control of fisheries, for example, strict reporting requirements, catch documentation schemes, vessel monitoring systems, satellite monitoring, and observer coverage. Such enforcement measures may need to be made more broadly applicable to other users when the agreed MPA provisions regulate other uses beyond fishing (Gjerde, 2007). To reduce enforcement costs, it is helpful to have the support and participation of all stakeholders (Alban *et al.* 2006).

Information and knowledge challenges

We are still at the outset in understanding deep-sea environments ecosystems. Their remoteness renders research on, and monitoring of, ecosystems and biodiversity both technically challenging and expensive. Moreover, our knowledge of threats induced by human activities is limited and so is our understanding of possible political responses.

Nevertheless, action is needed urgently as there is evidence that many human activities are already significantly affecting the deep sea. Innovative governance systems and management tools therefore need to be developed in parallel with the increasing scientific and socio-economic knowledge and in anticipation of emerging future deep-sea activities and uses. Scientific knowledge needs to be produced in an interdisciplinary way, bringing together scientists from various relevant disciplines of natural sciences (biology, microbiology, geochemistry, oceanography, geology, geophysics) as well as the social sciences (economics, sociology, law, political sciences). Such transdisciplinary research has been initiated, for instance in the integrated, interdisciplinary research project HERMES (Hotspot Ecosystem Research on the Margins of European Seas).

Equity aspects

As stressed above, equity is a central element of sustainability and governance systems need to encompass principles of fairness and distribution (Box 4.5). Most countries, especially developing countries and small island developing states, are not yet fully aware of deep-sea issues and their relevance to them. There is often a lack of capacity and resources to address deep-sea governance challenges and implement commitments. Access to technology is limited and only the richer countries and big corporations have the means to study, exploit and manage deep-sea environments. Hence, the need for practical support and collaboration to transfer expertise and provide suitable technology and methodologies to the countries that need them and to establish and implement conservation and management measures adapted to their local, national and regional circumstances.

Equity aspects are also strongly present in the issue of bioprospecting for marine genetic resources. The Convention on Biological Diversity (CBD) encompasses the objective of fair and equitable sharing of the benefits from the use of genetic resources within areas under national jurisdiction, however, the governance situation for genetic resources of the High Seas is less clear. Some countries would like to give deep seabed genetic resources in the Area the status of common heritage of mankind similar to mineral resources, hence providing for sharing of benefits, while others would prefer to have a regime of free access to all, which, in practice may come down to access to those who have the technological capacity and financial resources. Another related issue is that of patentability of genes or compounds derived from marine species, which is far from being resolved (for example, Gambini, 2006). It remains to be seen how the concept of equity, as embedded in UNCLOS and the CBD, will be translated to the full range of uses of the deep sea beyond national jurisdiction.

Ways forward

To address these key issues in deep-sea governance a series of priority policy steps need to be considered. These include:

- immediate protection of most vulnerable areas based on the precautionary principle;
- shifting the burden of proof to those carrying out the activity so that they show that they do not harm ecosystems;
- minimizing impacts of human activities and developing environmental impact assessments;
- improving implementation of existing regulations and instruments;
- analysing gaps in deep-sea governance and management;
- upgrading existing international and regional bodies and improving coordination and collaboration between institutions;
- investing in research to improve knowledge and understanding;
- developing environment-friendly technologies;
- sharing benefits between stakeholders and with developing countries and SIDS;
- raising awareness and willingness to act amongst the public, stakeholders and policy makers.

In this respect, a series of suggestions have been put forward in various international policy fora, among which a call for a Global Programme of Action (GPA) for the Oceans. Such an intergovernmental programme would have an environmental focus and address issues across all sectors in collaboration with all stakeholders. The objective would be to move from a fragmented to an integrated and coordinated approach in the conservation, sustainable management and use of deep waters and the High Seas. It would operate at national, regional and global levels and support those in need of help.

Another proposal was made by the European Union (EU) and tabled at the first meeting of the UN "Ad Hoc Open-ended Informal Working Group to study issues relating to the conservation and sustainable use of marine biological diversity beyond areas of national jurisdiction", in February 2006. The EU proposes that an Implementing Agreement consistent with UNCLOS should be developed to provide for the conservation and management of marine biological diversity in areas beyond national jurisdiction (ABNJ), including the establishment and regulation of MPAs, where there is a scientific case for establishing such areas (EU, 2006). Such a mechanism could augment the provisions of UNCLOS in relation to regulation of ABNJ and to coordinate an ecosystem-based approach for sustainable use of resources (Hart, 2007).

While these and other proposals are still under consideration, significant efforts are required to improve and implement deep-seas governance and management to ensure long-term sustainable use and conservation through better use of currently available mechanisms.

RESEARCH NEEDS

The above discussion highlights the importance of increasing our understanding of governance and management issues for the deep sea. In particular, we need interdisciplinary institutional and governance analyses that explore the linkages between different institutions and the multi-level governance challenges. This should include critical appraisal of existing and potential governance institutions and management tools and how they are linked, as well as legal studies of existing and potential regimes. Studies should also focus on mechanisms to increase institutional capacity to respond to three important factors: (i) the high levels of uncertainty given the gaps in knowledge of deep-sea systems; (ii) the high vulnerability and long recovery times for many deep-sea ecosystems and (iii) increasing rates of change that are predicted as a consequence of global climate change (for example, changing temperatures, ocean current regimes, acidification).

Research is also needed on ways to implement the ecosystem approach and on holistic, integrated, intersectoral and adaptive management in practice including empirical testing of options and benchmarking for best practices. This must comprise mapping of stakeholders and proactive research on how to manage new and emerging issues or activities (for example, those that are not yet covered by existing governance arrangements). This implies foresight research into technology, business and market developments.

Practical environmental impact assessment methodologies for the deep sea need to be developed as well as operational socio-economic and ecological indicators, which can be used for ecosystem management. This should be linked to research into spatial planning and geographic information systems including socio-economic data for management support. Economic studies of subsidies and other economic incentives/disincentives as well as of different market-based instruments are also needed.

Finally, research is needed on public attitudes and awareness, their evolution and their relation to the conservation and sustainable use of deep-sea ecosystems and resources.

5. Conclusions

This scoping study has explored the key socio-economic, governance and management issues relating to the conservation and sustainable use of deep-sea biodiversity and ecosystems. After a succinct overview of habitats and ecosystems of the deep, the goods and services they provide were presented and issues pertaining to their valuation were discussed. Human activities and impacts on deep-sea ecosystems were then described. Finally, key governance and management issues have been addressed. Based on this overview, two particular objectives of the study were to highlight: (i) issues and areas that need further investigation to close gaps in knowledge and understanding and (ii) the needs and means for interfacing this research with policy processes related to deep-sea ecosystems and biodiversity. These are discussed below and constitute a draft road map to serve as a basis for consideration and future action.

RESEARCH NEEDS ON SOCIO-ECONOMIC, GOVERNANCE AND MANAGEMENT ISSUES

Research priorities

Knowing and understanding the deep sea better will certainly improve our ability to comprehend – in a qualitative and quantitative sense – both human impacts on deep-sea biodiversity and ecosystems, and deep-sea contributions to human well-being. This will allow us to better account for the deep-sea environment in decision-making processes.

Research gaps and needs on the natural environment and ecosystems of the deep sea are numerous. We also lack understanding of the role played by the deep sea in a complex and dynamic Earth system (Cochonat *et al.*, 2007). In addition, as this report has shown, vast research gaps exist on the socio-economic, governance and management aspects of the deep sea. The following important research topics have been identified:

Socio-economy

- relationships between biodiversity, ecosystem structure and functioning and the provision of goods and services;
- monetary and non-monetary valuation techniques and whether and how these can be applied to goods and services provided by the deep sea and its ecosystems, including the question of the pertinence of using (monetary) economic valuation for the deep sea;
- costs imposed to society or environment as a consequence of unsustainable uses of deep-sea resources;
- economic effects of subsidies and other economic incentives/disincentives and market-based instruments;
- development of comprehensive decision-support tools, including in particular multicriteria approaches and participatory integrated assessments, which allow for the combination of different types of values;
- spatial planning and geographic information systems including socio-economic data for management support;
- development of plausible scenarios of future trends in economic activities, including foresight research into technology, business and market developments;
- indirect drivers of ecosystem changes such as demographic, economic, socio-political and cultural factors, which have the potential to act as better leverage points for policy;
- public attitudes and awareness, their evolution and their relation to the conservation and sustainable use of deep-sea ecosystems and resources;

Impact assessment

- mapping of human activities in the deep-sea, including threats, direct impacts, stakeholders, and potential conflicts between activities;
- mapping of indirect impacts of human activities on deep-sea biodiversity and ecosystems;
- studies on how various direct and indirect impacts may act in synergy and consequent combined/cumulative effects;
- long-term monitoring of deep-sea environments and human activities impacting on them, in support of research, policy and adaptive management;
- life-cycle analysis and footprint of processes of exploitation of deep-sea resources compared to exploitation of similar resources in terrestrial or shallow-water environments;
- environmental impact assessment methodologies for the deep sea;

Management and governance

- methods for prioritization of threats and impacts, and consequently of areas for policy action;
- interdisciplinary institutional and governance analyses that explore the linkages between different institutions and the multi-level governance challenges;
- critical appraisal of existing and potential governance


Ifremer/Victor 6000/Medeco 2007

Human impact in the deep sea: plastic rubbish at the bottom of the Var Canyon, Western Mediterranean, 2 200 m water depth.


Alfred Wegener Institute for Polar and Marine Research

German research vessel 'Polarstern' on a deep-water expedition in the Arctic Ocean.

institutions and management tools; including institutional capacity to respond to high uncertainty, high and long-term vulnerability, irreversibility, and high rates of global environmental change;
- ways of implementing the precautionary principle and other governance principles;
- governance and management systems for new and emerging issues or activities;
- ways of implementing the ecosystem approach and holistic, integrated, intersectoral, anticipative and adaptive management in practice, and empirical testing of options, including benchmarking for best practices;
- development and assessment of various policies and measures towards sustainable use of deep-sea resources;
- management of networks of MPAs within and outside EEZs;
- development of operational socio-economic and ecological indicators that can be used for the management of deep-sea ecosystems.

Integrating natural and social science research

Social sciences (for example, economics, law, sociology, political sciences) have important roles to play in the study of biodiversity loss and change, since the main causes of the global biodiversity crisis are anthropogenic. Social sciences have a long and pluralistic tradition of studying human aspects of the world: behaviours, activities, societies and their values and institutions (political, economic, cultural or social).

The roles of social sciences in interdisciplinary biodiversity research programmes are manifold. By providing explanations for social phenomena and how they relate to the natural phenomena in question, they improve knowledge and contribute to finding potential solutions. For instance, social sciences can contribute to the identification and understanding of the direct and indirect anthropogenic drivers of deep-sea biodiversity change, and help assess the societal impacts of response strategies. Social scientists can also contribute to prediction exercises that are operating at the science-policy interface, through integrated models, scenarios or narratives. Moreover, social scientists are sometimes particularly well placed to build bridges between different scientific disciplines or between the different actors (scientists, policy makers, other stakeholders). Hence, they can also reinforce the science-policy interfaces by contributing to their design, evaluation or even implementation by acting as translators, mediators or facilitators (van den Hove, 2007).

Socio-economic and governance research for the deep sea can only develop in synergy with natural-science research on deep-sea ecosystems and their functions, hence the importance of interdisciplinary endeavours. Deep-sea scientists have only recently started to work jointly in interdisciplinary teams, bringing together biologists, microbiologists, geochemists, geologists, oceanographers and geophysicists. The next step is to integrate social sciences in these partnerships, in order to develop an integrated science in support of deep-sea governance. This process has started in the integrated, multidisciplinary research project HERMES (Hotspot Ecosystem Research on the Margins of European Seas).

Training and capacity-building

Specific social science expertise on socio-economic and governance aspects of the deep sea is still very sparse and often non-existent. Consequently, there is a need for transferring social science knowledge and expertise from other environmental topics to the deep-sea research area with a view to train and motivate a new generation of social scientists to work on these questions. Moreover, training in communication and mediation could be proposed as part of training of young (natural and social) scientists to reinforce these skills for those who are interested in linking science and society.

On the governance side, training for managers, policy makers and other stakeholders in various aspects of deep-sea science and governance is also needed, both in developed and in developing countries. Fostering good human, institutional and technical capacity in scientific and policy institutions could be achieved via such efforts as exchanges of experience and bilateral or multilateral cooperation.

IMPROVING THE SCIENCE-POLICY INTERFACES FOR THE CONSERVATION AND SUSTAINABLE USE OF DEEP-SEA ECOSYSTEMS AND BIODIVERSITY

In recent years, deep-sea governance issues have become more and more prominent on the policy agendas at international and national levels. Many stakeholders and policy makers are increasingly involved in those issues. They urgently need integrated, interdisciplinary natural and social-science knowledge to prioritize and guide action in support of policy development and implementation strategies. To ensure the effective use of deep-sea science in deep-sea governance and management, as well as the policy relevance of deep-sea research, effective science-policy interfaces must be developed. For instance, a well-functioning science-policy interface is required to decide whether, when, and how to go forward with exploitation of deep-sea resources and whether, when, and how exploitation should be restricted or prohibited for conservation purposes.

To improve the deep-sea science-policy interfaces, priority actions include:

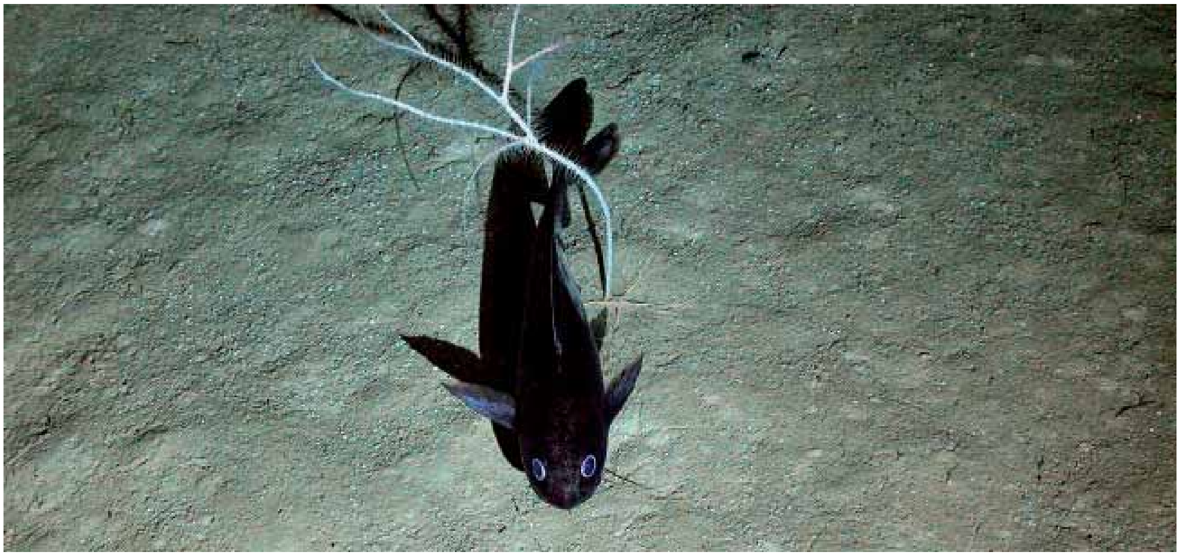
- translating relevant research results to make them available to policy makers and other users;
- removing barriers and improving processes and tools for presenting, sharing and exchanging data between different user groups;
- developing real-time dialogue with, and input to, the policy processes; in particular through: (i) participation of scientists from the deep-sea research community in international, regional and national policy meetings; (ii) provision of scientific advice to States, Regional Fisheries Management Organisations, international organizations, etc; (iii) close cooperation with NGOs to support the provision of science into policy processes;
- increasing scientists' awareness of policy and governance issues and policy makers' awareness of developments in science; for instance, through exchange of staff between policy and research institutions and through joint workshops and training sessions;
- accelerating the uptake of scientific advice in policy decisions (for example, for fisheries management);
- developing strategic dialogues and partnerships between scientists and other stakeholders (policy makers, industry, resource managers, NGOs) to foster adaptive management, generate debate and learning across the science-policy interface, and allow for collaborative strategies to emerge;
- establishing more open consultations with all stakeholders (including scientists) in the course of policy development;
- collaborative and participatory identification of gaps in knowledge in relation to the deep-sea and avenues to fill these gaps;
- developing synergies among deep-sea research programmes, projects and networks to consolidate the system of scientific expertise in support of policy;
- developing less sectoral and more integrated holistic ocean governance approaches;
- mandatory dynamic environmental impact assessments incorporating scientific research and observation for the exploitation of new areas;
- encouraging research institutions to bring about the participation of scientists in science-policy interfaces and outreach activities by acknowledging and valuing these activities in career development and research funding criteria.

As a final note, it must be stressed that communication of research results to the public is of paramount importance for the deep sea. The remoteness of the deep sea makes it practically inaccessible to human experience, except for a handful of scientists – and even for them, the deep-sea experience is highly mediated by technology. This creates a strong responsibility for scientists to contribute to outreach and dissemination efforts. To do so, scientists need support in terms of infrastructure, funding and human resources. As of today, it is still very hard to obtain funding for outreach and education activities, even though these necessitate skilled and qualified individuals and are extremely time-consuming. The development of accessible, interoperable databases helping to store and retrieve ecological and socio-economic knowledge – including *inter alia* metadata, environmental parameters, species description, human activities, images and video footage – is also needed. Such support is indispensable if scientists are to contribute to raising awareness of, and willingness to act for, the deep sea.

Glossary

See also Table 1.1 on page 12 for short definitions of major deep-sea features.

Area (The):	The seabed and ocean floor and subsoil thereof, beyond the limits of national jurisdiction (UNCLOS, 1982 Art. 1.1)
Benthos:	All organisms living on, in, or close to the seafloor.
Biodiversity:	The variability among living organisms from all sources including, *inter alia*, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems. (Convention on Biological Diversity, Art. 2)
Biome:	A major ecological community type (as for example, tropical rain forest, grassland, desert).
Civil society:	The arena of uncoerced collective action around shared interests, purposes and values. In theory, its institutional forms are distinct from those of the state, family and market, though in practice, the boundaries between state, civil society, family and market are often complex, blurred and negotiated. Civil society includes organizations such as charities, non-governmental organizations, community groups, professional associations, trade unions, social movements, business associations, coalitions and advocacy groups (www.lse.ac.uk/collections/CCS/Default.htm).
Continental crust:	The layer of granitic, sedimentary and metamorphic rocks that forms the continents and the continental margins. It is less dense than oceanic crust, though it is considerably thicker (35 to 40 kilometres). About 40 per cent of the Earth's surface is underlain by continental crust.
Cyst:	A small capsule-like sac that encloses certain organisms in their dormant or larval stage.
Exclusive Economic Zone:	Sea zone over which coastal states have special rights over the exploration and use of marine resources. EEZs usually extend to 200 nautical miles seaward or to the edge of the continental shelf, whichever is farthest.
Emergence:	The arising of novel and coherent structures, patterns and properties during the process of self-organization in complex systems (Goldstein, 1999).
Endemism:	A endemic species that is endemic is unique to a defined place, region or biota and not naturally found anywhere else.
Environmental Assessment:	Procedure that ensures that the environmental implications of decisions are taken into account before the decisions are made. In principle, environmental assessment can be undertaken for individual projects such as a dam, motorway, airport or factory ("Environmental Impact Assessment") or for plans, programmes and policies ("Strategic Environmental Assessment"). (ec.europa.eu/environment/eia/ home.htm)
Externalities:	In economics, externalities are defined as costs or benefits incurred by parties outside of a transaction. When considering the environment, and public goods in general, most externalities tend to be costs, and economists dub them market failures, until a market exists for them. Greenhouse gas emissions are an example. Ecological economists argue that market failures are cost-shifting "successes", for example when social and environmental costs go unpaid or are passed on to society at large.
Gas regulation:	The balance and maintenance of the gaseous composition of the atmosphere and oceans. One of the most important processes is the exchange of carbon dioxide at the surface by photosynthesis. Marine organisms facilitate the slow



NOCS/JC10 cruise

Morid fish at the Carlos Ribeiro mud volcano in the Gulf of Cadiz, East Atlantic Ocean.

	migration of carbon dioxide to great depths and long-term storage. Changes in biodiversity would therefore modify the ability of the oceans to act as a carbon sink.
Ghost fishing:	Ghost fishing is the term used for lost or abandoned fishing gear (for example longlines, gill nets, entangling nets, trammel nets, traps and pots constructed from modern, non-biodegrable synthetic fibres) that continues to catch fish and other organisms. Catch rates drop off to around 20 per cent after three months (*inter alia* due to gear degradation), and appear to stabilize at around 5-6 per cent after 27 months. This catching efficiency is believed to continue over several years. Ghost fishing is environmentally deleterious and the fish caught is wasted. The issue of ghost fishing was first brought to the attention of world at the 16th Session of the FAO Committee on Fisheries in April 1985 (FAO, 1991).
High Seas:	The water column beyond the EEZ (or beyond territorial sea where no EEZ has been declared).
Institutions:	Sets of rules of the game, or codes of conduct that serve to define social practices, assign roles to the participants in these practices and guide the interactions among occupants of these roles (Young, 1994). In other words, institutions are ways of organizing human activities (Dietz *et al.*, 2003).
IUU:	Illegal, unreported and unregulated fishing that: takes place where vessels operate in violation of the laws of a fishery (illegal); has been unreported or misreported to the relevant national authority or regional organization (unreported); is in contravention of applicable laws and regulations; is conducted by vessels without nationality or flying the flag of a country that is not party to the regional organization governing the particular fishing area or species, or is conducted in areas or for fish stocks where there are no conservation and management measures in place (unregulated) (High Seas Task Force, 2006).
Lithosphere:	The solid outermost shell of the planet; includes the crust and the uppermost mantle.
Macrobenthos:	Bottom-dwelling organisms greater than 500 microns (0.5 millimetre) in size.
Meiofauna:	Fauna between 100–500 microns length

	living in the spaces between sediment grains.
Nodule:	A nodule is an irregular and rounded aggregate of base metals, approximately the size of a tennis ball. Manganese nodules typically contain other metals such as iron, copper, cobalt and zinc. They are found primarily in the abyssal plains of the Clarion Clipperton Fracture Zone in the central Pacific Ocean.
Oceanic crust:	The part of Earth's lithosphere that surfaces in the ocean basins. It is thinner, generally less than 10 kilometres thick, but more dense than the continental crust. Most of the present-day oceanic crust is less than 200 million years old, because it is continuously being created at oceanic ridges and desolved/melted by being pushed back under less dense continental crust in subduction zones.
Phyla:	Plural of phylum, taxonomic category/rank at the level below kingdom and above class. Represents the largest generally accepted groupings of animals and other living things with certain evolutionary traits
Primary production:	The production of organic compounds from atmospheric or aquatic sources (for example carbon dioxide), principally through the process of photosynthesis and (to a lesser extent) chemosynthesis. All life on Earth relies directly or indirectly on primary production.
Prokaryotes:	Cellular organisms without a cell nucleus or other membrane-bound organelles. Comprising the kingdoms Archaea and Eubacteria.
Recruitment :	Additions to a population through birth or immigration. Net recruitment is the difference between these additions and losses arising from death or emigration.
Resilience:	Ecosystem resilience is the capacity of an ecosystem to tolerate disturbance without collapsing into a qualitatively different state that is controlled by a different set of processes (Holling, 1973)
Science-policy interfaces:	Science-policy interfaces are social processes that encompass relations between scientists and other actors in the policy process and that allow for exchanges, co-evolution and joint construction of knowledge with the aim of enriching decision making at different scales (van den Hove, 2007).
Sessile:	Animals permanently attached to a substrate so unable to move to another location.
Stakeholder:	Although definitions vary from areas under considerations, stakeholders are most likely to be individuals, groups or organizations who are in one way or another interested, involved or affected (positively or negatively) by a particular project or action toward resource use (Pomeroy and Rivera-Guieb, 2006).
Terrigenous:	Being or relating to oceanic sediment derived directly from the erosion rocks on land.
Unconventional oil:	Unconventional sources of oil commonly include fields located in harsh environmental conditions or fields where oil itself is difficult to recover. In both cases, unconventional sources present a low-energy return on energy invested. Such fields become exploited when oil prices make investment economically attractive. Tar sands, oil under ice shelves and deep-water oil are some examples.

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Cover images: (*left to right*) Ifremer; Department of Trade and Industry (UK); PhotoNewZealand/TopFoto; S. McGowan, Australian Maritime College, 2006/Marine Photobank; Wolfgang Schmidt/Das Fotoarchiv/Still Pictures.
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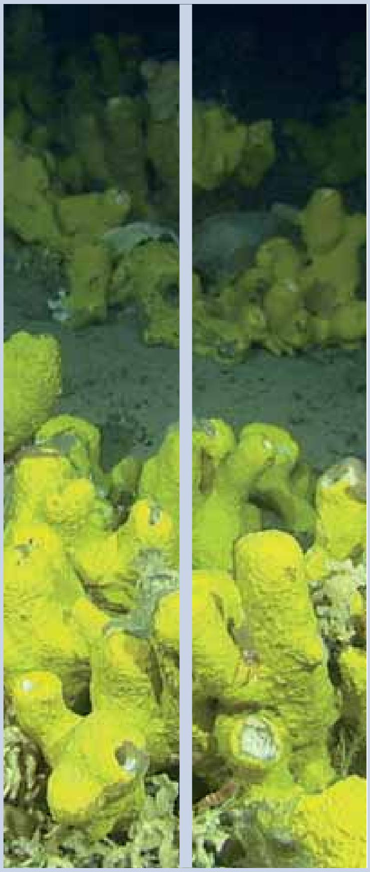

Deep-sea biodiversity and **ecosystems**

The deep sea is the oldest and largest biome on Earth, yet we have little knowledge of the ecosystems and processes in these dark, hidden depths. Only in the last two decades have new technologies enabled scientists to start exploring this last frontier – and their discoveries are fascinating but alarming: the deep sea is teeming with life but is already showing clear signs of anthropogenic impacts despite its remoteness. Many vulnerable deep-sea habitats and communities are being destroyed by fishing and are under threat from increasing exploitation of their mineral and living resources.

Since 2003, the protection, conservation and sustainable use of habitats, ecosystems and biodiversity in the deep sea and high seas have been on the agenda of international meetings. However, our knowledge is insufficient, and the existing governance and management systems are inadequate, to develop, implement and enforce concerted, effective action.

Deep-sea biodiversity and ecosystems responds to key questions, including: where do we find vulnerable deep sea and high sea ecosystems, what are the goods and services they provide, and how are they affected or threatened by existing or emerging human activities and climate change.

Deep-sea biodiversity and ecosystems scopes new ways and perspectives for answering these questions by applying modern methods and concepts used in the context of the Millennium Ecosystem Assessment. With input from leading experts, the report highlights gaps in socio-economic and governance knowledge, analyses shortcomings in assessment methodologies and valuation concepts, and identifies research needs. This results in strong arguments for urgent action to protect and conserve the deep waters, seabed, and high seas, and for the governance and sustainable management of human activities impacting on them. The deep sea is of crucial importance for life on Earth - we have to stop irreversible damages before it is too late.

UNEP Regional Seas Report and Studies No 184
UNEP-WCMC Biodiversity Series No 28

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ISBN: 978-92-807-2892-7

February 2008 DEP/1021/CA