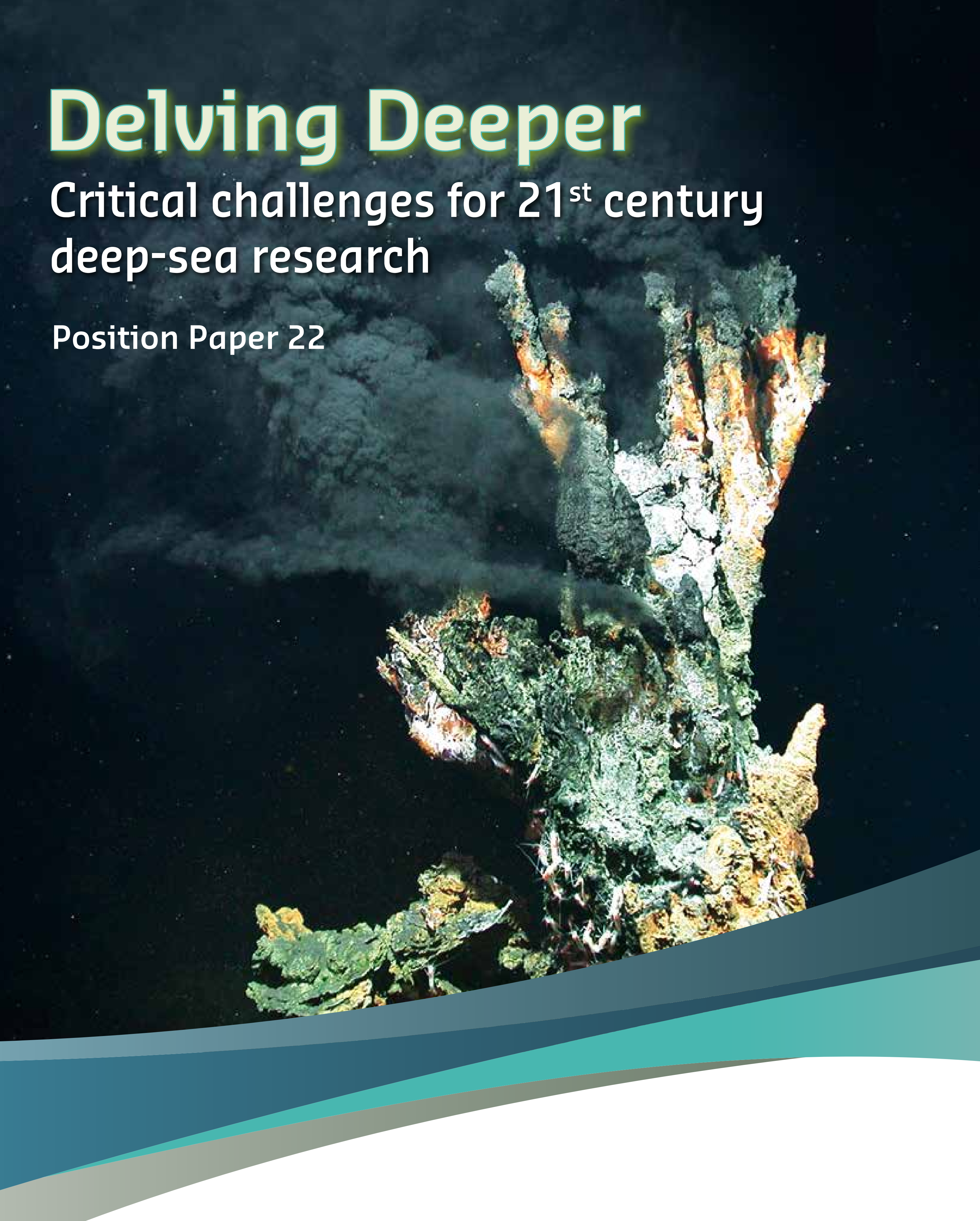
Delving Deeper

Critical challenges for 21st century deep-sea research

Position Paper 22



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Delving Deeper: Critical challenges for 21^{st} century deep-sea research

European Marine Board Position Paper 22

This position paper is based on the activities of the European Marine Board Working Group Deep-Sea Research (WG Deep Sea)

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Internal review process

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The European Marine Board extends thanks to the members of international deep-sea stakeholder community who contributed to this position paper, and in particular the investment study.

Suggested reference

Rogers, A.D., Brierley, A., Croot, P., Cunha, M.R., Danovaro, R., Devey, C., Hoel, A.H., Ruhl, H.A., Sarradin, P-M., Trevisanut, S., van den Hove, S., Vieira, H., Visbeck, M. (2015) Delving Deeper: Critical challenges for 21st century deep-sea research. Larkin, K.E., Donaldson, K. and McDonough, N. (Eds.) Position Paper 22 of the European Marine Board, Ostend, Belgium. 224 pp. ISBN 978-94-920431-1-5

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Second edition, September 2015

Foreword

For centuries humans have been crossing the ocean in search of resources and new lands to occupy. Long-distance mariners have a rare insight into the sheer scale of the ocean beyond the continental shelf, where the seabed falls away to depths measured in kilometres. There is no agreed definition of what constitutes the "deep sea". If we define it as that part of the ocean below 200m in depth (i.e. beyond the penetration of natural light and the reach of humans without the use of submersible technology), then the deep sea covers about 65% of the earth's surface and provides 95% of its biosphere. Its importance within the earth system as a regulator of climate and a provider of ecosystem goods and services cannot be overstated, although the nature and value of these benefits remain poorly understood. Arguably, we know more about the moon and Venus than the deep sea and spend considerably more on space exploration than on deep-sea research. It is imperative that we rectify this knowledge (and funding) deficit by moving beyond piecemeal and short-term scientific studies. In short, we must embark on a new era of exploration of the earth's final frontier: the deep sea.

Why now? Europe is a maritime continent and the EU Blue Growth strategy, launched in 2012, aims to expand our maritime economy, creating 1.6 million new jobs by 2020. Until now, human maritime activities such as fisheries, aquaculture, oil and gas production, aggregate extraction, and recreation and tourism have largely been conducted in coastal and shallow shelf seas. However, there has been a rapid development in interest in accessing ocean resources in deeper waters beyond the continental shelf. Commercial interests include deep-sea mining (mining the ocean floor for valuable minerals and rare earth elements), deep-sea oil and gas production, and deep-sea fisheries. There is also interest in using organisms found in extreme deep-sea environments as a source of interesting bioactive compounds which could be used to generate new drugs, nutraceuticals and industrial products.

While activities such as fishing, mining and oil and gas production in the deep sea are becoming technically and economically feasible, they remain highly contentious. Many believe that the potential risks and environmental impacts associated with such activities in the deep sea are too great. We also lack adequate legal and policy frameworks to regulate access to and utilization of deep-sea resources - both living and non-living - in areas beyond national jurisdiction (ABNJ) and international discussions on these issues are currently ongoing in the framework of the United Nations Convention on the Law of the Sea (UNCLOS). What is clear is that technology development and commercial interest is moving at a pace that outstrips the ocean governance discussions and the generation of new knowledge through scientific research. If commercial activities are to proceed, it is imperative that we develop a much greater knowledge and understanding of the deep sea.

It is important to note that in producing a position paper that addresses deep-sea research explicitly, we are not advocating a reductionist approach whereby the deep sea is studied in isolation from other parts of the ocean and earth system. Indeed, understanding the links between the deep ocean, shallow and coastal waters, the land and atmosphere is an important recommendation of this paper. Nonetheless, there are particular challenges to studying the deep sea that merit special attention. Deep-sea exploration is costly, requires extensive and long-term planning, and carries with it a greater level of risk. In addition, most of the deep sea falls outside of national jurisdiction which presents legal and regulatory challenges. For these reasons, international cooperation is especially important in addressing deep-sea research and in deciding on appropriate management and governance frameworks for deep-sea resources.

Industrial development in the deep sea will require advanced technologies and significant investment, the vast majority of which will come from private sources. Hence, an overarching recommendation of this position paper is that, to support Blue Growth, European public research funding should target fundamental scientific research on all components of the deep sea environment and the establishment of environmental baselines. Where possible, this should be done in a time frame that will complement and keep track with industrial expansion in the deep sea. Key areas for public research investment include, *inter alia*, mapping deep-sea terrain and habitats; studying deep-sea biodiversity; understanding deep-sea ecosystem functioning, connectivity and resilience; developing sustained deep-sea observing systems; identifying appropriate indicators and targets for environmental health in the deep sea; and developing innovative governance frameworks to ensure efficiency, transparency and fairness in accessing, utilizing and deriving benefits from deep-sea resources.

On behalf of the EMB membership, I would like to extend my sincere thanks to the deep-sea working group experts for their dedication and hard work in producing this detailed paper. Particular thanks must go to Professor Alex Rogers, Chair of the working group. It is a well-worn adage that if you want to get something done, ask a busy person. This is notably true in Alex's case. He has worked tirelessly and always in good spirit to guide the process at all stages, despite his numerous other committments. My thanks also to the EMB Secretariat, in particular to Niall McDonough, Kate Larkin and Karen Donaldson, who worked continuously behind the scenes to support the work of the group and the finalization of the paper. I sincerely hope that this paper will provide the basis for a new impetus in European deep-sea research and a guide to funders and decision makers on the most pressing deep-sea research challenges.

Jan Mees
Chair, European Marine Board

Table of contents

Executive Summary

Sometimes referred to as the earth's "inner space," the deep sea remains the last frontier on our planet. Although there is no common agreement on what constitutes the deep sea, for the purposes of this paper, it is defined as that part of the ocean deeper than 200m (see section 1.1). Taking this definition, the deep sea covers 65% of the earth's surface area and provides 95% of its habitable space or biosphere. Yet this vast domain is almost entirely unexplored. The Census of Marine Life found that every second specimen collected from abyssal waters deeper than 3,000m belonged to a previously undescribed species.

Human activities in the ocean have accelerated rapidly in recent years and recent figures set the EU's blue economy at approximately €500 billion per year in gross value added (GVA) (EC, 2012). Yet this figure does not fully take account of the extensive ecosystem services provided by the seas and ocean and the societal benefits that we accrue from them. In the past, with the exception of shipping and the laying of trans-oceanic cables, commercial activities have been largely restricted to coastal and shelf seas. However, economic drivers coupled with technology developments mean that existing activities such as fisheries and oil and gas production are moving into increasingly deeper waters. In addition, emerging activities such as mining the seabed for mineral resources, the development of renewable energy schemes, and carbon capture and storage are the subject of major interest from both the private sector and some national governments.

From a policy perspective, seabed mining and blue biotechnology are two of the five priority areas identified for further support and development under the EU Blue Growth Strategy (the others are aquaculture, renewable energy and coastal tourism). Significant levels of interest in the collection of biotic (biotechnology) and abiotic (mining) material for both of these activities has focused on the deep sea, often in areas beyond national jurisdiction (ABNJ). The increased emphasis on advancing international ocean governance by the European Commission reflects the fact that there are considerable remaining challenges in developing a robust and agreed legal basis to regulate the access to and utilization of resources from ABNJ, whether from the water column (the "High Seas") or the seabed and subsoil ("The Area"). These policy goals and governance discussions are severely hampered by a knowledge deficit of the deep sea. There is a clear need for further research to support evidence-based decision-making on managing human activities in the deep sea, ensuring that environmental impacts are minimized and the environment and its biodiversity are protected.

This report presents the findings of a European Marine Board working group that was convened to make recommendations on future deep-sea research priorities, taking account of the European economic and policy context. The working group reviewed the current deep-sea research landscape and the knowledge gaps and needs to underpin future management and exploitation of living and non-living deep-sea resources. A key recommendation of the paper is that there are serious deficiencies in basic knowledge which can hinder sustainable ocean development and ecosystem-based management of the deep sea. In particular, a lack of understanding of the complex deep-ocean ecosystem including its biodiversity and its spatial and temporal variation, ecology, biology, physics and chemistry were all recognized as problematic. Major progress is also required in mapping the deep seabed, deep-sea observing, and understanding human impacts on deep-sea ecosystems. Barriers and enablers to meeting these scientific challenges in terms of funding, infrastructure and human capacities were also examined.

The ultimate recommendations of this position paper are presented as eight high-level goals and associated action areas for deep-sea research (see summary in Table 1.1 with further detail in Chapter 7). It is proposed that these goals and action areas, taken as a coherent whole, can form the basis for a European integrated framework to underpin the development of deep-sea activities and support blue growth.

Table 1.1 Summary of goals and key action areas for next generation deep-sea research

GOAL	KEY ACTION AREA
Increasing our fundamental knowledge of the deep sea	- Support fundamental research on deep-sea ecosystems and wider science - Develop innovative, science-based governance models for deep-sea resources - Promote long-term monitoring and observing programmes and systems targeting deep-sea locations of recognized importance
Assessing drivers, pressures and impacts in the deep sea	- Develop improved knowledge of natural and human drivers, pressures and impacts - Understand stressor interactions and cumulative impacts - Establish “Good Environmental Status” for deep-sea ecosystems - Investigate alternative supply strategies for targeted resources - Reduce impacts and develop area-based strategic environmental management plans
Promoting cross-disciplinary research to address complex deep-sea challenges	- Promote cross-sectoral research collaboration (e.g. industry-academia; academia-NGO) - Develop a marine Knowledge and Innovation Community (KIC) - Embed cross-disciplinary, problem-orientated approaches in the training of early career researchers
Innovative funding mechanisms to address knowledge gaps	- Target public funding (EU and national programmes) at fundamental research in support of sustainability and protection of natural capital - Develop and deploy innovative funding mechanisms and sustained funding streams for research and observation (e.g. long-term time-series) - Advance progress towards internationally coordinated mapping of the deep-sea floor to advance research and spatial planning
Advanced technology and infrastructure for deep-sea research and observation	- Promote and fast-track new technologies for platforms, sensors and experimental research - Develop and utilize multi-purpose deep-sea platforms - Improve current computational capacity and approaches for physical and biological modelling for deep-sea science - Develop sensors for biological and biogeochemical parameters - Support industry-academia collaboration in technology development
Fostering human capacities in deep-sea research	- Promote and expand training and career opportunities for research, policy and industry - Take account of needs for both scientific and technical/ICT expertise
Promoting transparency and open data access and appropriate governance of deep-sea resources	- Ensure adequate representation of scientific expertise contributing to developing legal and policy frameworks addressing deep-sea resources (notably preparation of a new Implementing Agreement under the United Nations Convention on the Law of the Sea (UNCLOS) and development of ISA regulatory framework for seabed mining) - Promote transparency and open access to data as guiding principles for deep-sea governance - Improve technology transfer between public research and industry - Develop deep-sea ecosystem restoration protocols
Deep-ocean literacy to inspire and educate society to value deep-sea ecosystems, goods and services	- Promote communication and education on the societal importance of deep sea to students and the general public using the best principles of ocean literacy - Embed ocean literacy approaches in deep-sea research projects and programmes

Credit: MARUM

1

Introduction

1.1 The deep sea

For the purposes of this position paper, the "deep sea" is defined as all areas where the water is deeper than 200m and includes both the seabed and water above (see Box 1.1). The deep sea is also referred to as the deep ocean and deep water, and those terms are used interchangeably in this position paper. It covers more than 65% of the earth's surface and provides more than 95% of the global biosphere (Fig. 1.1). For a long time, the deep ocean was thought to be a desert in terms of species diversity but thanks to nearly 200 years of deep ocean exploration (Box 1.2) we now know that life occurs in all parts of the deep ocean and even beneath the seabed at temperatures ranging from -2^{o}C to more than 120^{o}C.

The deep sea encompasses many "extremes" compared to more familiar terrestrial or coastal environments, with an average depth of 4.2km, near total darkness, average temperatures less than 4°C, and hydrostatic pressures between 20 to nearly 1,100atm (Danovaro *et al.*, 2014). The lack of solar light negates net photosynthetic primary production deeper than approximately 200m, so deep-sea organisms depend largely upon food exported from surface water layers, coastal waters, or land. The exception to this is primary production based on chemical energy, or chemosynthesis, which supports life at hydrothermal vents, seeps and in other ecosystems such as the subsurface biosphere (life under the seabed). Chemosynthetic processes within the dark water column are known to convey dissolved inorganic carbon into biomass (Yakimov *et al.*, 2011). The contribution of this to deep-sea food webs is currently unknown. In addition, chemolithotrophic production (the use of inorganic compounds as energy sources, exclusive to microorganisms) in the sediments of the deep sea may make a significant contribution to carbon cycling in deep-sea benthic ecosystems (Molari *et al.*, 2013).

Although the general perception of the deep seabed is of vast flat and muddy plains, the ocean seafloor is characterized by a high habitat heterogeneity, which is increasingly resolved by new and sophisticated technologies. A variety of highly diverse landscapes have been recently described, including canyons, seamounts, ridges, deep-water coral reefs, cold seeps, pockmarks, mud volcanoes, carbonate mounds, brine pools, gas hydrates, fractures and trenches that host rich and highly diversified microbial and animal assemblages (e.g. Fig. 1.2).

Compared to the deep seafloor, the deep water column appears a more homogeneous environment, but shows variation in its physical structure and biota over a range of scales. The deep sea also includes earth's largest hypoxic and anoxic environments encompassing areas of seabed and water column (e.g. oxygen minimum zones; Table 1.2). The application of new technologies (multibeam echosounders, submersibles, ROVs, AUVs, landers) to scientific and biological investigations have enabled the discovery of new benthic ecosystems such as hydrothermal vents and seeps as well as documenting and quantifying elements of the deep pelagic biota difficult to sample using conventional nets. Such technology has also allowed ocean scientists to carry out the first manipulative experiments on seafloor communities, to extend habitat mapping to the most extreme ecosystems of the deep sea, and to begin to quantify the abundance of life in the deep water column.

Chapter 1 cover image: A school of shrimp
600m below the surface in the Gulf of Cádiz.

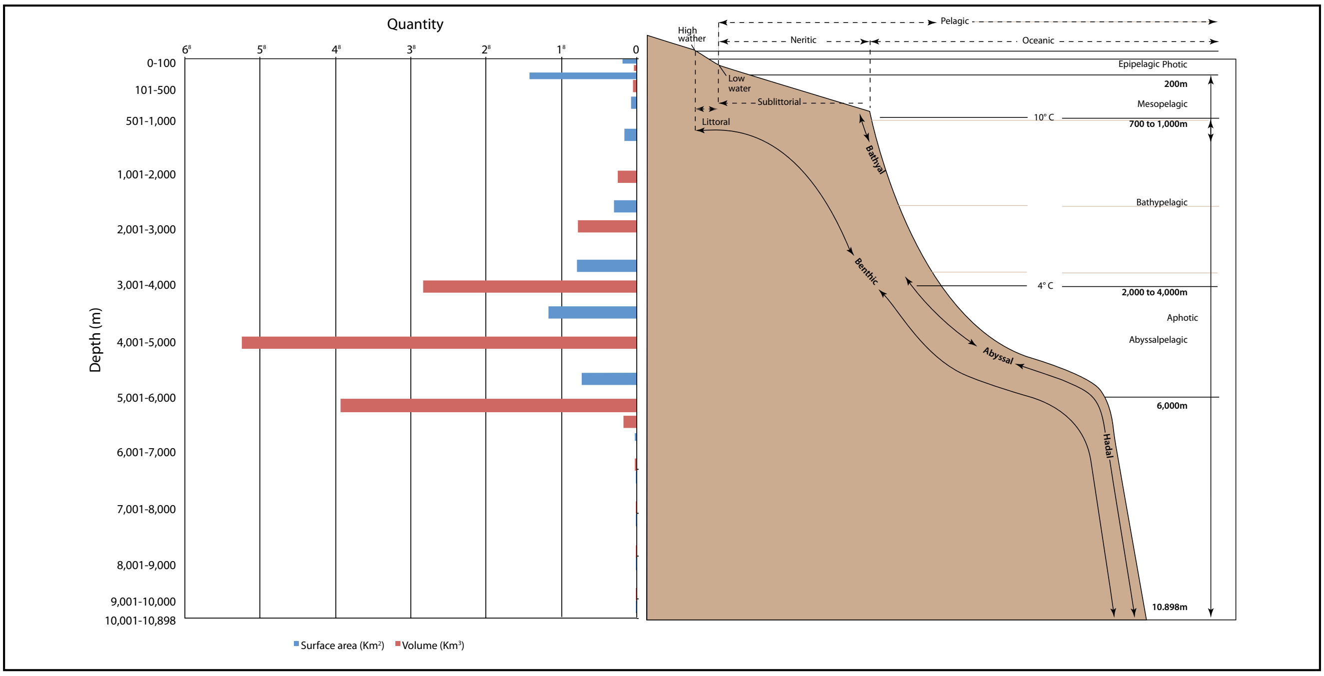
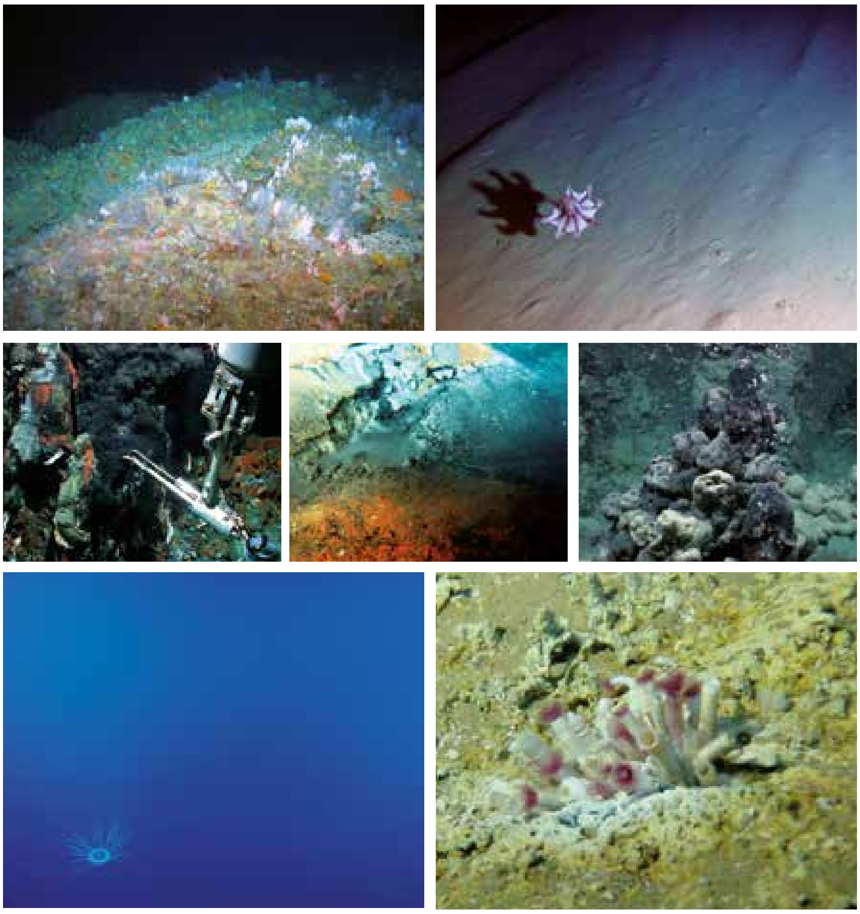


Fig. 1.1 Left: Surface area and volume versus depth for the global ocean and zonation of the deep ocean (numbers originate from Costello *et al.*, 2010; 2015). Right: Schematic redrawn from, based on original by Gage and Tyler (1991; Fig.2.4 therein, first edition)

Fig. 1.2 Examples of different deep-sea habitats:
Top row (left to right): Rich community of stylasterids, stony corals, black corals, sponges and other invertebrates, summit of Melville Bank seamount, South West Indian Ridge; cirrate octopus, Sargasso Sea Observatory, Atlantic Ocean.
Middle Row (left to right): The submersible vehicle *MARUM-QUEST* measures the temperature at the Mid-Atlantic Ridge 3,000m below the surface. Mud volcano emitting brine and gas; Methane bubbles released at a carbonate chimney
260m below the surface of the Black Sea.
Bottom Row (left to right): Dinner plate jelly encountered at a depth of 1,052m, North Pacific Ocean; sulfide dependent tube worms within methane carbonate.


Credit: Alex Rogers

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BOX 1.2 EXPLORING THE DEEP

Credit: online open source

Fig. 1.3 H.M.S. *Challenger*

For a long time, the deep ocean was thought to be azoic, that is, empty of life. This theory was put forward by distinguished British naturalist Edward Forbes in 1847 but was soon overturned during an era of ocean exploration and discovery in which European countries played an important role. The British Royal Navy began to expand coastal exploration into deeper waters by the 19th century as it searched for the Northwest Passage (Mills, 2012), and routes for submarine cables, with the laying of the first trans-Atlantic cable in 1857. In 1818 John Ross, a British Polar explorer, recovered animals from depths up to 1.8km in the Artic aboard HMS *Isabella* and *Alexander*. In 1839 – 1843, James Clark Ross, the nephew of John Ross, led a series of expeditions to Antarctic waters accompanied by Joseph Hooker. Animals were dredged from the deep sea to depths as great as 400 fathoms (730 metres) or more (Hooker, 1845) but were poorly accounted for as specimens from the expedition were not curated (Rozwadowski, 2005). From 1850 to 1860, Norwegian biologist Michael Sars sampled animals from deep water in the fjords at depths between 300 and 800m and in 1860, GC Wallich sampled brittlestars from depths of more than 2,300m on HMS *Bulldog* which was investigating routes for a North Atlantic telegraph cable.

There then followed the “heroic age” of deep-sea exploration with expeditions of HMS *Porcupine* and *Lightning* in the North Atlantic, followed by the circumnavigating voyage of HMS *Challenger* (Fig. 1.3). The latter, which also related to surveying routes for deep-sea cables, laid the foundations of our knowledge of deep-sea biology and was followed by expeditions by France (*Travailleur* and *Talisman*), Monaco (*Hirondelle*, *Princess Alice I* and *Princess Alice II*), Denmark (*Ingolf*), Norway (*Michael Sars*), Germany (*Valdivia*) and the USA (*Blake* and *Albatross*).

The advent of echo-sounding in 1923 expedited data acquisition at great depths that accumulated rapidly after World War II, providing evidence of the complexity of the deep ocean basin. The momentum of the “contemporary” approach to deep-sea exploration continued with the quantitative analyses carried out in the 1960s and 1970s, first using semi-quantitative anchor dredges (Sanders *et al.*, 1965) and subsequently using box corers (Jumars and Hessler, 1976; Grassle and Maciolek, 1992). This led to the discovery of the extremely high species richness in the benthic ecosystems of the continental slope and abyssal plains. In the 1970’s the discovery of deep-sea hydrothermal vents on the Galápagos Rift and their unique ecosystems and biodiversity changed our ideas about where life could occur on Earth, in the solar system and beyond. Over the last 170 years, new habitats have been discovered in the deep ocean on average once every 8 years with a particularly high rate of discovery in the last 30 years (Ramirez-Llodra *et al.*, 2010). For hydrothermal vent ecosystems, on average two new species are described each month—a rate of discovery that has been sustained over the past 25–30 years (Fisher *et al.*, 2007) (Fig. 1.4). This momentum in deep-sea discovery has been partly driven by industry (e.g. oil exploration and development, mining, technological and infrastructural development). The broader application of submersibles and the subsequent development of Remotely Operated Vehicles (ROVs) and Autonomous Underwater Vehicles (AUVs) has enabled the study of specific habitats (e.g. canyons, seamounts, deep-water corals) and added new environments to the deep-sea landscape (pockmarks, brine pools and domes).

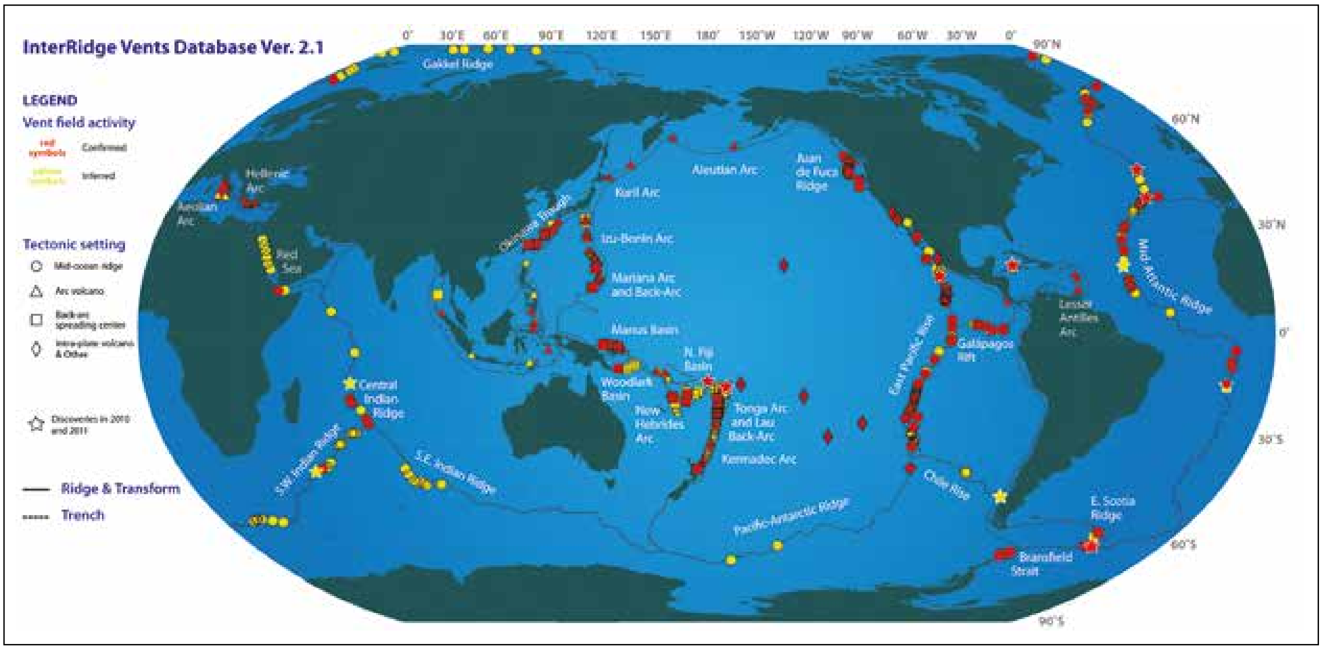


Fig. 1.4 Distribution of confirmed and inferred deep-sea hydrothermal vent ecosystems (InterRidge; http://vents-data.interridge.org/maps)

Credit: S. Beaulieu, K. Joyce, J. Cook, and S.A. Soule, Woods Hole Oceanographic Institution, 2015

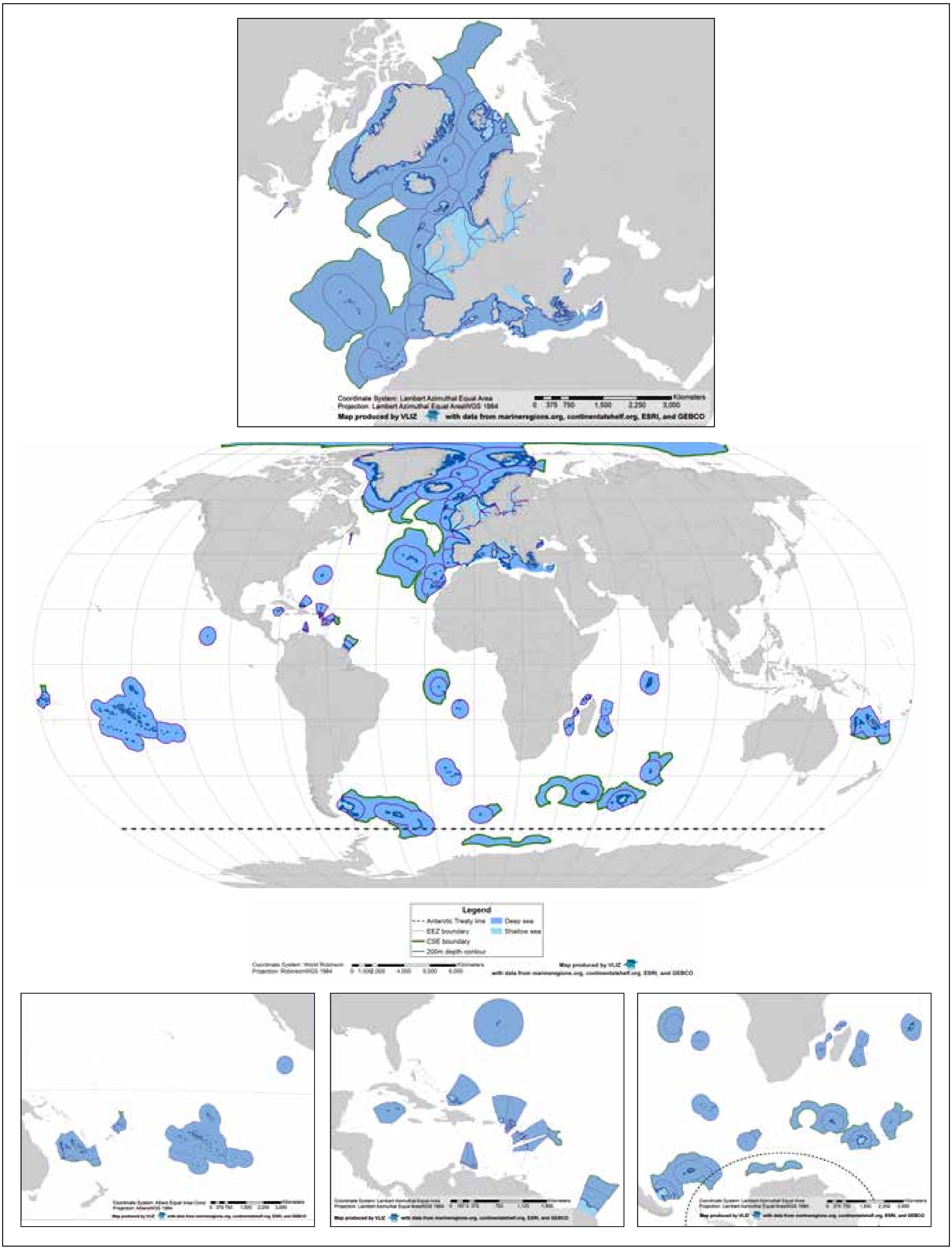
Credit: NOAA

Fig. 1.5 NOAA Ocean Explorer sampling the submarine ring of fire, explorer ridge, Pacific Ocean.

Credit: *CSSF/MBL/SOI*; Schmidt Ocean Institutee

Fig. 1.6 The “snowblower” mouth-like vent named “Boca”, Northeast Pacific Ocean.

A large proportion of European waters are classified as the deep sea, especially when overseas countries and territories are taken into account (see Fig. 1.7). The seafloor and sub seafloor portion of this is expected to increase as Continental Shelf Extensions are submitted to the Commission on the Limits of the Continental Shelf (CLCS) and approved under the United Nations Convention on the Law of the Sea (UNCLOS). To date, about 75 submissions have been made and the CLCS has issued recommendations on less than 20. A continental shelf extension can vastly increase a country’s deep-sea area of jurisdiction, as seen for Portugal, and has implications for economic activities that take place on the seafloor and sub seafloor such as oil and gas exploration and seabed mining, as well as the related environmental risks. Many European overseas countries and territories, referred to as outermost regions, may have potential for deep-sea economic development, such as seabed mining in the Indian Ocean and South Pacific.



Credit: VLIZ

Fig. 1.7 Global and regional maps of the European maritime Exclusive Economic Zones (EEZ) including outermost regions. The inner circles (purple) represent the EEZ boundaries. The outer delimitations (green) represent the claimed Extended Continental Shelves. **Top:** European seas and ocean; **Middle:** Global; **Bottom:** Pacific Ocean, Caribbean Sea, Southern and Indian Ocean

1.2 The knowledge deficit

1.2.1 Our inner planet

Fig. 1.8 Sulphide-dependent *Beggiatoa* (bacterial) mat

The deep ocean is the world's largest connected biome but our knowledge of the deep sea is very limited as only a fraction of it has been investigated (see Table 1.2). Despite international efforts for ocean exploration and discovery, only 0.0001% of the deep sea has been sampled biologically (European Marine Board, 2013). Hydrothermal vents on mid-ocean ridges (MORs) and back-arc spreading centres are probably the best known deep-sea ecosystems even though many of the identified sites have not been explored in detail and large areas of the MOR system remain poorly studied for hydrothermal vent sites (e.g. South West Indian Ridge; Beaulieu *et al.*, 2015).

The deep pelagic zone probably represents the most poorly studied part of the ocean (see Webb *et al.*, 2010). The deep pelagic fauna is difficult to sample because the animals are highly mobile (e.g. Kaartvedt *et al.*, 2012) or very delicate (Robison, 2009) meaning that our understanding of even basic biological parameters such as diversity, abundance, and biomass are poor. It is remarkable that so much of the deep sea has never been seen by human eyes at a time when we are viewing the far reaches of the universe using modern technology.

1.2.2 Deep-sea ecosystems and connectivity

Deep-sea ecosystems comprise a high diversity of organisms, some of which may be familiar from coastal or shallow waters, but also including others which are restricted to the deep sea, including ancient taxa such as stalked crinoids. Since the 1960s, semi-quantitative and quantitative sampling of deep-sea ecosystems has enabled scientists to identify some general patterns. For example, because of increasingly limited supplies of food with increasing depth, the abundance, biomass and body size of multicellular animals (metazoans) decreases with depth (Rex *et al.*, 2006; Van Der Grient and Rogers, 2015), although the latter is influenced by lifestyle and other life history traits (e.g. scavenging fish increase in body size with depth; Collins *et al.*, 2005).

Benthic species richness (the number of species in a local sample) shows a more complicated pattern with depth exhibiting a peak of diversity often occuring at mid-slope depths before declining from the continental slope to the abyssal plains (Rex and Etter, 2010). This is not a universal pattern with exceptions documented in various regions related in some cases to surface primary production or levels of oxygen. Food supply almost certainly plays a role in driving this pattern but other factors are likely to be important including sediment heterogeneity, levels of natural disturbance at different depths and even historical patterns of speciation and extinction (see Rex and Etter, 2010, for full discussion).

Patterns of abundance, biomass, body size, and diversity are less well-known in deep-pelagic communities. Data suggest that abundance and biomass decline with depth (Angel and Baker, 1982; Sutton *et al.*, 2010) but body size may show an increase to 1,000m, possibly followed by a decline (i.e. a parabolic pattern with depth; Angel, 1989). Species richness may also follow a parabolic pattern with depth but knowledge is extremely limited for the pelagic fauna (Angel and Baker, 1982).

Table 1.2 Area covered by the major deep-sea habitats with estimates of the proportion of the seafloor they cover and the proportion investigated to date. Based on Table 2 in Ramirez-Llodra *et al.* (2010). Updated for some habitats based on Harris and Whiteway (2011); Yesson *et al.* (2011); Beaulieu *et al.* (2015). The term 'Minimal' is used as a qualitative description where the value was small and not possible to quantify.

HABITAT	AREA (KM^2) OR VOLUME (KM^3)	% OF OCEAN FLOOR	PROPORTION INVESTIGATED
Deep water pelagic	1,000,000,000km^3	73% of ocean water	<< 0.0001%
Deep seafloor	326,000,000km^2	100%	0.0001%
Abyssal plains	244,360,000km^2	75%	<1%
Continental slope	40,000,000km^2 (150-3500m depth)	11%	Minimal
Ridges	30,000,000km^2	9.2%	10%
Seamounts	33,452 seamounts (elevation >1000m) with an area of 17,200,000km^2. Note there are >138,000 knolls (elevation <1000m)	5.3% (seamounts >1000m elevation only)	<0.002% based on 250-280 seamounts sampled out of >170,000 seamounts and knolls
Canyons	5,849 canyons with a cumulative length of 254,129km	Unknown	Minimal
Hadal zone	37 trenches	1%	Minimal
Benthic oxygen minimum zones	1,148,000km^2	0.35%	<1%
Cold-water coral reefs	280,000km^2	0.08%	Minimal
Hydrothermal vents on spreading centres	Approx. 1305, area unknown	Unknown	435 known (33%)
Cold seeps	10,000km^2	0.003%	2%
Whale falls	~35km^2 (~690,000 whale falls)	0.00001%	0.005%

Microorganisms do not seem to show a particular pattern of abundance and biomass with depth (Rex *et al.*, 2006). Our understanding of global patterns of species richness of microbial communities in the deep sea is rudimentary but communities are known to be diverse.

Despite the high connectedness of the deep sea and the vastness of the abyssal plains, the distribution of most distinctive ecosystems or habitats is discontinuous. Similar habitats are often separated by distances that challenge their colonization by specialized organisms. The study of life history traits is of fundamental importance in understanding the establishment and maintenance of populations as well as their connectivity. However, its progress in deep-sea ecosystems has been relatively slow. We do not understand the complete life cycle of any deep-sea species (either invertebrate or fish) and fundamental processes of larval supply, settlement and recruitment are virtually unknown. Knowledge of connectivity is essential to elucidate the processes that lead to specific biogeographic patterns and to understand ecosystem resilience to environmental change and has implications for conservation management (including the design of Marine Protected Area [MPA] networks). In addition to understanding the connectivity between deep-sea ecosystems, there is also evidence for an important link between the surface ocean, mid-water pelagic and deep-sea (Thorrold *et al.*, 2014)

With every new discovery and investigation of known and unknown sites and communities, our knowledge of biodiversity and ecosystem functioning increases, helping us to understand better the deep sea and global biosphere and to learn how to sustainably use them to the benefit of our society. However, the fact that we are still discovering entirely new groups of organisms that carry out previously unsuspected functions in the deep ocean demonstrates that there is much to learn. Information on biodiversity and functioning is crucial to consolidate knowledge about the status of trends in, and possible threats to deep-sea species and communities, and to the identification and implementation of technical options for their conservation and sustainable use (UNESCO, 2009). This imperative derives from the many key functions and services provided by deep-sea ecosystems and by the increasing impact of human activities and global climate change.

1.3 What the deep sea provides for us

The economic value of coastal and oceanic environments is valued conservatively at US$2.5 trillion per year, and the overall value of the ocean as an asset is ten times that (Hoegh-Guldberg *et al.*, 2015). It should be noted that it is almost impossible to accurately value coastal oceanic environments and their direct and indirect benefits. The Millennium Ecosystem Assessment is the most-used ecosystem services framework, though it has been criticized as reducing the focus on mechanisms underpinning the system (Thurber *et al.*, 2014). Despite their remoteness, deep-sea environments provide us with ecosystem goods and services that we are often unaware of (see Box 1.3 and Fig. 1.9 therein). Some ecosystem services to humankind have a direct market value, such as the provision of food through fisheries, marine-derived compounds and oil, gas and mineral resources (Armstrong *et al.*, 2012). However, the deep sea also provides a broad range of ecosystem services that cannot be valued directly but upon which we rely such as atmospheric gas and climate regulation through biogeochemical cycling (Armstrong *et al.* 2012; see below). While some ecosystem services are relatively easy to identify and also to value, (such as the provision of food from wild-capture fisheries that can be quantified in terms of what is being caught, from which location, the value at first landing as well as added value through the marketing chain) many other ecosystem services are not so easily quantified and valued, or even recognized (Table 1.3).

BOX 1.3 ECOSYSTEM SERVICES

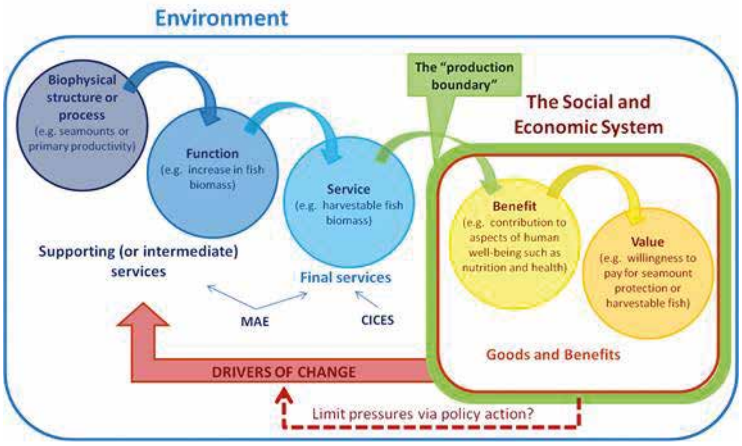
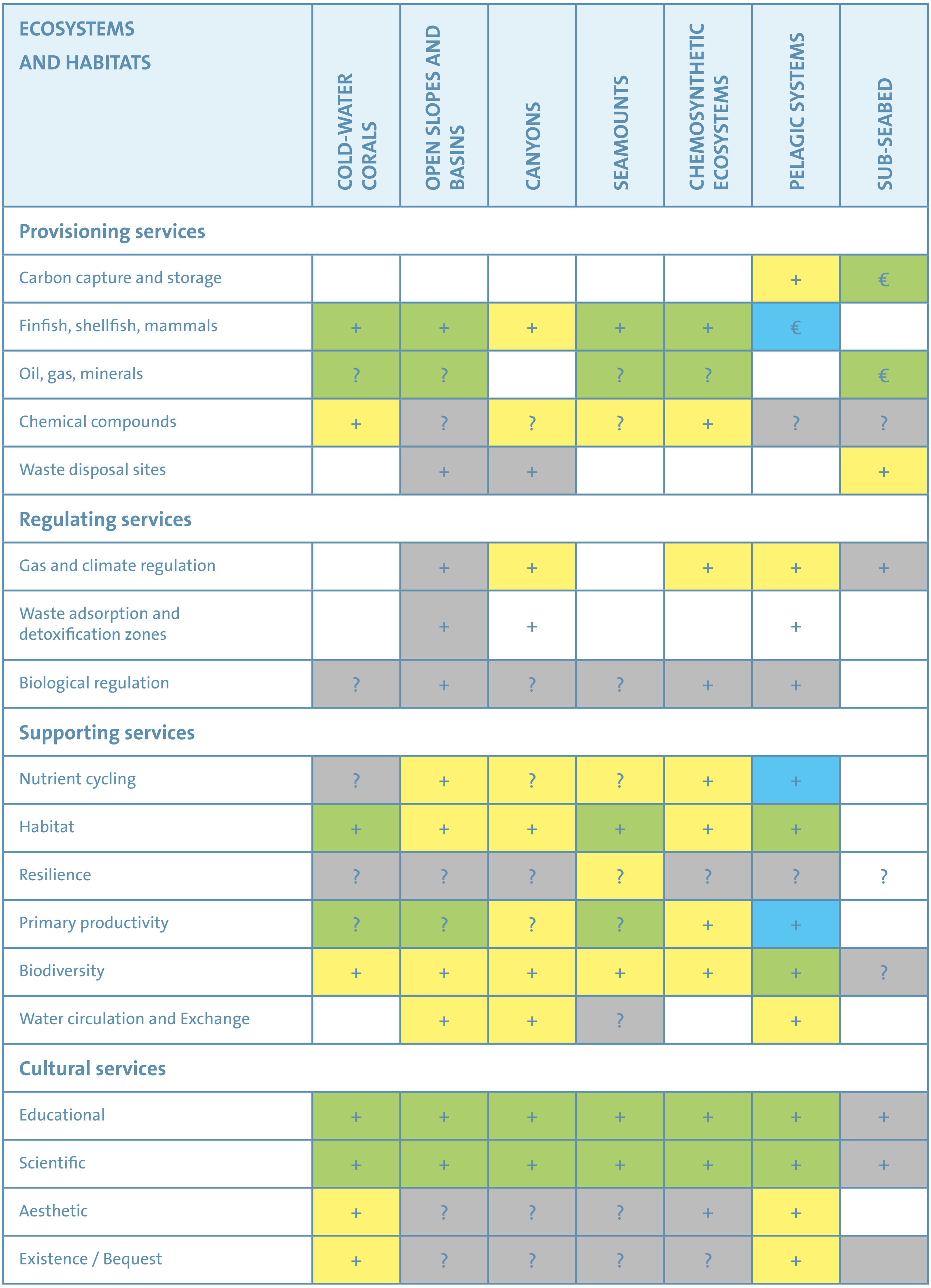


Fig. 1.9 Ecosystem services cascade. Adapted from Haines-Young and Potschin (2013)

Sometimes called Ecosystem Goods and Services, these are the direct and indirect contributions that ecosystems make to human wellbeing (Böhnke-Henrichs *et al.*, 2013; de Groot *et al.*, 2010). Ecosystem services are nature's products and services - the outputs of ecosystems and their associated living organisms and functions. Ecosystem services are classed into provisioning, regulating, supporting and cultural services, as defined by the Millennium Ecosystem Assessment (2005). Along with essential physical factors and processes, these ecosystems comprise the Earth's natural capital.

Table 1.3 An evaluation of the ecosystem services of the deep sea as presented by Armstrong *et al.* (2012). These have been re-ordered from Armstrong *et al.* (2014) to move from the better known and understood ecosystem services to the less intuitive. Key: blue = good knowledge; green = some knowledge; yellow = little knowledge; grey = no knowledge; white = irrelevant). Value is defined as being; present(+); not present (0); unknown(?); monetarily known (€).



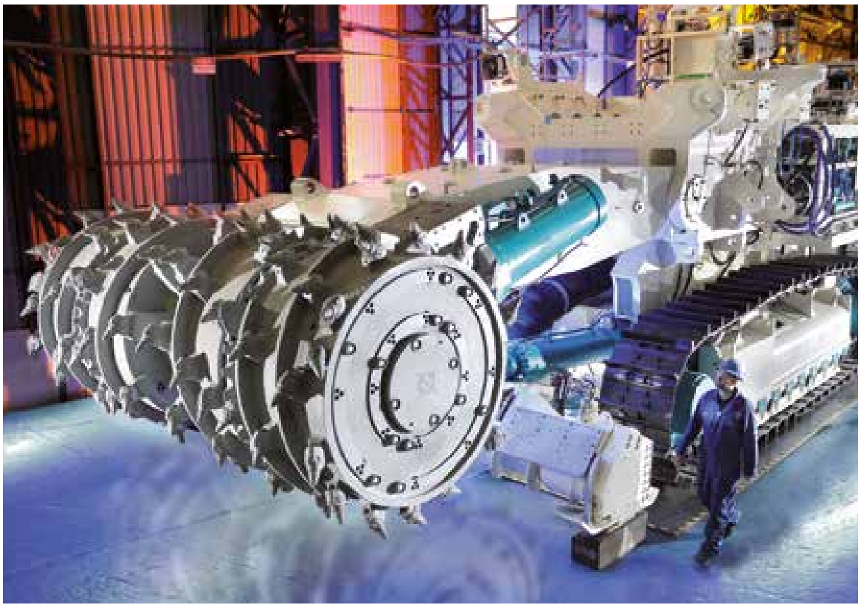
ECOSYSTEMS AND HABITATS	COLD-WATER CORALS	OPEN SLOPES AND BASINS	CANYONS	SEAMOUNTS	CHEMOSYNTHETIC ECOSYSTEMS	PELAGIC SYSTEMS	SUB-SEABED
Provisioning services							
Carbon capture and storage						+	€
Finfish, shellfish, mammals	+	+	+	+	+	€	
Oil, gas, minerals	?	?		?	?		€
Chemical compounds	+	?	?	?	+	?	?
Waste disposal sites		+	+				+
Regulating services							
Gas and climate regulation		+	+		+	+	+
Waste adsorption and detoxification zones		+	+			+	
Biological regulation	?	+	?	?	+	+	
Supporting services							
Nutrient cycling	?	+	?	?	+	+	
Habitat	+	+	+	+	+	+	
Resilience	?	?	?	?	?	?	?
Primary productivity	?	?	?	?	+	+	
Biodiversity	+	+	+	+	+	+	?
Water circulation and Exchange		+	+	?		+	
Cultural services							
Educational	+	+	+	+	+	+	+
Scientific	+	+	+	+	+	+	+
Aesthetic	+	?	?	?	+	+	
Existence / Bequest	+	?	?	?	?	+	

It is important to note that some of these ecosystem services rely on a "healthy" ocean[1] (e.g. fisheries, marine-derived compounds), whilst others do not (e.g. mineral resources). The ocean has been undergoing a process of industrialization since the mid-twentieth century and this has accelerated dramatically over the last 30 years in tandem with global economic cycles and driven by factors such as technology development, globalization, and the demand for resources by a growing human population. An example of this is the doubling in size of the global shipping fleet since 1984 and an eleven-fold increase in cruise tourism in the same period (Stojanovic and Farmer, 2013). Shipping is forecast to continue to grow at a rate of about 4.1% per annum (Corbett and Winebrake, 2008). Estimates of the value of the maritime economy to European States are difficult to make but have been estimated as approximately 4.0% of the combined European gross domestic product (GDP) (Surís-Regueiro *et al.*, 2013).

Projected increases in the value of maritime sectors vary greatly. Some analyses already estimate current gross added value at €500 billion (EC, 2012). Others are more conservative, predicting an increase in the value of maritime sectors from €103.5 billion in 2010 to €178.3 billion by 2030 (de Vivero and Mateos, 2012).

Credit: Ifremer

Fig. 1.10 Giant *Riftia pachyptila* in their habitat and abyssal fauna 2,630m below the surface on the East Pacific Rise, during Oceanographic campaign Phare.



Credit: Nautilus

Fig. 1.11 Bulk Cutter (BC) built to be used for seabed mining. The machine is designed to cut material at high rates from seafloor massive sulfide deposits.

[1] Here we consider a healthy ecosystem as one where sufficient biodiversity and ecosystem structure remain that ecosystem functions and services are not significantly degraded and there is resilience to natural and anthropogenic disturbances. Such systems are characterised by spatial and temporal heterogeneity (Thrush and Dayton, 2010).


Credit: Murray Roberts

Fig. 1.12 *Trachyscorpia cristulata*, a deep-sea demersal fish species, amongst cold-water coral. Image courtesy of Heriot-Watt University's Changing Oceans Expedition (*RRS James Cook* cruise 073) funded by the Natural Environment Research Council through the UK Ocean Acidification programme

The poorly understood nature and value of the ecosystem services of the deep sea is a significant barrier to making decisions on whether or not to exploit deep-sea resources and to what level exploitation should take place. Such decisions often require trade-offs between one ecosystem service (e.g. fishing) versus another (e.g. habitat provision). An example has been provided by examination of the ecosystem services provided by forage fish globally. Here, the catch value was estimated as US$5.6 million per annum but the value of fisheries that depend on forage fish as prey (predators such as tuna) was estimated at US$11.3 billion (Pikitch *et al.*, 2012). These estimates did not consider the other ecosystem services provided by forage fish but demonstrate the need for careful consideration of the trade-offs involved when setting limits for exploitation of marine living resources (Pikitch *et al.*, 2011).

A more relevant example for the present discussion is analysis of the role of deep bentho-pelagic fish in carbon capture and storage on the continental slope of Ireland and the United Kingdom. Estimates of the standing stock of biomass along with the consumption to biomass ratios of deep-sea fish suggest that between the depths of 500m and 1,800m, 3.5-6.2 x 10^5 tonnes per year of carbon is sequestered by bentho-pelagic fish in this region (Trueman *et al.*, 2014). This is equivalent to a value of €8-14 million per year at a CO_2 tradeable value of €6 per tonne CO_2, about 10-50% of the total value of fish landed from slope fisheries in the same region (Trueman *et al.*, 2014).

However, valuation of CO_2 sequestration on the basis of marketable values is a very simplistic approach as it does not reflect the social costs of CO_2 emissions. Other approaches are available such as estimation of replacement costs (the costs to capture a tonne of CO_2 using technological means) or more sophisticated approaches based on modelling estimated costs of social damage of CO_2 emissions[2]. Recent integrated assessment models of the social costs of CO_2 emissions range from US$12 to US$129 per tonne (€9.44 to €101.55 per tonne). Under these more sophisticated estimates of the social costs of carbon (SCC), the sequestration value of deep-sea fish between 500m to 1,800m on the continental slope of the UK and Ireland ranges from €12 to €21 million for the lowest estimated SCC up to between €130 to €231 million for the highest. According to the EC (2012), deep-sea catches from the whole of the NE Atlantic represent approximately 1% of the total catch at an estimated value of approximately €101 million (Pew Environment Group, 2012 based on 2010 catch figures). Thus the trade-off between capture of deep-slope species by fisheries should be considered in the context of removal of the capacity for these fish to sequester carbon. This is before other impacts of such fisheries on ecosystem services are considered (such as habitat destruction) and also does not consider costs to the taxpayer (e.g. direct and indirect subsidies) of such fisheries.

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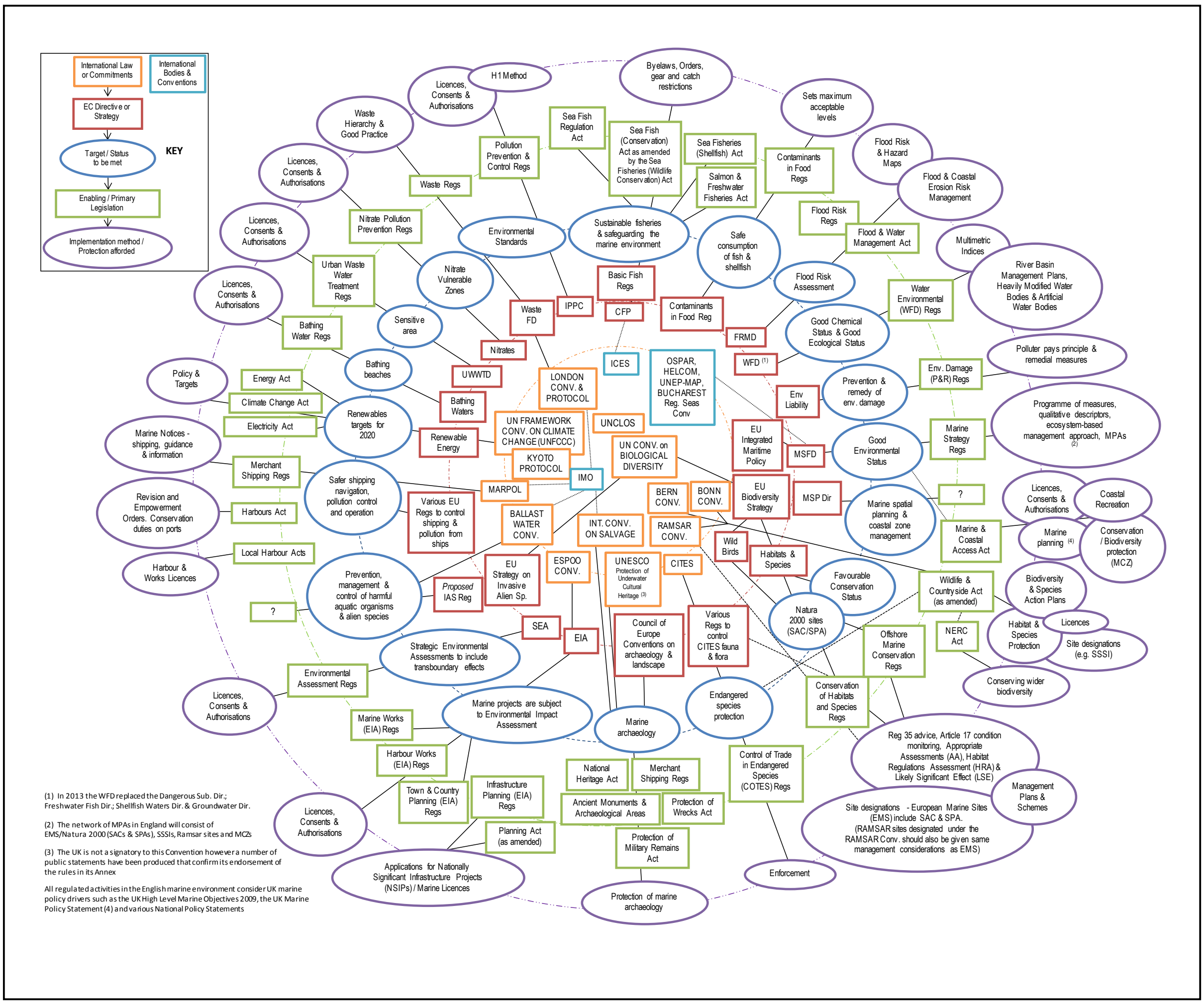
[2] Based on document: https://www.whitehouse.gov/sites/default/files/omb/inforeg/social_cost_of_carbon_for_ria_2013_update.pdf

1.4 Legal and regulatory framework

1.4.1 Legal background

Throughout history, the growing demands for ocean space and our knowledge about this space have driven increased legislation and development of policy (Stojanovic and Farmer, 2013; Vidas, 2011). This has been a response to competition in accessing ocean resources, equitability in the division of resources, and the balancing of increased economic activity and environmental conservation. However, the organic growth of marine legislation and the institutions that regulate activities in the deep sea and wider ocean means that governance is now complex (e.g. Boyes and Elliot, 2014; Fig 1.13). The 1982 United Nations Convention on the Law of the Sea (UNCLOS) provides the global framework for ocean governance and international instruments for the regulation of marine activities and for the environmental management and conservation of marine ecosystems. Mechanisms for managing activities and mitigating them are evolving over time to incorporate ecosystem approaches, but are demanding in terms of the science needed to underpin them. As a result, many efforts have been launched to better understand the deep seas and, on that basis, develop standards to better protect them. The development of knowledge-based policy, legal, and institutional regimes will likely be a deciding factor in determining how blue growth can be reconciled with ensuring a healthy and productive ocean into the future.

Fig. 1.13 International, European and English Legislation giving protection to the marine environment. (Boyes and Elliot, 2014)



(1) In 2013 the WFD replaced the Dangerous Sub. Dir.; Freshwater Fish Dir.; Shellfish Waters Dir. & Groundwater Dir.

(2) The network of MPAs in England will consist of EMS/Natura 2000 (SACs & SPAs), SSSIs, Ramsar sites and MCZs

(3) The UK is not a signatory to this Convention however a number of public statements have been produced that confirm its endorsement of the rules in its Annex

All regulated activities in the English marine environment consider UK marine policy drivers such as the UK High Level Marine Objectives 2009, the UK Marine Policy Statement (4) and various National Policy Statements

Ocean governance is inextricably linked to developments in ocean science (Vidas, 2011) and the challenges for deep-sea research. It is not the intention of this paper to provide an in-depth assessment of marine policy and law, rather to provide an overview of the relevant frameworks to set the context for current and future activities in the deep sea. Further information on legal and regulatory frameworks relevant to specific sectors is presented in Chapter 3.

1.4.2 Legal Definitions

Whilst the global ocean can be divided into biophysical zones, it is also divided into zones in which coastal states exercise varying degrees of sovereignty and jurisdiction and in which states have certain rights and responsibilities. These zones were established under UNCLOS and include: Internal Waters, Territorial Sea, Contiguous Zone, Exclusive Economic Zone, the Continental Shelf, the Area, and the High Seas (Fig. 1.14). The expression ‘the Area’ legally refers to the seabed and ocean floor and subsoil thereof beyond the limits of national jurisdiction.

Therefore, geographical ‘deep sea’ (marine areas located at a depth of more than 200m) is submitted to a legal regime which is the result of the juxtaposition, and sometimes overlap, of these special regimes. The application of one or another special regime depends on a combination of geographical and legal criteria, which are set out in the UNCLOS in order to delimit maritime zones and who can manage and exploit their resources. Moreover, UNCLOS makes specific provisions concerning navigation, the protection of the marine environment (in particular for the prevention, reduction and control of pollution) and the conduct of marine scientific research which applies to the deep sea (see Box 1.4).

BOX 1.4 MARITIME ZONES – AN OVERVIEW

Maritime zones have been defined by the United Nations Convention on the Law of the Sea (UNCLOS) (Fig. 1.14).

The Area: “the floor and the subsoil of areas beyond national jurisdiction, is subject to the regime of the “common heritage of mankind” (UNCLOS art. 136), The International Seabed Authority (ISA) was established in 1994 as the forum to organize and control activities in the Area. As part of its responsibilities, the ISA must provide for the equitable sharing of financial and other economic benefits derived from activities in the Area. Marine scientific research is also to be carried out for exclusively peaceful purposes and for the “benefit of mankind as a whole”. (UNCLOS Article 143). Article 133 of UNCLOS defines resources as “all solid, liquid or gaseous mineral resources in situ in the Area at or beneath the seabed, including polymetallic nodules”. This narrow definition suggests the exclusion of genetic resources from regulation by the ISA, though genetic resources, as part of the seabed and seafloor, can be considered a part of the common heritage of mankind (UN doc. A/RES/25/2479 (XXV), 17 December 1970).

The High Seas: “all parts of the sea that are not included in the exclusive economic zone, in the territorial sea or in the internal waters of a State, or in the archipelagic waters of an archipelagic State” (UNCLOS art. 86). The Law of the Sea Convention reaffirms the right of all States to exercise the freedom of the high seas under conditions laid down in the Convention. In some areas these freedoms have been substantially reduced by subsequent legal developments, for example the UNFSA and other instruments in the realm of fisheries.

The Continental Shelf: “the seabed and subsoil of the submarine areas that extend beyond its territorial sea throughout the natural prolongation” of the land territory of a coastal state “to the outer edge of the continental margin, or to a distance of 200 nautical miles from the baselines from which the breadth of the territorial sea is measured” (Art. 76.1 UNCLOS). On the continental shelf the coastal state has sovereign rights for the purposes of exploring and exploiting its natural resources (Art 77 UNCLOS).

The Exclusive Economic Zone: “an area beyond and adjacent to the territorial sea, with a maximum of 200 nautical miles distance from the baseline (Art. 57 UNCLOS). In its EEZ, the coastal State has “sovereign rights for the purpose of exploring and exploiting, conserving and managing the natural resources, whether living or non-living, of the waters superjacent to the seabed and of the seabed and its subsoil, and with regard to other activities for the economic exploitation and exploration of the zone, such as the production of energy from the water, currents and winds”. Coastal States determine the allowable catch of the living resources in their EEZ on the basis of “the best scientific evidence available” to them in order to ensure the maintenance of the living resources and avoid over-exploitation through proper conservation and management. measures (Art. 61 UNCLOS).

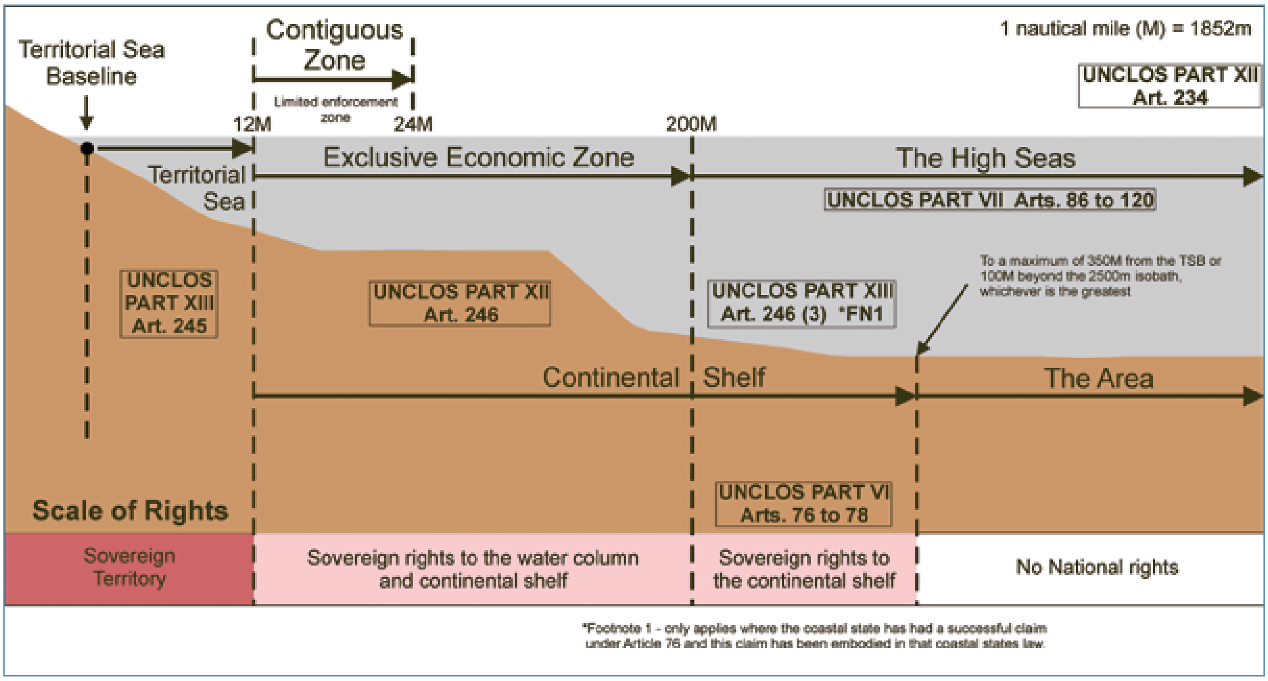


Fig. 1.14 Maritime zones as defined by the United Nations Convention on the Law of the Sea (UNCLOS). Credit: Alan Evans and Rolly Rogers (NOC) www.unclosuk.org

1.5 Scope of this report

This report is the output of the European Marine Board working group (WG) on deep-sea research. The WG was launched in January 2014 to respond to the commercial interest – and growing capabilities – to exploit the deep sea, and the need to articulate a deep-sea research vision to ensure that the science base exists to underpin sustainable development in the deep sea whilst maintaining ocean health. The EMB WG consisted of 14 experts spanning natural sciences, socio-economics and marine law who examined the key scientific, societal, economic, environmental and governance drivers and issues confronting the deep sea and the exploitation of its resources.

The WG also engaged with wider stakeholders spanning the deep-sea research community, industry (deep-sea mining, oil and gas, renewable energy, marine biotechnology and deep-sea fisheries), civil society (NGOs) and policy through stakeholder workshops and an online consultation. This included an assessment of the current landscape of deep-sea research in Europe and perspectives and trends in deep-sea research investments across Europe including current infrastructure and research capabilities. The WG also addressed key societal opportunities in the deep sea including both well-established sectors, such as oil and gas extraction and fishing, and also new forms of exploitation such as mining, biodiscovery and CO_2 sequestration, and how deep-sea research can inform these activities with expert knowledge. The WG identified gaps and priorities (thematic and geographical) for future European research efforts (in the context of international research efforts).

This report delivers recommendations for future European deep-sea research in the context of societal challenges and policy needs that can be taken up by policy makers and funders to inform future research agendas, underpin economic development and impact monitoring and provide further guidance on the holistic, ecosystem-based approaches to ocean stewardship and governance that are required to achieve ecological sustainability of the deep sea.

Fig. 1.15 Deep-sea crab at 700m depth off the coast of Ireland

Credit: MARUM

Credit: Andrew Gooday

Credit: OET

Credit: Alex Rogers

Credit: Ifremer

Credit: NIOZ

Credit: NOAA

Credit: Henry Ruhl

Credit: MARUM

Fig. 1.16 Deep-sea biodiversity.
Top row (left to right): Trochamminacean sp. B (a foraminiferan protist) from 10,897m water depth, western equatorial Pacific; Deep sea blue anemone found on the periphery of an active hydrothermal vent site along the Galapagos Rift.
Second row (left to right): Brisingid seastar, Melville Bank, SW Indian Ocean; Giant *Riftia pachyptila* in their habitat in 2,630m water depth on the East Pacific Ridge, during the oceanographic capaign Phare.
Third row (left to right): A deep-sea red crab lurking on the periphery of a seep; A dumbo octopus uses his ear-like fins to slowly swim away – this coiled leg body posture has never been observed before in this species.
Bottom row (left to right): *Enypniastes* (a genus of deep-sea sea cucumber); Anglerfish at a depth of 320m in the western Mediterranean Sea.

2

The blue economy

Credit: MARUM

2.1 The Challenge: Development of a sustainable blue economy

World population is now predicted to reach between 9 and 12 billion by 2100 (Gerland *et al.*, 2014). This is coupled with societal changes such as a growing middle class with increased per capita resource consumption. The result is intensifying global competition for natural resources putting pressure on the earth's environment. Feeding, fuelling and healing the world have become major concerns of today's society. Worries about food security, access to raw materials (including base and strategic minerals) and biotechnological resources are increasing, and a series of unmet medical needs still prevail today despite the technological evolution we have seen so far. Human activities on land contribute to many of these issues as they are insufficient to meet demand now and in the future. The ocean is the next frontier of human exploitation, but our activities have tremendously increased the pressure on marine ecosystems, including the deep sea mostly through activities such as bottom trawling, dumping, pollution, hydrocarbon extraction, and, more recently, bio-prospecting (Ramirez-Llodra *et al.*, 2011). Not too far in the future, these impacts could lead to detrimental effects on the wellbeing of Europe's citizens and ecosystems if not avoided, mitigated or reduced.

There remains a lack of clear guidelines as to how the sustainable use of deep-sea natural resources may be achieved. We need a better understanding of the links between the diversity of deep-sea communities, the underlying functioning of these ecosystems, and their response to disturbance and stress. Modern mapping exists over only a very small portion of the seafloor, amounting to just 18% of the deep-sea area of the European EEZ (Galparsoro *et al.*, 2014). Sampling of the seafloor and sub-seabed biosphere are still very sparse, despite the enormous efforts undertaken within the framework of international scientific programmes such as the Census of Marine Life (CoML) and the Ocean Drilling Program (ODP). Hence, much about the composition and global distribution of biotic and abiotic resources of the deep sea, their importance for global biogeochemical cycles, and the potential impacts of exploitation on ocean chemistry and ecosystems is still incompletely understood. This lack of knowledge hinders decisions on whether or not we exploit such deep-sea resources and how to manage such activities should we decide they are necessary.


Credit: MARUM

Fig. 2.1 Nkhomo-benga peacock fish over cold-water corals and yellow anemones at 650m below the surface in the western Atlantic.


Credit: NautilusMinerals

Fig. 2.2 Collecting samples from a deep-sea vent chimney using an ROV robotic arm.

Chapter 2 cover image: Black smoker in 2,980m of water on the Mid-Atlantic Ridge

2.2 Definitions of the blue economy

The concept of a "blue economy" came out of the 2012 Rio+20 Conference and has its emphasis on sustainable development, conservation and management. This sustainability agenda is based on the premise that healthy ocean ecosystems are more productive, resilient and represent the only way that ocean-based economies can be sustained over the long term. It is worthwhile considering what the terms sustainable "blue economy" and "blue growth" mean in more detail. According to the United Nations Food and Agriculture Organization (UN FAO), blue growth looks to further harness the potential of oceans, seas and coasts, but certain preconditions are necessary:

- Eliminate harmful fisheries subsidies that contribute to overfishing and instead incentivize approaches which improve conservation, build sustainable fisheries and end illegal, unreported and unregulated fishing;
- Develop those sectors with a high potential for sustainable jobs such as aquaculture, tourism, marine biotechnology, taking into account the environmental impacts of such activities in the marine systems;
- Ensure tailor-made measures that foster cooperation between countries;
- Act as a catalyst for policy development, investment and innovation in support of food security, poverty reduction, and the sustainable management of aquatic resources.

In Europe, the European Commission launched the Blue Growth strategy in 2012 as the maritime contribution to achieving the goals of the Europe 2020 strategy for smart, sustainable and inclusive growth. This defines the blue economy as:

"All the economic activities related to the oceans, seas and coasts. This included the closest direct and indirect supporting activities necessary for the functioning of these economic sectors, which can be located anywhere, including in landlocked countries"

(European Commission, 2012a).

Further information on the Blue Growth strategy and the relevance for deep-sea research is presented in Box 2.1.

BOX 2.1 EUROPE’S BLUE GROWTH STRATEGY AND WHAT THIS MEANS FOR DEEP-SEA RESEARCH

In 2012 the European Commission launched the Blue Growth strategy as the maritime contribution to achieving the goals of the Europe 2020 strategy for smart, sustainable and inclusive growth (EC, 2012a). The strategy highlights five sectors that have high potential for sustainable jobs and growth: blue biotechnology, aquaculture, seabed mining, ocean energy, and maritime and coastal tourism. All of these sectors have potential growth opportunities in the deep sea, in varying stages of development (see Chapter 3). The deep sea is also highly relevant for the essential components of the Blue Growth strategy, namely: marine knowledge, marine spatial planning and integrated maritime surveillance. For example, as competition for freshwater and coastal waters increases with population growth, offshore and deep-sea options for sectors such as renewable energy, aquaculture and maritime tourism seem more attractive and viable with regards to marine spatial planning. In addition, as technology and marine knowledge improves, blue biotechnology and seabed mining in the deep sea are becoming more attractive options for future resource exploration and exploitation, however, treated with heavy skepticism from some individuals and organizations. Continued production of high quality knowledge of our marine environment remains crucial to underpin this development, especially in a system such as the deep sea of which we know so little about.

The European Commission conducted a consultation with stakeholders in maritime sectors as to what should be done with respect to development of the blue economy in Europe and where potential bottlenecks and opportunities lie (EC, 2012b). They received 66 responses from national and regional governmental institutions and the private sector. A number of themes prevalent in the EC (2012b) report are relevant to the present report:

- Access to finance and support for research, development and innovation are major requirements for the development of the blue economy;
- The importance of focusing existing funds on marine and maritime projects;
- The necessity of bridging gaps between science, industry and education, whether for training purposes or for research;
- Strengthening of networks of maritime clusters;
- Addressing of national and European-level governance issues that act as a bottleneck to blue growth, especially with reference to integrated maritime spatial planning;
- The possibility of generating significant environmental benefits through the development of innovative projects (e.g. renewable energy projects combined with provision of other services);
- Need to improve understanding of the value of ecosystem services;
- The importance of seabed mapping for sustainable exploitation of marine resources.

The EC (2014) also identified a number of barriers to achieving the full potential of blue growth for Europe, namely:

- Gaps in knowledge and data about the state of our oceans, seabed resources, marine life and risks to habitats and ecosystems;
- Diffuse research efforts in marine and maritime science that hinders interdisciplinary learning and slows the progress of technological breakthroughs in key technologies and innovative business sectors;
- Lack of scientists, engineers and skilled workers able to apply new technologies in the marine environment.

Basic underpinning knowledge is also a main focus of the Marine Knowledge 2020 Roadmap published by the EC (2014b). This document emphasizes basic research on seabed mapping, geology, biology and chemistry as well as human impacts. It also promotes a more integrated approach to data collection, curation and storage across the EU for the purposes of promoting the blue economy.

2.3 Human impacts on the ocean and deep sea

"A lot of basic research is still needed in the deep sea before a solid blue economy can be properly developed."
Deep-sea researcher, Spain

The industrialization of ocean space as well as human population growth and the associated increased inputs of anthropogenic materials into marine ecosystems now mean that the footprint of impacts extends over most of the global ocean (Halpern *et al.,* 2008). With increasing demand for products traditionally extracted from the oceans and new opportunities being identified for industrial exploitation there is an opportunity for novel economic activities but it is inevitably linked to the danger of growing pressure on marine ecosystems. An example of how poorly regulated activities in the deep ocean can lead to resource depletion and environmental damage has been provided by deep-sea fisheries (Carreiro-Silva *et al.*, 2013). Unregulated, unreported or poorly managed fishing in the deep sea has led to the rapid depletion of stocks of fish that live there, as well as the destruction of vulnerable marine ecosystems located on the seabed.

The deep sea is a food-limited environment, with the exception of ecosystems such as vents and seeps where chemical energy allows the *in-situ* fixation of carbon, so called chemosynthesis or chemoautotrophy. This means that many deep-sea species are characterized by slow growth rates and low levels of recruitment. In the case of deep-sea fish, which in some cases live for more than 100 years, this renders them exceptionally vulnerable to overexploitation. However, by-catch fish species, such as deep-water sharks, are also vulnerable to depletion. Deep-sea fishing methods that involve contact of the gear with the seabed, especially trawling, are particularly destructive to fragile deep-water species such as habitat-forming corals. These animals have been found to live for hundreds to thousands of years whilst deep-sea coral reefs may exist for more than ten thousand years at a single location (Robinson *et al.*, 2014). Such ecosystems have a low resilience to fishing impacts and evidence has been gathered globally of the damage that they have sustained since the 1960s. In some cases, such deep-sea fisheries would not have been economically viable without government subsidies. To determine the scale and significance of an impact, the international community have developed the concept of Significant Adverse Impacts (see Box 2.2 below and FAO, 2009). Whilst the standard definition pertains to deep-sea fishing, it is applicable to other human impacts on deep-sea ecosystems.

Credit: Giovanni Marola

Fig. 2.3 A close-up of a deep-sea red coral, Corallium sp. Red and pink coral are the most valuable of all deep-sea precious corals. This animal and others like it are used to make jewelry and home decor items that are sold as necklaces, earrings, and objet d'art, and sometimes even lamp stands. There are no international agreements to monitor the international trade of these precious coral species. International trade is decreasing the ability of these species to survive.

Recent events surrounding the *Deepwater Horizon* disaster also demonstrate the challenges of newer deep-sea activities (e.g. White *et al.*, 2012; Montagna *et al.*, 2013) and particularly the issues associated with inadequate regulation, risk assessment, and development of technologies for dealing with accidents in such ecosystems. It is also important to stress that the deep ocean is not immune to other human threats as a result of its distance from the surface (Ramirez-Llodra, 2011; Pham *et al.*, 2014). The ocean was historically a repository for litter from shipping, of particular note being clinker, waste from coal-fired boilers on steam ships. Although dumping at sea was banned by the London Convention (1972) it is estimated that more than 636,000 tonnes per year of litter is still discarded into the ocean from shipping (Ramirez-Llodra *et al.*, 2011). Litter from terrestrial sources is also a major issue, particularly plastics. Recently, microplastic fibres have been discovered as being ubiquitous in deep-sea ecosystems and it appears the deep-ocean may be a major sink for this type of material (Woodall *et al.*, 2014). The consequences of such litter for deep-sea ecosystems are currently not understood (Ramirez-Llodra *et al.*, 2011). There has also been dumping of sewage, mining waste, dredge spoil, pharmaceuticals and radioactive waste in the deep sea although most of these activities have now ceased (apart from illegal dumping). There is evidence that chemical contaminants are accumulating in the deep sea including persistent organic pollutants (POPs), e.g. polychlorinated biphenyls (PCBs), heavy metals , e.g. Mercury (Hg), radioelements, pesticides, herbicides and pharmaceuticals. Again the biological effects of such contaminants are unknown (Ramirez-Llodra *et al.*, 2011). They are being taken up by deep-sea organisms such as fish and crustaceans and are subject to biomagnification (accumulation up the food chain). Climate change is also likely to influence the deep-sea fauna through the effects of warming, acidification and reduced oxygen concentrations in the water column and in benthic ecosystems (e.g. Jones *et al.*, 2014, Mora *et al.,* 2013, Monteiro *et al.*, 1996).

To foster sustainable blue growth adequate to our current societal needs and profitable for all stakeholders (both private and public), the right balance must be found between conservation and exploitation of the oceans, especially in the deep sea. This is because many aspects of deep-sea ecosystems render them particularly vulnerable to human disturbance from which recovery is slow or non-existent.

BOX 2.2 SIGNIFICANT ADVERSE IMPACTS

The concept of "Significant Adverse Impacts" was considered during the preparation of the United Nations Food and Agricultural Organisation (UN FAO) International Guidelines for the Management of Deep-Sea Fisheries in the High Seas (FAO, 2009). These guidelines were produced in response to increasing evidence of depletion of stocks of deep-sea fish as well as destruction of associated ecosystems by deep-sea bottom trawling, which led to several UN General Assembly Resolutions calling for improved management of deep-sea fisheries (Rogers and Gianni, 2010). Significant Adverse Impacts were considered by FAO (2009) as:

"Those that compromise ecosystem integrity (i.e. ecosystem structure or function) in a manner that: (i) impairs the ability of affected populations to replace themselves; (ii) degrades the long-term natural productivity of habitats; or (iii) causes, on more than a temporary basis, significant loss of species richness, habitat or community types. Impacts should be evaluated individually, in combination and cumulatively.

When determining the scale and significance of an impact, the following six factors should be considered:

I. The intensity or severity of the impact at the specific site being affected;
II. The spatial extent of the impact relative to the availability of the habitat type affected;
III. The sensitivity/vulnerability of the ecosystem to the impact;
IV. The ability of an ecosystem to recover from harm, and the rate of such recovery;
V. The extent to which ecosystem functions may be altered by the impact; and
VI. The timing and duration of the impact relative to the period in which a species needs the habitat during one or more of its life history stages.

Temporary impacts are those that are limited in duration and that allow the particular ecosystem to recover over an acceptable time frame. Such time frames should be decided on a case-by-case basis and should be in the order of 5-20 years, taking into account the specific features of the populations and ecosystems.

In determining whether an impact is temporary, both the duration and the frequency at which an impact is repeated should be considered. If the interval between the expected disturbance of a habitat is shorter than the recovery time, the impact should be considered more than temporary. In circumstances of limited information, States and RFMO/As should apply the precautionary approach in their determinations regarding the nature and duration of impacts."

Whilst this definition of Significant Adverse Impacts pertains to deep-sea fishing (hence reference to RFMOs; Regional Fisheries Management Organisations) the definition is applicable to other human impacts on deep-sea ecosystems. Significant Adverse Impacts, as defined by FAO (2009) invariably result in loss of deep-sea ecosystem services (Armstrong *et al.*, 2012). This is because loss of biodiversity (populations, species, habitats and ecosystems) degrades ecosystem functions which underpin services to humankind.

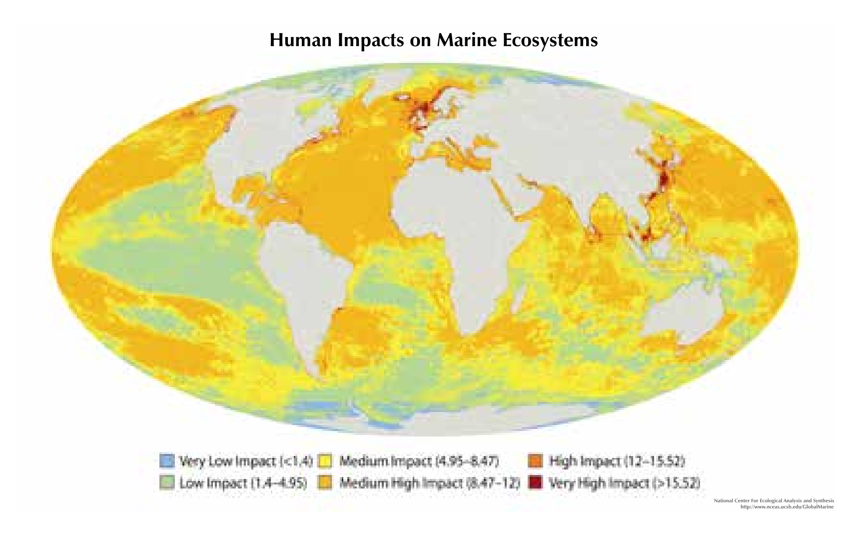


Fig. 2.4 Map of the human footprint of impacts on the global ocean (Halpern *et al.*, 2008)

It is clear that the deep sea has potential as an important area for growth in the maritime or "blue" economy of the European Union. This is both through the extraction of resources within the European EEZ or in areas beyond national jurisdiction including the high seas and seabed but also in supporting such activities through technology development, ocean engineering, research, risk assessment, and planning whether the activities should be for operations or for exceptional occurrences. Such activities focus on European waters and the adjacent high seas areas but also extend to overseas territories and the global high seas. An example of this is the building of the enormous excavating machines for exploitation of seabed massive sulphides within the EEZ of Papua New Guinea by the Chinese owned Soil Machine Dynamics. Overall, it has been estimated that the annual turnover from deep-sea mining could rise from almost nothing in the present day to €5 billion in the next ten years and €10 billion by 2030 supplying as much as 10% of the world's minerals (EC, 2012). It is not clear, however, that such industries are environmentally sustainable over the long term because of, for example, the impacts of habitat destruction and disposal of large amounts of debris or mining waste on the seabed. This needs to be properly resolved before any exploitation phase and projects, e.g. European Framework 7 project MIDAS are investigating such impacts (see Box 2.3). Management of human activities in the deep sea to attain the goal of maintaining ecosystem health will also rely on marine research and technology development. There is therefore a clear requirement for ensuring that there is sufficient technical and human infrastructure to meet the research needs of the deep blue economy, as well as adequate management and regulation of deep-ocean industry, both now and in the future. It is also noted that as knowledge and our understanding increases on the impact of blue growth, there may be a need to establish limits to it, in particular if this growth is in addition to impacts on the ocean from continuing unsustainable growth on land.

BOX 2.3 THE MIDAS PROJECT: MANAGING IMPACTS OF DEEP SEA RESOURCE EXPLOITATION

The MIDAS project is a multidisciplinary research programme that brings together 32 organizations from across Europe, including scientists, industry, social scientists, legal experts, NGOs, and SMEs, to investigate the environmental impacts of extracting mineral and energy resources from the deep-sea environment. The project focuses research on the nature and scales of the potential impacts of mining, including 1) the physical destruction of the seabed by mining, creation of mine tailings and the potential for catastrophic slope failures from methane hydrate exploitation; 2) the potential effects of particle-laden plumes in the water column, and 3) the possible toxic chemicals that might be released by the mining process and their effect on deep-sea ecosystems. Key biological unknowns, such as the connectivity between populations, impacts of the loss of biological diversity on ecosystem functioning, and how quickly the ecosystems will recover will be addressed. A key component of MIDAS is the involvement of industry and other stakeholders to find feasible solutions and develop recommendations for best practice in the mining industry.

MIDAS is funded under the European Commission's Framework 7 programme and started on 1 November 2013 for a period of 3 years.

http://www.eu-midas.net/

3

Opportunities and challenges of human activities in the deep sea

Credit: Siemens

3.1 Introduction

In this chapter we review the current and future economic opportunities in the deep ocean, the challenges that such opportunities present and future research priorities by sector. This chapter also includes a review of wider activities, e.g. military activity or waste disposal where human activity is taking place in the deep sea. In such cases, the activities may have generated significant environmental impacts in the deep ocean and are in need of research to assess the extent and severity of the problem, as well as potential solutions, whether there needs to be further development of policy frameworks to govern such activities, and whether further research infrastructure is required to address these needs. In the following sections, we also attempt to examine the pros and cons of economic activities in the deep sea whilst recognizing that such judgements imply a black and white perspective, in other words the rights and wrongs of such activities. This approach is obviously a simplification as very often positive and negative effects will depend on the scale of the activities, the size and biological characteristics of the ecosystem impacted, and the trade off in terms of economic benefit, and also the potential impacts alternatives may entail.

Fig. 3.1
Top row: Commercial species of lobster, *Jasus*, from Sapmer Bank SW Indian Ocean (left); NaKika, operated by British Petroleum, is the first floating production storage facility in the Gulf of Mexico. It is also the deepest permanently moored facility at a water depth of 1,932m (right).
Bottom row: Bubbles of methane gas rise through a mussel bed at the Pascaguola Dome (left); The capstan of a twentieth century warship is covered and damaged by derelict fishing gear (right).

Chapter 3 cover image: As the only laboratory of its kind in the world, Siemens scientists in Trondheim study how the components of a power grid behave under extreme water pressure. In the future, the system will supply major oil and gas plants with energy on the seabed at a depth of 3,000m.

3.2 Opportunities: Living resources

3.2.1 Fishing

Credit: Alex Rogers

Fig. 3.2 Orange roughy, *Hoplostethus atlanticus*, Melville Bank, SW Indian Ocean. Also known as deep-sea perch, orange roughy are found in the cold, deep waters of the Pacific, Atlantic and Indian Oceans. Commercial fishing of this long-lived deep-sea species is relatively new but has already led to severe decline of populations.

3.2.1.1 Introduction

Fishing has shown a continuous increase in depth since the 1950s (Watson and Morato, 2013) with European bottom fishing now exceeding 200m as an average depth of fishing (Villasante *et al.*, 2012) and some fisheries fishing as deep as nearly 2,000m (Rogers and Gianni, 2010). When targeted at low productivity deep-sea species, such as orange roughy (Fig. 3.2), oreos (Oreosomatidae) and some grenadiers (Macrouridae), these fisheries have shown a history of rapid depletion. As a result of the behavior of some of these species, for example where the response to a threat is to dive to the seabed (AD Rogers pers. obs.), many of these fisheries were undertaken using bottom trawling. Robust bottom trawl gear targeted at habitats such as seamounts which host communities of vulnerable marine species such as cold-water corals have led to serious damage to the ecosystems of which the target species are a part (e.g. Althaus *et al.*, 2010; Williams *et al.*, 2011). Many of these fisheries were initiated before there was adequate scientific knowledge of the target fish stocks for management purposes and in the absence of consideration of the wider ecosystem impacts by both the fishing industry and fisheries managers.

To address the lack of sustainable management practices by governments and the deep-sea fishing industry, the International Guidelines for the Management of Deep-Sea Fisheries in the High Seas (hereinafter referred to as the FAO Guidelines), negotiated under the auspices of the UN FAO, established globally agreed sets of criteria, standards, and recommendations for implementing the UNGA resolutions for the management of these fisheries (FAO, 2008). In response, RFMOs responsible for deep-sea bottom fisheries on the high seas initiated a number of measures, all of which require basic research to be implemented effectively. For example, seabed mapping and surveying is needed to identify areas known to, or likely to host VMEs so they can be protected from bottom-trawling. Implementation of such measures has been patchy amongst RFMOs and amongst their member states (see Rogers and Gianni, 2010; Weaver *et al.*, 2011; Gianni *et al.*, 2011). In Europe, there has been a continual growth in the capacity of the deep-sea fishing fleet with an increase of 34-44% between 1990 and 2006 and a subsequent increase of approximately 3% per annum (Villasante *et al.*, 2012). The catch figures for species regulated as 'deep-sea' species by NEAFC are 167,439 tonnes across 39 species (2013 figures), most of which is taken within EEZs, with the largest catches being of greater silver smelt, Greenland halibut, ling and tusk (NEAFC, 2015). This is compared with a total fish catch of 5,670,000 tonnes (2012 figures[3]) across all fish products for the EU and 10 million tonnes for the entire NE Atlantic.

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[3] http://ec.europa.eu/eurostat/statistics-explained/index.php/Fishery_statistics_in_detail

3.2.1.2 Current management of deep-water fisheries in Europe

There have been marked improvements in the management of deep-water fisheries in this region, primarily as a result of an EU regulation for the management of deep-sea fisheries in both EU waters and high seas areas in the Northeast Atlantic adopted in 2002 (updated in 2008)[4] and the measures taken by NEAFC in response to the UNGA resolutions. Two ICES scientific Working Groups, WGDEC and WGDEEP, provide Europe and NEAFC with advice on preventing impacts to VMEs and on the level at which quotas should be set. The Working Group on Biology and Assessment of Deep-Sea Fisheries Resources (WGDEEP) undertakes assessments using a variety of methods, which depend largely on data quality generally, every two years for each species or stock they analyse. Whilst many stocks of deep-sea fish remain in a depleted state (e.g. orange roughy) the move to provide advice on stock size and quotas by WGDEEP is a significant improvement over the previous situation where deep-sea stocks were fished without restrictions. In addition there has been investment from the EU in research projects to try and improve the assessment of deep-water fisheries in the NE Atlantic. An example of these under the EU Framework 7 programme was DEEPFISHMAN which aimed to develop more effective short-term management strategies for deep-sea fisheries whilst also enabling a long-term framework identifying data gaps and areas of scientific work required to achieve greater sustainability in the future[5].

Significant issues remain within deep-water fisheries in the NE Atlantic. Some of these problems are largely political, for example, between 2002, when the EU first began setting quotas for deep-sea species, and 2011 in more than 60% of cases the quotas exceeded the scientific recommendations (Villasante *et al.*, 2012). This situation remained as late as November 2014 when quotas for deep-sea species in various fisheries management sub-areas were set above scientific recommendations, in one case exceeding it by 225% (red seabream; NEF, 2014). Other issues are more relevant to science and thus require attention within this report. For example, approximately half of the species listed in the EU deep-sea fisheries regulation are not subject to any quotas or catch limits. Other significant problems remain with these fisheries in terms of the use of destructive fishing methods (e.g. bottom trawling) and lack of provision of data on catches to WGDEEP as well as under-reporting and possible misreporting of catches by some European States (ICES, 2014). Also, there is a lack of data pertaining to a number of the stocks preventing assessment of their current state (e.g. round-nose grenadier on the Mid-Atlantic Ridge; ICES, 2014). The Working Group on Deep-Sea Ecology (ICES) assesses scientific information on the presence of VMEs in the deep sea off the European margin and in the NEAFC area. This advice is passed on to fisheries managers and has translated into the initiation of spatial conservation measures to prevent damage from bottom trawling to VMEs. WGDEC have assessed the efficacy of these protected areas in the NEAFC area and have found that generally vessel monitoring system (VMS) data suggests that legal fishing vessels are avoiding fishing in protected areas (WGDEC, 2015). However, it has recently been reported that concerns have been raised with respect to fishing in closed areas at NEAFC[6]. This issue will be addressed at future meetings by the RFMO.

As a result of known impacts of deep-sea fishing methods, the European Union is currently discussing proposals to put stronger regulations in place for deep-sea trawling, including the proposal for a ban on deep-sea trawling below 800m. However, there is growing scientific evidence to limit bottom trawling to the upper 600m of the ocean (Clarke et *al.,* 2015) in order to maximize biodiversity preservation (e.g. 85% or more of corals). A depth ban below 600m would have

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[4] http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52012PC0371

[5] http://wwz.ifremer.fr/deepfishman/Project-description/Description-of-the-work)

[6] http://eu.savethehighseas.org/north-east-atlantic-fisheries-commission-makes-limited-progress-to-protect-deep-sea-species-and-habitats/

minimal commercial impact since the percentage of a catch that is commercially viable plummets below 600m (Clarke *et al.*, 2015).

3.2.1.3 Legal and institutional framework

Exploitation of deep-sea fisheries in the NorthEast Atlantic is managed through a combination of bilateral and multilateral agreements and unilateral setting of quotas by coastal states in the region, with a scientific advisory organization, The International Council for Exploration of the Sea (ICES) playing a key role (see Box 3.1). The 1980 Convention on Future Multilateral Co-operation in North-East Atlantic Fisheries[7] (NEAFC Convention) has five parties (Denmark in respect of the Faroe Islands and Greenland, EU, Iceland, Norway, and the Russian Federation). Its objective is to ensure the long-term conservation and optimum utilization of the fishery resources, providing sustainable economic, environmental, and social benefits. NEAFC has amended its convention to bring it up-to-date with developments in international law, and provide a mandate to regulate fisheries with regard to the marine ecosystem and marine biodiversity, by using the precautionary approach and ecosystem-based management. However, several key conservation provisions of the UNFSA have not been incorporated into the new convention text and it is not yet in force.

BOX 3.1 ICES

The Convention for the International Council for the Exploration of the Sea (ICES)[8] was established in 1902 and works in fisheries, oceanography, and environmental sciences, including the study of marine pollution. As the oldest intergovernmental marine science organization in the world, the main focus of ICES has continued to be on international cooperative scientific studies. A major responsibility for ICES is the provision of scientific advice for fisheries conservation and protection of the marine environment to intergovernmental regulatory commissions[9], the European Commission, and the governments of ICES member countries. ICES is a forum for the promotion, coordination, and dissemination of research on the physical, chemical, and biological systems in the North Atlantic and adjacent seas such as the Baltic Sea and North Sea, and advice on human impacts on its environment, in particular fisheries effects in the Northeast Atlantic. In support of these activities, ICES facilitates data and information exchange through publications, working groups and meetings, in addition to functioning as a marine data centre for oceanographic, environmental, and fisheries data. For deep-sea fisheries ICES hosts two main expert groups: The Working Group on Deep-Sea Ecology (WGDEC)[10] and The Working Group on Biology and Assessment of Deep-Sea Fisheries Resources (WGDEEP)[11]. These groups have made significant contributions to improving the science-based management of deep-sea fisheries in the NE Atlantic.

http://www.ices.dk

In addition to the arrangements listed above, there are several other regional arrangements, such as coastal state agreements on fisheries management. These are often complex consisting of a multilateral agreement as well as a number of supplementing bilateral agreements renewed on an annual basis. They include some major deep-sea fisheries such as blue whiting[12], which are high-productivity species. Such arrangements also define the scope of NEAFC management of the high seas portion of deep-sea stocks. Also, one of the international tuna commissions is relevant in this context. The International Convention for the Conservation of Atlantic Tuna[13] has a management area overlapping that of NEAFC[14].

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[7] http://neafc.org/basictexts

[8] http://www.ices.dk/aboutus/convention.asp

[9] NEAFC, HELCOM, OSPAR, NASCO, Norway-Russia Fisheries Commission, Norway-EU Fisheries Cooperation.

[10] http://www.ices.dk/community/groups/7 Pages/WGDEC.aspx

[11] http://www.ices.dk/community/groups/Pages/WGDEEP.aspx

[12] http://www.regjeringen.no/upload/FKD/Vedlegg/Kvoteavtaler/2011/Kolmule/Agreed_record_Blue_whiting_2011.pdf

[13] http://www.iccat.int/en/

[14] http://www.wcpfc.int/convention-area-map

3.2.1.4 Pros

At least some deep-sea fisheries resources can be sustainably fished if sufficient scientific data is gathered to allow accurate assessment of stock size and appropriate harvesting levels. They can thus contribute to local and global supplies of fish for food and for other purposes (e.g. animal feed). Such fisheries can be particularly important at local levels where they can supply high value deep-water species into local markets, restaurants and hotels (e.g. some Atlantic islands such as the Azores, Madeira, and the Canaries). Some deep-sea fish can be viewed as “luxury” species sold into markets in wealthy countries such as the US, Europe, and Japan where they can fetch high prices.

3.2.1.5 Cons

As outlined above, many deep-sea fisheries are unsustainable with respect to levels of exploitation and the environmental damage incurred by the methods of fishing. In some cases, where deep-sea fish species are located in highly biodiverse ecosystems such as seamounts where fragile biologically structured habitats such as cold-water coral reefs occur, it may be the case that such fisheries are environmentally unsustainable and should not take place. The expense and difficulty in collecting data on target and bycatch species of deep-sea fisheries as well as on the distribution of VMEs within areas fished mean that attaining the goal of sustainable management of deep-sea fisheries will continue to be a difficult and expensive goal to achieve. In situations where data are poor, a highly precautionary approach is required in the management of deep-sea fisheries potentially even requiring moratoria until the resource and the environment it lives in are more fully understood. Another issue with deep-sea fishing is the great distance vessels must travel to fishing grounds and the power required to use certain fishing gears to catch them (e.g. active gears like trawls). This means that industrial deep-sea fisheries tend to be carbon intensive. They are also likely to be taking advantage of subsidies such as fuel subsidies to maintain their profitability. The operation of distant fisheries also present significant problems in monitoring, control and surveillance to ensure compliance with fisheries regulations such as closed areas.

3.2.1.6 Alternatives

Deep-sea fisheries in general represent a very small part of the global fish catch and this holds true for the NE Atlantic. An alternative to targeting such fish stocks is better management of shallow-water resources which will lead to greater fisheries yields for less effort and lessen the need for deep-sea fishing. Aquaculture has been termed the ‘Blue Revolution’ as a potential answer to overfishing and by 2015, the world will be consuming more farm-raised fish than wild caught. Offshore aquaculture is being seen as a solution to make aquaculture more sustainable and to help supplement onshore farms in the face of ever growing demand. Technology has steadily improved over the past decade making offshore aquaculture more feasible, with better designed pens (often spherical) that can withstand open ocean conditions and decrease the number of fish escapes. Because of the high fixed costs associated with this type of activity, offshore farming must be carried out on a large scale. For example, a minimum level of 10,000 tonnes per year, per operation would be required to make Atlantic salmon economically viable. Currently, there are many pilot projects taking place globally for offshore aquaculture. However, scaling up, including larger pens, better technology, and more automation is an issue. An example is the Velella Project, being developed by Kona Blue, Kampachi Farms and

© Kampachi Farms, LLC, Photo credit: Jeff Milisen

Fig. 3.3 Offshore aquaculture using submerged cages. Fish farming in the deep-sea (i.e. 200m or more below the sea surface) is not currently operational, although some test studies are ongoing, e.g. http://www.kampachifarm.com/offshore-technology/ .

other partners, whereby large spherical cages with a high level of automation are being developed to farm fish in the deep sea (see Fig. 3.3 for technology in offshore surface farms). Though a successful test has been performed, Kampachi Farms estimates that the technologies required to support a commercial drifter farm (unanchored, free-drifting fish culture system in 3,000-4,500m water) is probably 10-15 years away. Research is still needed on alternative, sustainable feed material, fish escapes, overuse of antibiotics and disease. Scientific research is key to resolving these issues, an example of which is the recent successful production of omega-3 oils by transgenic camelina or false flax plants (*Camelina sativa*; Usher *et al.*, 2015). Such a source of omega 3 may form an alternative source for aquaculture feed for this essential nutrient to fish meal.

Another alternative is to de-industrialize deep-sea fisheries and to move over to smaller vessels. This is only possible where deep waters are located close to shore (e.g. oceanic islands) but one case study has shown that such shifts can lead to higher employment, better catches, higher value fish, are less fuel intensive and more sustainable both in terms of targeted stocks and the habitats they live in (Carvalho *et al.*, 2011).

3.2.1.7 Research questions

Better scientific data are required on almost every aspect of deep-sea fisheries including data on the targeted fish, non-target (bycatch) species, ecosystems in which the fishing takes place, and on what species are caught, how much and where. Many of these issues relate to the wider ecosystem-level impacts of deep-sea fishing and thus require interdisciplinary approaches with input from biological and physical sciences as well as significant infrastructure (e.g. ROVs, AUVs) which lay outside the scope of government-funded fisheries laboratories. In addition, the development of better tools to model deep-sea fisheries, so that they can make more accurate predictions on what levels of catch are appropriate for deep-sea fish stocks requires alternative approaches and input from a range of scientific expertise such as represented in the European Framework 7 DEEPFISHMAN project (see above). Technical modifications to fishing methods may also require research to provide less destructive methods of fishing that more precisely target the species that fishers wish to catch. Reasons that EU quotas are often set above scientific recommendations also need to be researched and solutions found in terms of communicating to policy makers that such action is unsustainable. Better understanding must also be reached in terms of the role of subsidies in maintaining the deep-sea fishing industry and, overall how economically sustainable they are (for more information see Cordón Lagares *et al.*, 2014; and specifically regarding food security implications see Sumalia *et al.*, 2013).

Monitoring, control, and surveillance (MCS) of deep-sea fisheries also requires improvement and the answer to this lies with developing technologies in which Europe has a strong lead. Improved MCS will need approaches that involve fusion of data from a number of different sources including satellite-based remote sensing (vessel-monitoring systems, automated identification systems, synthetic aperture radar, optical sensors, radar, and phone transmissions), autonomous surface vessels, autonomous underwater vessels, gliders, long-range drones, aerostats, moored monitoring installations (e.g. passive acoustic sensors), unmanned platforms, and on board real-time video monitoring. The European Framework 7 and Horizon 2020 programmes have funded the testing and development of some of these technologies but there is scope for further development of both different platforms as well as sensors. Such systems should be incorporated with the European Integrated Maritime Surveillance system[15] but obviously would need to extend beyond European waters into the high seas to cover deep-sea fishing in the NE Atlantic undertaken by European vessels. Links may also be appropriate to the European Defence Agency's MARSUR programme[16]. Such surveillance technologies will also require research into legal implications, both in terms of practical implementation for enforcement and also in terms of privacy issues.

3.2.2 Blue biotechnology

Credit: Greenpeace / Gavin Newman

Fig. 3.4 Close-up of a sea cucumber, Inner Hebrides, North Atlantic. Research conducted as a joint venture with Scottish Association for Marine Science (SAMS) and Greenpeace.

3.2.2.1 Introduction

Blue biotechnology is currently more of a scientific than an economic sector, but its future economic potential is large. Suitable natural sources for the discovery of new potentially bioactive molecules are numerous. The marine environment, harbouring a great variety of organisms differing in their physiology and adaptive capacity, is becoming a hot spot for the identification of marine natural products (MNPs). From the 39 or more animal phyla recognised to date, the majority are represented in the aquatic environment, and many are exclusively marine (Margulis and Schwartz, 1998; Ruggiero *et al.*, 2015). Because of the technical limitations, exploitation of marine organisms started with the collection of large organisms such as red algae, sponges, and soft corals, which were shown to produce a large variety of compounds with unique chemical structures (Gerwick and Moore, 2012) (Fig. 3.5). With the continuous exploitation of the marine environment, attention turned to microorganisms such as marine bacteria and fungi, because of their biological and habitat diversity (e.g. extremophiles found in deep-sea hydrothermal vents), which resulted in the ability to produce metabolites with unique structures (Bhatnagar and Kim, 2010). Because of their broad panel of bioactivities, MNPs are exceptionally interesting high-value ingredients for applications in the pharmaceutical, and health

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[15] http://ec.europa.eu/maritimeaffairs/policy/integrated_maritime_surveillance/index_en.htm

[16] http://www.eda.europa.eu/what-we-do/activities/activities-search/maritime-surveillance-%28marsur%29

industry (see 3.2.2.4) and there is a high level of investment in this from both the private and governmental sectors. For instance, deep sea organisms are revealing properties that could revolutionize our ability to treat human diseases. Examples include Topsentin, a compound isolated from a deep-water sponge *Spongosorites ruetzleri* with anti-inflammatory properties e.g. to treat arthritis (Wright *et al*., 1992) and the recent discovery that deep-sea holothurians (sea cucumbers) have evolved the ability for voluntary and reversible stiffening of regulatory proteins as an act of defence - an attribute that could aid development of microelectrodes for brain implants in the quest to restore motor function in people with paralysis (Scott, 2015). The beauty, cosmetic and well-being industries are also progressively turning to the sea in the search for new ingredients and functionalities (Martins *et al.,* 2014; see 3.2.2.4 and Box 3.2). Furthermore, today we can recognize MNPs in a vast array of applications including agricultural, in food and feed, functional textiles, shipping, aquaculture, in the household, and for domestic consumables.

Marine biodiscovery depends upon access to these marine organisms, collectively termed marine genetic resources (MGR). Several bottlenecks still persist in this field namely biodiversity assessment, technology and legal challenges, the latter being a particular problem in ABNJ. More in-depth studies of the biodiversity of the deep sea are needed in order to better understand what organisms are present and their biochemistry so we can select and evaluate potentially useful services outputs. Technology development for access to the deep sea in a sustainable and economically viable way, for collecting, cultivating and laboratory study of deep-sea organisms, and for sustainable large scale production and manufacturing of products derived from them, needs to be further enhanced and developed. Finally, the legal framework regulating access and utilization of MGR is becoming increasingly dense and complex. The “Nagoya Protocol on Access and Benefit Sharing” or (full title) “The Nagoya Protocol on Access to Genetic Resources and the Fair and Equitable Sharing of Benefits Arising from their Utilization” is an international effort to increase transparency in the discovery of genetic resources and to ensure benefit sharing in a fair and equitable way[17] (Broggiato *et al*., 2014). This creates an important opportunity to develop international rules that stimulate investment in this area, given the potential wider benefits to humankind that come from discovery of new pharmaceuticals and other MNPs.

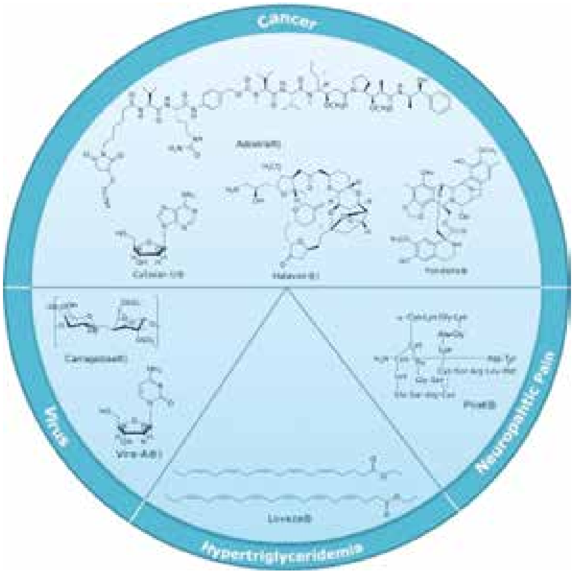

Fig. 3.5 Chemical structures of marine drugs on the market divided by therapeutic area Credit: Martins *et al*., 2014.

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[17] https://www.cbd.int/abs/#tab=0

Aligned with the EU definition of bioeconomy, biotechnology is the key to the production of renewable biological resources and their conversion into food, feed, bio-based products and bioenergy via innovative and efficient tools. The marine environment is the next global frontier in biotechnology and especially to Europe under its Blue Growth strategy. With respect to biological resources, there is a great potential for marine genetic resources in Europe's waters to be used and transformed by biotechnological tools that can open the way to directed strategic scientific research activities and many new innovations that can be translated into economic impact for Europe's growth.

3.2.2.2. Legal and institutional framework

Three main legal instruments contribute to the parameters of the legal regime applicable internationally to biotechnologies: the United Nations Convention on the Law of the Sea (UNCLOS), the Convention on Biological Diversity (CBD) and the Trade Related Intellectual Property Rights Agreement (TRIPS).

The status of marine genetic resources under UNCLOS is unclear. UNCLOS provides that the deep seabed beyond national jurisdiction ("the Area") is subject to the common heritage of mankind regime (Art. 136) and managed by the International Seabed Authority. Article 133 defines resources as "*all solid, liquid or gaseous mineral resources in situ in the Area*." This narrow definition of the resources has led some to posit that the common heritage of mankind regime does not apply to marine genetic resources, though many others disagree. However, what are applicable are the provisions concerning marine scientific research and the preservation of the marine environment in the Area, in the EEZ and on the continental shelf. Moreover, Article 241 provides that "*[marine] scientific research activities shall not constitute the legal basis for any claim to any part of the marine environment or its resources*."

Under the CBD, the exploitation of MGR is to be carried out according to two fundamental principles enshrined in the CBD: (i) the prior and informed consent to access to marine genetic resources and (ii) the fair and equitable sharing of benefits from these resources. The Bonn Guidelines on Access to Genetic Resources and Fair and Equitable Sharing of the Benefits Arising out of their Utilization (UNEP/CBD/COP/6/20) are aimed at facilitating access to genetic resources and ensuring that benefits of any commercialization are duly shared with provider states. Additionally, the CBD framework has expanded with the adoption of the 2010 Protocol on Access to Genetic Resources and the Fair and Equitable Sharing of Benefits Arising from Their Utilization (UNEP/CBD/COP/DEC/X/1). This has led to a gap in the regime of ocean governance under UNCLOS where exploitation of MGRs in ABNJ is largely based on a first come first serve basis with no obligations to share benefits with the international community (Chiarolla, 2014).

The UNGA, adopted on 19 June 2015, mandates for a further process regarding "*Development of an international legally-binding instrument under the United Nations Convention on the Law of the Sea on the conservation and sustainable use of marine biological diversity of areas beyond national jurisdiction*" (Doc A/69/L.65). Here, MGRs are a major theme. The negotiations, which will commence in 2016 by way of a Preparatory Committee, will address "*the conservation and sustainable use of marine biological diversity of areas beyond national jurisdiction, in particular,* *together and as a whole, marine genetic resources, including questions on the sharing of benefits, measures such as area-based management tools, including marine protected areas, environmental impact assessments and capacity-building and the transfer of marine technology."* This may create an important opportunity to develop international rules that stimulate investment in this area, given the potential wider benefits to humankind that come from discovery of new pharmaceuticals and other MNPs.

A further complicating issue here is what exactly is patentable in terms of MGRs. TRIPS require patents for new technologies, provided they involve an inventive step and have industrial application (Chiarolla, 2014). Biomolecules, DNA/RNA constructs, and microorganisms can be replicated in the lab and subject to modification for industrial applications and thus have been considered as patentable. However, WTO members are allowed to prohibit the patenting of animals, plants and biological processes particularly in order to protect public order, morality or public health (Chiarolla, 2014). Thus there are different regulations existing across states although in some cases the genetic material (DNA sequences) have been patented and the species of origin named in the patent applications (Chiarolla, 2014). Furthermore the geographic origin of the patented material, in terms of whether it originated in EEZs or ABNJ is often unclear (Chiarolla, 2014). Such patents, especially when they comprise processes that take place in natureed, risk inhibiting further research on certain MNPs although TRIPS provides that research exemptions may be allow in such cases (Chiarolla, 2014). Work is required to ensure that the gaps between CBD requirements for benefit sharing and TRIPS as applied to marine biotechnological resources. The WTO Doha Ministerial Declaration charged the TRIPS Council with the task of examining the relationship between the TRIPS and the CBD. 52 WTO members agreed to implement a "disclosure of origin clause," i.e., the grant of a patent conditioned on disclosure of the source of the material upon which the invention is based, as a requirement for patent application[18].

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[18] Trade Negotiations Comm., Draft Modalities for TRIPS Related Issues, T/NC/W52 (Jul. 18, 2008).

3.2.2.3 Potential opportunities (Next Generation)

Europe is well-placed to take advantage of deep-sea MNPs, mostly as a result of high-level competencies in research and patenting activities as well as the presence of key commercial players from the cosmetic, pharmaceutical and chemical industries. In this respect, the strong linkages between these industries and the relevant fields of research are important. Accessing financing for development purposes, engaging companies and fostering a stable regulatory framework are crucial for the growth of blue biotechnology. The fastest developing blue markets where marine by-products can have an impact are:

- Unmet medical needs through pharmaceutical development - innovative and novel drug leads;
- Well-being, personal care and cosmetic products – novel bioactive ingredients, and innovative delivery systems; substitution of chemical-based formulations by biobased products (see case study in box 3.2);
- Biomaterials – bioplastics, biopaints, anti-fouling, regenerative medicinal implants and materials, bioconducters and batteries;
- Industrial bio-processes - enzymes, solutions, biofactories;
- Aquaculture, feeding and food – novel species aquaculture (microalgae), feeding composition for fish aquaculture and sustainable novel foods and biomass, nutraceutical and functional food ingredients;
- Biorefineries and CO_2 capture - microalgae;
- Bioremediation – disaster control, wastewater treatments, toxic blooms control
- Agricultural pest control and fertilizers – novel bioactive materials and ingredients.

In order to take these opportunities to the next level in Europe a serious investment in technology development and clear lines of research must be implemented. If the market entry success rates of what is currently being done is increased by just 10%, instead of dozens of unique marine derived bio-based products, hundreds of hits could reach the market (Martins *et al.*, 2014). A close relationship between academia and industry is needed in order to direct the efforts to real needed market outputs that can have a true impact on Europe's bioeconomy growth and independence. Also, such partnerships and strategic definitions will allow a wise use of limited resources and help to ensure successful development programs.

3.2.2.4 Pros

Because of their broad panel of bioactivities such as anti-tumor, anti-microtubule, anti-proliferative, photoprotective, antibiotic and anti-infective (Pettit *et al.*, 1982; Berdy, 2005; Sudek *et al.*, 2007; Molinski *et al.*, 2009; Schumacher *et al.*, 2011; Mishra and Tawari, 2011), MNPs are exceptionally interesting high-value ingredients for applications in the pharmaceutical industry and cosmetics industry, and an increasing number of companies are investing in this field. Traditionally, cosmetics were defined as articles to be applied to human body for cleansing, beautifying, promoting attractiveness, or altering appearance without affecting body structure or function (Nelson and Rumsfield, 1988). However, more recently, the cosmetic industry introduced a special class of products, cosmeceuticals, as a combination of cosmetics and pharmaceuticals, where bioactive ingredients are combined with creams, lotions and ointments (Wijesekara, 2012). Interestingly, an increasing number of suppliers of the cosmetic industry are being pushed to include extracts made from coastal plants, seaweeds, algae and sea minerals as cosmeceutical ingredients. These extracts contain vitamins and minerals and they show ultraviolet and anti-oxidant protection and general anti-aging benefits (Thomas and Kim 2013; Raposo *et al.*, 2013; Kim *et al.*, 2008; Kijjoa and Pichan, 2004). In fact, activities such as antioxidant, anti-wrinkle, anti-tyrosinase and anti-acne are among the most usual activities of marine cosmetic ingredients for skin health (Wijesekara, 2012; Imhoff *et al.* 2011). Selected marine-derived actives have started to appear in new prestige skin care launches, including Elemis (The Steiner Group), La Prairie (Beiersdorf), Crème de la Mer (Estée Lauder), Blue Therapy (Biotherm), amongst many others. Hence, an entire new paradigm of beauty care, combining cosmetic and pharmaceutical properties into novel products with biologically active ingredients, will be the hallmark of the next decades.

Biotechnology also holds promise in contributing to the technology toolbox that can tackle societal problems such as pollution and creating a more sustainable economy. Using such tools, different industrial processes can become greener by using new natural products instead of chemical products that pollute the environment. By developing new technologies and services that are eco-friendly, sustainable, and intelligent blue biotechnology can deliver through:

- Fostering scientifically driven curiosity to better understand the deep sea using the opportunity presented by industrial development whilst addressing societal needs;
- Giving an alternative to land-based solutions for large societal challenges (e.g. food, animal feed, energy, novel medicines and therapies, novel biomaterials and products);
- Taking advantage of the great potential of marine microorganisms which may reduce the ecosystem impact as a source of novel bioproducts (compared to large organisms) and have an increased success rates in marketability and industrial applications;
- Potentially sustainable provision of raw materials and production processes, especially from marine microorganisms;
- Ecofriendly industry and applications;
- Large market value potential and economic driver for the EU which has key expertise in fields such as nutraceuticals, biomaterials, and cosmeceutical development;
- Being a large driver of EU employment of highly skilled human resources.

3.2.2.5 Cons

Progress in the past 50 years of exploration of the marine environment has resulted in the isolation of approximately 20,000 structurally unique bioactive MNPs. Just in 2012, 1241 new compounds were reported that clearly identified the marine environment as a rich source of bioactive molecules (Montaser and Luesch, 2011). Nevertheless, despite this enormous number of structurally unique bioactive MNPs, to date the global marine pharmaceutical pipeline includes only eight approved drugs, twelve MNPs (or derivatives thereof) in different clinical phases, and a large number of marine chemicals in the preclinical phase (Skropeta, 2008; Mayer and Glaser, 2013; Blunt *et al.*, 2012).

To foster the development of the blue biotechnology sector, several current bottlenecks in product development need to be tackled (see Fig. 3.6). Amongst these can be included:

- Microorganisms versus macro – the sustainability issue can be tackled by focusing development more on exploitation of sustainable microorganism products and fermentation manufacturing versus the use of macroorganisms;
- Ocean degradation through human activity may be destroying current ecosystem biodiversity including at a microbiological level, risking the loss of current potential new material for innovative developments;
- Unknown biodiversity – we know less than 5% of ocean's biodiversity and we use even less than 1% of that known biodiversity. Fostering expeditions, biodiversity studies, mapping, and data gathering is crucial for continuous development of a sustainable blue biotechnology worldwide;
- Legal barriers/complex framework – there is a lack of clear guidelines as to the use and abuse of deep-sea biological materials even more evident when it relates to genetic biodiversity;
- Market and development barriers – there are several bottlenecks in current marine natural product development for successful market penetration. The example of health-related challenges for blue biotechnology derived products is a good starting point and further research and development is needed to overcome these issues;
- Unsuitability or commercial unviability of collections of marine compounds, extracts or organisms. This is largely a result of three main factors:
    - Biodiversity and biological challenges - Poor levels of characterization and knowledge of these collections (phylogenetically, biochemically, fermentation profiles, upscaling method availability or even identification of interesting and marketable bioactivities) that make them inappropriate for immediate transfer to industry;
    - Supply and Technical/Legal Challenges - Lack of compliance to the current legal framework or clear ownership hierarchy leading industry to select only a few of these collections;
    - Market Challenges - Market inexperience from the curators and holding institutions make it difficult to understand current industry needs and leads to constraints in negotiating with them.

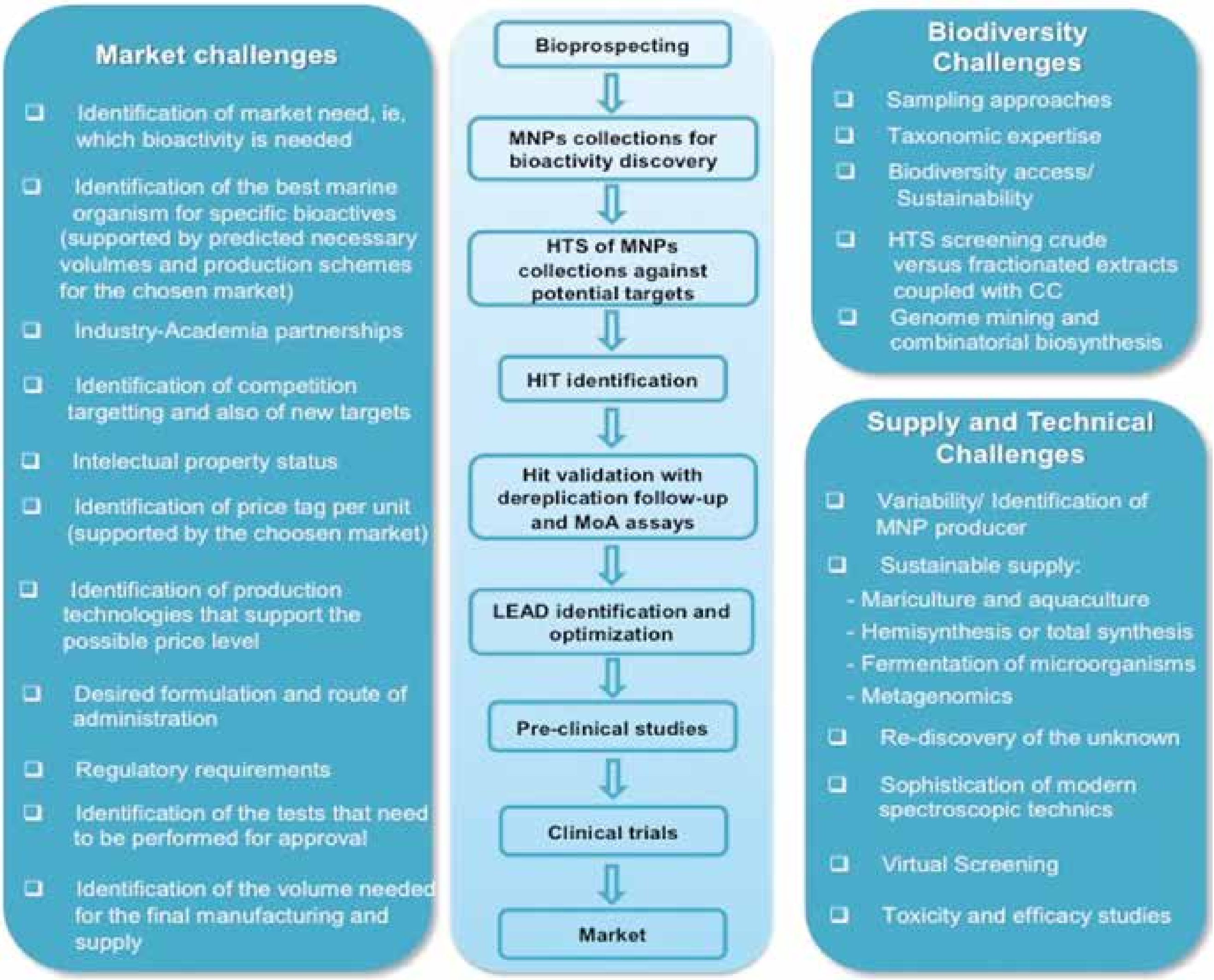


Fig. 3.6 Marine Natural Products from bio prospecting to market, highlighting biodiversity, supply and technical and market challenges faced during the process (after Martins *et al*,, 2014).

BOX 3.2 REFIRMAR® BY BIOALVO AND FACULTY OF SCIENCES UNIVERSITY OF LISBON

RefirMAR® by BIOALVO/Faculty of Sciences University of Lisbon is one of the few, if not the only, marine microorganism derived personal skin care active ingredient with an intracellular origin.

The Mid-Atlantic Ridge (MAR), that extends from the Arctic Ocean to the far South Atlantic, is mainly constituted by submerged mountains and contains several hydrothermal fields such as Menez Gwen, Menez Hom, Rainbow, Lucky Strike, and Mount Saldanha. These vents are in the Portuguese Exclusive Economic Zone (EEZ) and extended continental shelf, and have mostly been studied in terms of their biodiversity composition and geochemical conditions. The organisms surviving in these extreme environments have developed unique and surprising defence functions and this is the basis of MNP development for many industries. A new bacterial strain from *Pseudoalteromonas* sp was isolated from one of these extreme vents and characterized.

Credit: Helena Vieira

Fig. 3.7 RefirMAR® lyophilised powder produced from bacterial fermentation and non-chemical intracellular extraction.

RefirMAR® is a natural ingredient derived from an intracellular extract produced by biotechnological fermentation of this new *Pseudoalteromonas* sp strain isolated at about 2300m depth from the Rainbow vent (Figure 3.7). RefirMAR® is a complex mixture of macromolecules, mostly proteins, that together act as a potent muscle contraction inhibitor. This natural function was adapted to cosmetic applications and this extract is the basis of the RefirMAR® ingredient - a potent hydrating, anti-wrinkle and expression lines attenuator comparable to other injectable and/or synthetic solutions. Tests performed in mice synaptosomes showed that this ingredient displays an activity similar to botulinum toxin A (BoNT/A), inhibiting localized muscle contraction by inhibiting acetylcholine release from the neuromuscular synapses. This *in vitro* activity was confirmed by *in vivo* assessment of its anti-aging and hydrating potential. RefirMAR® decreases wrinkle depth up to 23% (average 7%) and increases hydration up to 64% (average 34%) after 28 days of topical application. Moreover, RefirMAR® has the major advantage of being suitable for topical application, with no need to make use of injections for getting the desired effect (data not shown). Structural data on RefirMAR® is not yet available.

Despite the potential pharmaceutical applications of RefirMAR® to disorders where neuromodulation and acetylcholine release inhibition can play a role in disease control, BIOALVO has chosen to firstly develop this bioactive product for applications in the cosmeceutical market. This choice was grounded on the fact that this is a faster route to market, a detail very important for small companies to be able to survive by using the cash from sales generated by this cosmetic route to finance the much more costly and – lengthy – pharmaceutical development.

More success stories exist in marine biotechnology applications and it is crucial to continue the investment and technological development in this sector with industry and academia side by side. Increasing scientific knowledge about the deep-sea ecosystems and their biodiversity will help to fuel further innovations and developments in the field.

3.2.2.6 Research Questions

Enzymes with pharmaceutical and biotechnological applications must be able to work under process-relevant conditions which are often extreme in terms of salt concentrations, the presence of solvents, extreme pH, and/or temperature. It is of no surprise therefore that the deep sea as an extreme environment harbours great potential for MNPs. Overriding questions are what are the biotechnological resources of the deep sea and where are they distributed, both within ecosystems and the organisms which live within them. Specific types of organisms may be of particular interest in this context.

Organisms adapted to high pressure (Piezophiles)

The potential of piezophiles for application to biotechnology has been known for some time (Abe and Horikoshi, 2001), however, barriers to development still remain, most notably with regard to the isolation and maintenance of organisms from high pressure environments (Imhoff *et al.*, 2011). Bioactive molecules investigated to date have been isolated from microorganisms associated with higher trophic marine organisms predominantly from the benthos (König *et al.*, 2006), and from sediments (Pettit, 2011) but there has been little work on pelagic bacteria, though new genomic data (Orcutt *et al.*, 2011) indicate there is considerable diversity in these communities. High pressure environments require a number of adaptations at the cellular level (Simonato *et al.*, 2006) most notably to maintain the structure and function of enzymes (Eisenmenger and Reyes-De-Corcuera, 2009). The adaptations to enzyme function employed by piezophiles may provide optimal routes for biosynthesis or have application to other biotech processes. As our understanding of the biogeochemistry of piezophiles (Fang *et al.*, 2010) expands the identification of specific processes and the organisms which perform them will become more routine allowing better targeting and development of new biotech applications.

Organisms from Oxygen Minimum Zones

Oxygen minimum zones (OMZs) also have potential for yielding new products of biotechnological importance. OMZs arise in the ocean from a combination of oxygen utilization by organisms through respiration of organic matter and low supply of oxygen through ocean currents. The strongest OMZs are found at intermediate depths below high productivity zones associated with eastern boundary upwelling systems (EBUS) and recent analysis suggests these regions are expanding in the ocean (Stramma *et al.*, 2009). Organisms adapted to low oxygen environments ($< 20\ \mu M\ O_2$), may possess biomolecules or enzymes that are useful for new biotech applications. Bacteria and archaea from OMZs are capable of performing anammox (Kalvelage *et al.*, 2011) , methane oxidation (Tavormina *et al.*, 2010) and sulphate reduction (Canfield *et al.*, 2010). Further genomic studies of OMZs (Ulloa *et al.*, 2012) coupled with transcriptomics (Stewart *et al.*, 2012) and metabolomics will undoubtedly yield data of relevance for biotech applications where low O_2 is a critical parameter.

Organisms from Hydrothermal Vents

The high temperatures, low or high pHs and variable salinities associated with hydrothermal vents make them an obvious potential source of MNPs. Various polysaccharides, lipids and enzymes with novel biochemical properties have been isolated from vent bacteria and archaea (Pettit, 2011). Some of these have been found to be potentially useful in industrial processes such as an alpha-amylase which is active at high temperature and low pH which is used in starch liquefaction (Mathur *et al.*, 2005), and a high temperature cellulase probably of archaeal origin (Leis *et al.*, 2015). Other molecules isolated from vent organisms have been found to stimulate bone or wound healing or may be useful as UV protectants (Martins *et al.*, 2013). The increasing ability to culture thermophilic deep-sea microorganisms from hydrothermal vents along with increasing access to these environments via ROVs and HOVs means that they have large potential as a source of novel MNPs in the future (Pettit, 2011). Other chemosynthetic ecosystems such as hydrocarbon seeps or the deep subsurface biosphere are also likely to prove rich in microorganisms with valuable MNPs.

3.4 Opportunities: Non-living resources

3.4.1 Oil and gas

Credit: Siemens AG, Munich/Berlin

Fig. 3.8 *Odfjell* deep-sea offshore drilling rig in the Atlantic.

3.4.1.1 Introduction to sector

The continued societal dependence on hydrocarbons and advancement of technology has driven oil and gas production into waters extending off the continental shelf to nearly 2,500m depth. Offshore deep-water finds form a large proportion of newly discovered reserves globally and are likely to provide the major source of large oil and gas finds in the 21st century (Caineng *et al.*, 2010). For example in 2000-2008 37 large oil and gas fields were found in deep waters off passive margins representing 40% of the global large fields discovered in the period (Caineng *et al.*, 2010). In 2005 alone approximately 60% of new oil discoveries were in deep water or ultradeep water (Murphy and Hall, 2011). However, relatively few of these discoveries are in production compared to shelf or terrestrial wells. Thus, there is substantial potential for deep-water production to increase and this is reflected in the dramatic increase in investment in deep-water drilling (from US$58 billion in 2001-2005 to US$108 billion in 2008-2012; Merrie *et al.*, 2014) which is projected to continue increasing in the near future. In order for the industry to achieve more regular and reliable access to these resources, improvements are needed to better understand the environmental and ecological implications for working in the open-ocean and deep-sea habitats (Kark *et al.*, 2015). Improvements are also required in technical capability for observing and safely operating in such remote places especially as current data indicate an increase in reported incidents (blow-outs, fires, injuries and pollution) with increasing depth of the well for an oil or gas platform (data based on Gulf of Mexico from 1996-2010; Muelenbachs *et al.*, 2013). Addressing these challenges would improve efficiency and provide a step change in the quality and transparency of potential and actual impacts and thus drive the industry towards more sustainable ways of working.

3.4.1.2 Legal framework

As explained in chapter 1, the Law of the Sea Convention provides a general framework for governing the oceans, including obligations for the states to protect the marine environment against pollution. Coastal states have sovereign rights over the continental shelf, for the purpose of exploring it and exploiting its natural resources, including oil and gas resources[19]. At the regional level in the North Atlantic, the Oslo-Paris Convention for the protection of the marine environment of the North-East Atlantic (OSPAR) has a particularly important role when it comes to prevention and elimination of marine pollution including that arising from marine petroleum-related activities, alongside national legal frameworks and European Directives, such as the Environmental Impact Assessment (EIA) Directive. OSPAR Decisions and Recommendations are important, as they are more extensive and specific than the obligations to prevent pollution from seabed activities provided in UNCLOS. Its Annex II prohibits dumping of wastes and other matters from offshore installations, whereas its Annex V includes obligations to protect and conserve the ecosystems and the biological diversity of the maritime area. In addition to legally binding measures, the OSPAR Commission has adopted a number of non-legally binding strategies. The Offshore Oil and Gas Industry Strategy aims to prevent and eliminate pollution from offshore sources and to protect the OSPAR maritime area against the adverse effects of offshore activities so as to safeguard human health and conserve the marine ecosystems[20].

The 1993 Agreement Between Denmark, Finland, Iceland, Norway, and Sweden Concerning Cooperation in Measures to Deal with Pollution of the Sea by Oil or Other Harmful Substances is a regional agreement between the Nordic states. It applies within the waters under the jurisdiction of the Parties, who undertake to cooperate on the protection of the marine environment against pollution of the sea by oil or other harmful substances[21]. The agreement addresses monitoring the waters of the Parties and for responding to incidents such as an oil spill and pollution of the sea by other harmful substances. Where pollution of the sea by oil or other harmful substances may seriously threaten the marine environment, the Parties are required to investigate the situation, provide information, assist in the production of evidence, and establish measures for abatement of the pollution[22].

[19] The Law of the Sea Convention Article 77.

[20] http://qsr2010.ospar.org/en/media/chapter_pdf/QSR_Ch07_EN.pdf

[21] The Nordic Agreement Article 2.

[22] The Nordic Agreement Articles 3-7.

In addition to the OSPAR Convention are the non-legally binding Arctic Offshore Oil and Gas Guidelines, which were adopted by the Arctic Environmental Ministers in 1997[23] and revised in 2002 and in 2009 by the Protection of the Arctic Marine Environment (PAME) Working Group in the Arctic Council[24]. The Guidelines are intended to be of use to the Arctic nations for offshore oil and gas activities during planning, exploration, development, production and decommissioning. Under the purview of the Arctic Council, a number of regulations and guidelines have been adopted, including Guidelines on fuel transfer[25], Emergency Prevention, Preparedness and Response (EPPR) Working Group of the Arctic Council guidelines for oily waste management[26], EPPR field guide for oil spill response in Arctic waters,[27] Arctic Shoreline Clean-up Assessment Technique (SCAT) Manual-a field guide to the Documentation of Oiled Shorelines, and the Arctic Guide to National emergency response arrangements and contacts[28]. The most recent addition is an instrument for search and rescue preparedness and operations in the Arctic and an oil spill preparedness agreement.

3.4.1.3 Limiting factors

There are clear economic and political benefits to having access to hydrocarbons. However, there are several factors limiting more sustainable access. A key challenge to understanding the impact of oil and gas industry activity is disentangling natural compared to industry-driven environmental variation or change (Godø *et al.*, 2014). Other challenges include working across disparate legal frameworks, integration of contemporary observing programs, taxonomy, and sampling methods, as well as improved modelling of theoretical and actual spills. Some of these issues became the focus of discussions and recommendations following the *Deepwater Horizon* blowout in the Gulf of Mexico (Graham *et al.*, 2011; Peterson *et al.*, 2012). One of the clearest of the long-term challenges is finding a balance between meeting demand for energy and raw materials while also bearing in mind that dependence on hydrocarbons is questionable given they are contributing to long term climate change with serious impacts on Earth's ecosystems, including the oceans (e.g. Gattuso *et al.* 2015). In the nearer term, improving knowledge about the communities of life that occupy deep-sea habitats and the factors that influence their variation in space and time remains a key issue (Graham *et al.*, 2011; Kark *et al.*, 2015).

The ability to make fundamental observations in deep-sea habitats is improving, but continued advancement is needed. Too often, contractors have little knowledge of, or experience in, the special issues of working in deep-water environments and understanding their ecology (Barker and Jones, 2013). For example, contractors conducting baseline and environmental impact assessments (EIAs) have relatively little knowledge of the taxonomy of deep-sea life with many species not having been described. Thus there is a reliance on existing data or Strategic Environmental Assessments (Barker and Jones, 2013). Where new sampling is undertaken a common issue is lack of experience with sampling in the deep sea where the density and distribution of life is more difficult to ascertain as many organisms are generally smaller in body size, less abundant, and poorly described. These issues can lead to EIAs that don't have statistically robust descriptions of the areas they are intended to describe and/or a lack of comparability from one EIA to the next due to the lack of knowledge sharing between various contractors, resulting in the data and taxonomic knowledge becoming isolated.

[23, 24] http://www.pame.is/index.php/projects/offshore-oil-and-gas

[25] TROOP Guidelines for Transfer of Refined Oil and Oil Products in Arctic Waters 2004, https://oaarchive.arctic-council.org/handle/11374/333

[26] Guidelines and Strategies for Oily Waste Management in the Arctic Regions 2009, https://oaarchive.arctic-council.org/handle/11374/108

[27] Field Guide for Oil Spill Response in Arctic Waters (1998) http://arctic-council.org/eppr/completed-work/oil-and-gas-products/field-guide-for-oil-spill-response/

[28] Arctic Guide http://eppr.arctic-council.org/

3.4.1.4 Opportunities for progress on understanding impact

Open-access observing systems to monitor industrial activity provide a means to increase the ability to understand and verify impacts (Ruhl *et al.*, 2011). Several such systems already deliver images and data from the deep sea to desktops worldwide via the internet. Thus it is now feasible for future industrial operators to install real-time observing and sensing systems at appropriate locations around areas of potential impact (e.g. Godø *et al.*, 2014). Observing systems can operate before and throughout the period of industrial activity, as well as during decommissioning. Imagery and data can be publically available for interpretation by independent scientific experts. Such systems can help differentiate natural from anthropogenic variation and would have aided understanding of the *Deepwater Horizon* accident in the Gulf of Mexico. Feasibility is indicated by the already existing deep-sea sensor networks used in marine science and hydrocarbon production management.

Several national and European programs have already considered key aspects of monitoring in the deep sea such as what to measure and how. The Ocean Observatory LoVe[29] and DELOS[30] (Deep ocean Environmental Long Term Observatory System) projects have already begun such monitoring via cooperative effort between industrial and research groups. Other projects involving industry and ocean observing research have also been initiated. The design concepts developed in EMSO[31] (European Multidisciplinary Seafloor and Water Column Observatory), OOI[32] (Ocean Observatories Initiative), DONET[33] (Dense Ocean Floor Network System for Earth Quakes and Tsunamis, MARS[34] (Monterey Accelerated Research System), VENUS[35] and NEPTUNE Canada[36] (North East Pacific Time-Series Undersea Networked Experiments) and other such observatory efforts can inform industrial monitoring. These designs allow for data to flow from the seafloor in a plug-and-work mode into internet-based networks that facilitate early warning, data discovery, transparency, and archiving. Sensors for temperature, conductivity (salinity), pressure (depth), currents (transport), turbidity, dissolved oxygen, pan and tilt cameras, and passive acoustics are all widely considered as standard in deep-sea observatory systems. Multiple types of sensors for hydrocarbons have also become commercially available including fluorometers, mass spectrometers, and other optical sensors. These instruments can be situated together to stand alone or be integrated into planned infrastructures, and can be serviced annually by ROVs. Additional sensors and samplers can be brought to bear depending on foreseen requirements.

Information could be available from these monitoring systems in real time. A framework to register sensors and track standards and data provenance has also been developed. The dissemination of information can occur through already developed or developing standards including the Open Geospatial Consortium (OGC) Sensor Web Enablement (SWE) suite of standards. These standards allow for accessibility of data through already existing data centres.

The SERPENT project[37] (Scientific and Environmental ROV Partnership using Existing iNdustrial Technology) has also provided a progressive model for working with industry and taking advantage of existing infrastructure. The project has enabled site visits to rigs where scientists work with industrial contractors to make best use of ROV down time for scientific and impact assessment purposes. With nearly 400 site visits conducted to date and nearly 100 peer-reviewed publications, the SERPENT project provides an excellent example of the ways in which industry

[27] http://love.statoil.com/

[28] http://www.delos-project.org/

[29] http://www.emso-eu.org/

[30] http://oceanobservatories.org/

[31] https://www.jamstec.go.jp/donet/e/

[32] http://www.mbari.org/mars/

[33] http://venus.uvic.ca/

[34] http://www.neptunecanada.ca/

[35] http://www.serpentproject.com/

and researchers can work together for positive impact (Fig. 3.9). Key scientific outputs from SERPENT have included the documentation of recovery of deep-sea assemblages at various drill sites offshore Norway and United Kingdom (e.g. Jones et al., 2012), and the documenting of important, but poorly appreciated, fluxes of carbon in the marine environment from higher trophic levels in surface ocean food webs.


Credit: SERPENT Project

Fig. 3.9 Cod swimming around ROV, Schiehallion North Sea field.

When samples are collected during surveys in poorly known areas, as is usually the case with industrial surveys, many or even the majority of species found are new to science and are thus often only identified to a morphotype for a particular survey. The contractors used by industry often do not have the expertise to describe observed specimens for taxonomic description or catalogue their presence such that morphotypes can be discernible across multiple surveys or contractors. Inadequate taxonomic or curation methodology can result in samples not even being identified to genus with voucher specimens not curated, left to dry out, or be disposed of or lost. Even when samples are cared for, the ability to cross reference undescribed morphotypes is often very limited.

In order to achieve statistically and otherwise meaningful results from baseline studies and impact monitoring, more consistent application of contemporary sampling design including key elements of before or after control impact and stratified random sampling with adequate replication is needed. With animals tending to have smaller body sizes and larger animals having lower densities at deeper depths than those found on the continental shelf, survey designs need to consider which tools are best for quantifying across microbial, meio-, macro-, and megafuanal size classes as each has specific sampling and processing requirements. The latter, which includes fishes and marine mammals, often requires the most specialised equipment including deep-sea trawling and/or ROV/AUV image transects, time lapse and baited cameras, and active and passive marine acoustics monitoring. While each of these methods has been successfully used in the past their integrated use across a satisfactory sampling design is not well achieved. Examples also include the integration of scientific observing infrastructure or methods into industry infrastructure with some success, (e.g. SERPENT, LoVe and DELOS), but such practices do not have a broad adoption and remain in the realm of case studies and demonstration projects. Moreover, a broader review and update of best practices for baseline and EIA studies is warranted to improve the quality and long term utility of these surveys and studies to provide the kind of high quality data that should underpin the assessments, decisions, and legal positions associated with those assessments.

Quantitative and dynamic modelling can provide a useful tool to estimate the extent and impact of oil spills, as well as provide insights as to possible scenarios of spills in particular areas. Key areas to drive model improvement include more effective representation of oil as a quantity that can have neutral and non-neutral buoyancy properties, consideration of 3D models that can be run without time consuming efforts during emergency situations, and the inclusion of biogeochemical weathering and ecological mechanisms (e.g. the role of dispersants and microbial life in degrading oil spills). Experience from the *Deepwater Horizon* well blowout suggests that oil can not only come to the surface but also have demonstrable impact in the mid water and on the seafloor (e.g. White *et al.*, 2012; Quintana-Rizzo *et al.*, 2015). Several types of modelling are already in use to include the modelling of surface slicks with wind and other forcing factors, modelling of seafloor blowouts with fine scale site-specific settings, and 3D coupled ocean-atmosphere regional and global models. Some of the key factors in the utility of these models include the way in which hydrocarbons are represented in the model, if or how mid water dynamics or biogeochemical ecological factors are quantified, and if the model is useful for estimates related to possible or real scenarios. The latest generation of Earth System models are running at extraordinary resolution of 1/12 degree globally, which can bring what has been regional scale modelling capability to a global extent. The advantage of this is that contractors can adopt a single model domain in which to run simulations and rapidly respond to questions of trajectory likelihood because one does not have to know in advance where to set up the domain.

Data from *in situ* industrial monitoring can combine with data from *in situ* samples, satellites, climate, and quantitative models to not only understand industry impact, but also understand ocean and earth change more broadly. By being openly available the data could combine with other information streams and help form part of the Global Earth Observation System of Systems (GEOSS) and Global Monitoring of Environment and Security (GMES). The above-mentioned consultation and negotiation process should thus also consider how the various data can be used to develop a comprehensive means to evaluate impacts at various scales from sites to larger spatial planning units and regions. Recognising the strategic importance of access to deep-water production sites to both industry and societies internationally, these ideas should be considered at a high level when developing policy and regulation. The earlier such plans can be included into subsea infrastructure design, the lower the cost related to implementation.

3.4.1.5 Alternatives

A broader discussion of the alternatives to oil and gas production from marine and especially deep-sea environments is not in the scope of this report. Sufficient to say that the burning of fossil fuels remains one of the major contributors to CO_2 emissions and as such responsible for serious damage to the Earth's ecosystems and the services they provide (e.g. Gattuso *et al.*, 2015). Alternatives include various forms of renewable energy some of which may be located in, or associated with, deep-sea ecosystems. Mitigation strategies may include carbon sequestration in the deep sea or sub-seabed. We would like to point out that deep oil and gas production should only occur when the technology to face failures and subsequent environmental disasters at these depths are well developed and in place.

3.4.1.6 Research Questions

The need for baseline data

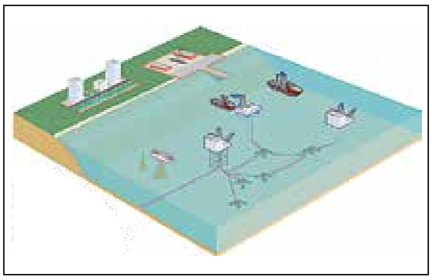
Stakeholder meetings which included oil and gas industry representatives identified the clear need for baseline data against which to monitor and identify impacts from exploration and production activities. Basic knowledge, such as how the species richness, abundance, and biomass of deep-sea species are distributed and how they vary naturally both spatially and temporally is rudimentary and largely based on a few regional studies. In the case of the water column the situation is particularly bad with some of the most detailed studies going back to the 1970s (reviewed in Rogers, in press) and large regions of the deep water column never visited or sampled by scientists or industry (Webb *et al.*, 2010). Climate change is likely to stimulate further change in deep-sea ecosystems driven by changes in the quantity and quality of surface primary production as well as through changes in physical parameters of the deep ocean and other less understood routes (Rogers, in press). There are, therefore, significant scientific challenges in understanding how deep-sea communities are distributed, how they vary in space and time, how they are connected and what drives these patterns, and the ecosystem services they provide. There must also be better understanding of the effects of oil and gas exploration on the deep sea, and in light of the *Deepwater Horizon* accident, better understanding of the impacts of catastrophic oil release.

Decommissioning impacts for deep sea

Decommissioning has been called the 'logjam of the moment' in terms of investment by the industry body Oil and Gas UK (OGUK) CEO. With estimations ranging from 300 structures scheduled for decommissioning in the North Sea by 2021 to 450 offshore structures by 2030 at costs of £15-20 billion, the problem is only going to get worse. The decommissioning of offshore structures is not new, however, most of the experience to date is in the relatively shallow waters of the Gulf of Mexico. In Europe, initial moves to dump an oil installation, the *Brent Spar*, by Shell at a depth of 2,500m on the North Feni Ridge met with opposition from Greenpeace and other organizations because of environmental concerns. The structure was eventually towed back to Norway where part of it was recycled in the building of a coastal installation and the rest cut up for scrap. Under a general rule established under OSPAR convention 98/3, decommissioning programmes in the North Sea will centre on reuse, recycling or final disposal of infrastructure on land. The existing rules suggest that over 90% of offshore infrastructure will be removed in its entirety and brought back to shore (see Fig. 3.10 for different decommissioning approaches). This is leading to a lack of investment in North Sea, as companies do not want to take over mature wells near the end of their life with the high costs of decommissioning. The UK government has pledged to offset some of the spending on decommissioning with tax relief, which is expected to extend the life of the UK's offshore oil and gas industry because it will give companies confidence to invest (Walker and Roberts, 2013).

Under the London Dumping Convention (1972) the disposal of offshore structures is permissible where this is found to be the best environmental option and with stringent environmental impact assessment. Therefore, a multi-criteria decision approach with direct stakeholder involvement in the decision process may be more effective. Taking into account criteria such as environmental, financial, socioeconomic, health and safety, and additional stakeholder concerns may result in a more efficient and effective decommissioning process, as long as transparency is ensured throughout the process. The European community has the opportunity to take the lead on innovative solutions as they tackle the technology, economic, and environmental challenges of the deep and inhospitable waters of the North Sea and Atlantic margin.

One of the largest challenges is the variety of structures and designs currently in place, making it impossible to establish a single method of removal. In deeper waters it can be more appropriate to leave larger structures at least partially intact. This might have environmental benefits in terms of forming artificial reefs. For example, 13 of the 14 North Sea oil rigs examined in a recent survey had *Lophelia pertusa* colonies, a reef-forming cold-water coral. In addition, in the case where converting obsolete rigs to artificial reefs is the most effective option, the money



Credit: DNS, Arup, Scottish Enterprise, 2014

Fig. 3.10 The manner in which assets can be decommissioned is subject to a Comparative Assessment. This assessment is used to make recommendations to the regulatory authority. It considers the technical feasibility, environmental and social impact, economic and health & safety implications of all viable decommissioning approaches in determining the optimal approach. The decommissioning approaches associated with the main infrastructure elements are influenced by the original installation design, and the strategy implemented by the operator.

saved by the oil and gas company could be invested into partnerships between science and industry, and independent research and monitoring programs to evaluate the effectiveness of the rig as an artificial reef. These decommissioned rigs would also restrict access to fishing trawlers, and therefore might enhance biological productivity, improve ecological connectivity and facilitate conservation/restoration of the deep-sea benthos. There are potential negative impacts including physical damage to existing benthic habitats, undesired changes in marine food webs, facilitation of the spread of invasive species, and the release of contaminants as rigs corrode, and therefore it should not be viewed as an easy solution. An alternative research activity that could take place is an investigation of the effects of deep-sea ship wrecks of various ages on deep-sea ecosystems.

Other options for reusing offshore platforms include turning them into renewable energy plants, carbon capture and storage plants, or recycling them for different infrastructure including piers or bridges. The Brent oil and gas field on the UK Continental Shelf (UKCS) has four platforms that need to be decommissioned, with a combined topside weight of more than 100,000 tonnes, and the *Brent Delta* platform alone is as tall as the Eiffel Tower. The decommissioning process is expected to take 10 years, and is an excellent opportunity, along with the other structures, to create a world-class hub for safe and responsible decommissioning, develop expertise, and create thousands of highly skilled jobs. Further information on the European project INSITE can be found in Box 6.4.

3.4.2 Methane Hydrates

Credit : Ifremer

Credit: NOAA

Fig. 3.11 ROV *Victor 6000* holds a piece of gas hydrate which at certain temperature and pressure conditions, resembles ice. Atlantic Ocean, Gulf of Guinea.

Fig. 3.12 Methane worms. NOAA Ocean Explorer: NOAA Ship Okeanos Explorer: 2012 “Gulf of Mexico”.

3.4.2.1 Introduction

Methane hydrate (made of methane and water ice) is an ice-like substance found in the pore-space of gas-rich seabed sediments in the gas-hydrate stability zone (GHSZ) (Mienert, 2012). To form methane hydrates several factors need to be combined: high contents of organic carbon in sediments, microbial or thermal degradation of the organic carbon to form gas, and pressure and temperature conditions which stabilize hydrate formation. Physically, the depth and thickness of the GHSZ varies with pressure (essentially water depth), temperature (in the seabed and the overlying water) and with the composition of the methane hydrate. Whather the GHSZ actually contains significant amounts of hydrate depends on the availability of gas either within the sediments in the GHSZ itself or migrating from deeper. Global estimates of the amount of methane stored in gas hydrates vary widely (Burwicz *et al.*, 2011) because their vast areal extent and multi-factor generation process mean that both direct and model-derived inventories have significant errors. They are likely, however, to be several times larger than the world´s inventory of conventional natural gas. Along the US Atlantic margin methane hydrates extend from approximately 500m depth to more than 2,700m (Phrampus and Hornbach, 2012). Increasing ocean temperatures may lead to thawing of methane hydrate reservoirs, bringing the risk of seabed slope collapse and release of methane gas.

Release of methane to the ocean can cause ocean acidification and de-oxygenation, and release to the atmosphere can cause warming because of the strong greenhouse effect of methane. Along the western North Atlantic margin changes in the Gulf Stream flow and temperature within the past c. 5,000 years may have brought warming of more than 8°C. This warming may be destabilizing about 2.5 gigatonnes of methane hydrate (Phrampus and Hornbach, 2012). Model studies have suggested that temperature rises at intermediate ocean depths of 5°C could release enough methane to explain extreme global warming events like the Palaeocene–Eocene thermal maximum (PETM) and trigger widespread ocean acidification (Biastoch *et al*. 2011). The 2.5 gigatonnes of methane hydrates presently under threat along the US Atlantic margin is only about 0.2% of that which caused the PETM. Methane hydrates in the Arctic and elsewhere are also under threat, and in the next 100 years release of methane from melting hydrates in these areas could enhance ocean acidification and oxygen depletion in the water column (Biastoch *et al*. 2011). However, the impact of methane release on global warming would not be significant within that time span. A 2009 consideration of methane hydrates on a global scale suggests an approximate 0.5°C additional warming from the hydrate response to fossil fuel CO_2 release (Archer *et al.* 2009). Recent work, however, suggests tens of thousands of seeps could be discoverable on the northern US Atlantic margin, where there could be widespread methane leakage from the sea floor. The impacts of thawing methane hydrates on global climate might need to be reconsidered in that light (Skarke *et al*. 2014).

Methane hydrates are not just a potential threat amplifying global climate change in a positive feedback mode but may also be used as a new energy resource. Several nations are exploring their national waters and are investing into technology development to quantify and unlock this reserve and harvest natural gas from methane hydrate (see Box 3.3). Resource potentials, technologies for field development and production, and the environmental risks associated with the exploitation of gas hydrates have not yet been fully explored.

3.4.2.2 Research Questions

Major research needs and gaps exist in the fields of both the processes of gas hydrate formation and knowledge of its 3-dimensional distribution. These include:

- What is the source rock of the gas?
- How does the gas migrate upwards (faults, pervasive pore-space flow)?
- How fast is methane generated by microbes of the deep biosphere?
- Which geophysical signals allow the best estimates of hydrate distribution and thickness to be made?
- How much hydrate is out there?
- Will hydrate dissociation amplify global warming and if so to what extent and on what timescale?
- Are propensity and impact of slope failure events rising as a result of global warming and enhanced gas hydrate dissociation?
- Are negative carbon excursions such as the PETM induced by gas hydrate dissociation or alternative mechanisms?
- Which fraction of the global hydrate stock occurs in sand-rich deposits and may thus be is used as an energy resource?
- What are the environmental risks of hydrate exploitation and how can they be minimized?

BOX 3.3: EUROPEAN ACTIVITIES IN METHANE HYDRATE RESEARCH AND DEVELOPMENT

Examples of ongoing European activities include:

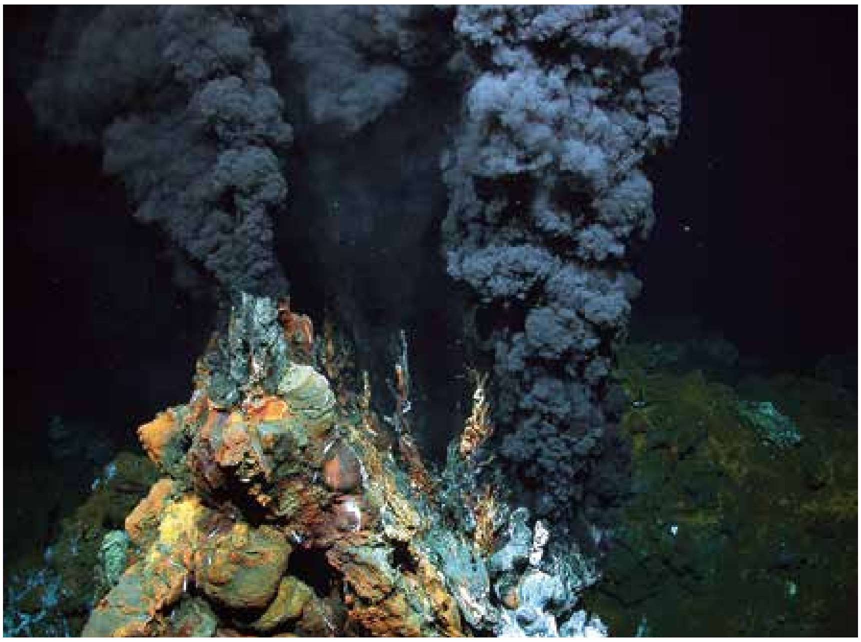
Submarine Gas Hydrate Reservoirs (SUGAR), a German national collaborative R&D project with 20 partners from SMEs, industry and research institutions which sets out to develop marine methane hydrates as a new, unconventional resource of natural gas and to combine its production with the safe sequestration of carbon dioxide from power plants and other industrial sources in CO_2 hydrates below the seafloor.

http://www.geomar.de/en/research/fb2/fb2-mg/projects/sugar-2-phase/

Marine gas hydrate - an indigenous resource of natural gas for Europe (MIGRATE), a European COST Action which is integrating the expertise of a large number of European research groups and industrial players to promote the development of multidisciplinary knowledge on the potential of gas hydrates as an economically feasible and environmentally sound energy resource.

http://www.cost.eu/COST_Actions/essem/Actions/ES1405

3.4.3 Marine mining



Credit: MARUM

Fig. 3.13 Black smoker hydrothermal vent at 2,980m depth, Mid-Atlantic Ridge.

3.4.3.1 Introduction to sector

Growth in demand for mineral resources is rendering the exploitation of deep-sea deposits increasingly favourable. Five types of deposits are now recognized as of potential interest: polymetallic nodules (also known as manganese nodules), cobalt crusts, seafloor massive sulphides, metal rich muds (e.g. Atlantis II Deep, Red Sea) and marine phosphates. The first four of these include a range of metals, including copper, nickel, cobalt, gold, silver and rare earth elements (REEs) while the fifth comprises the raw material for agricultural fertilisers. These deposits occur in markedly different geological settings including abyssal plains (polymetallic nodules), deep-sea hydrothermal vents located along mid-ocean ridges, tectonically active island-arc environments and seamounts (seafloor massive sulphides), metal rich basins in association with hydrothermal vents (metal-rich muds), seamounts (cobalt crusts), and on continental slopes or ocean plateaus (phosphates). Deep-water diamond deposits may also be added to this list although these have been exploited for a number of years and they are restricted to shelf depths (Rogers and Li, 2002). Deep-sea metal rich deposits are located at great depths and are only partially explored. They are also associated with poorly understood environments and ecosystems, some of which are identified as ’hot spots‘ of biodiversity.

The first deep-sea mining operations for seabed massive sulphides are likely to commence within the EEZ of Papua New Guinea in the next few years. Currently there is a “gold rush” amongst States to claim areas of the deep sea lying within the high seas (known as “the Area”) for exploitation of deep-sea metal deposits[38].

> *“Different sectors are at different levels of development. For deep-sea mining, there is a strong need for a policy guideline (e.g. regarding transparency practices) before mining begins.”*
>
> Seabed mining industry stakeholder, Germany

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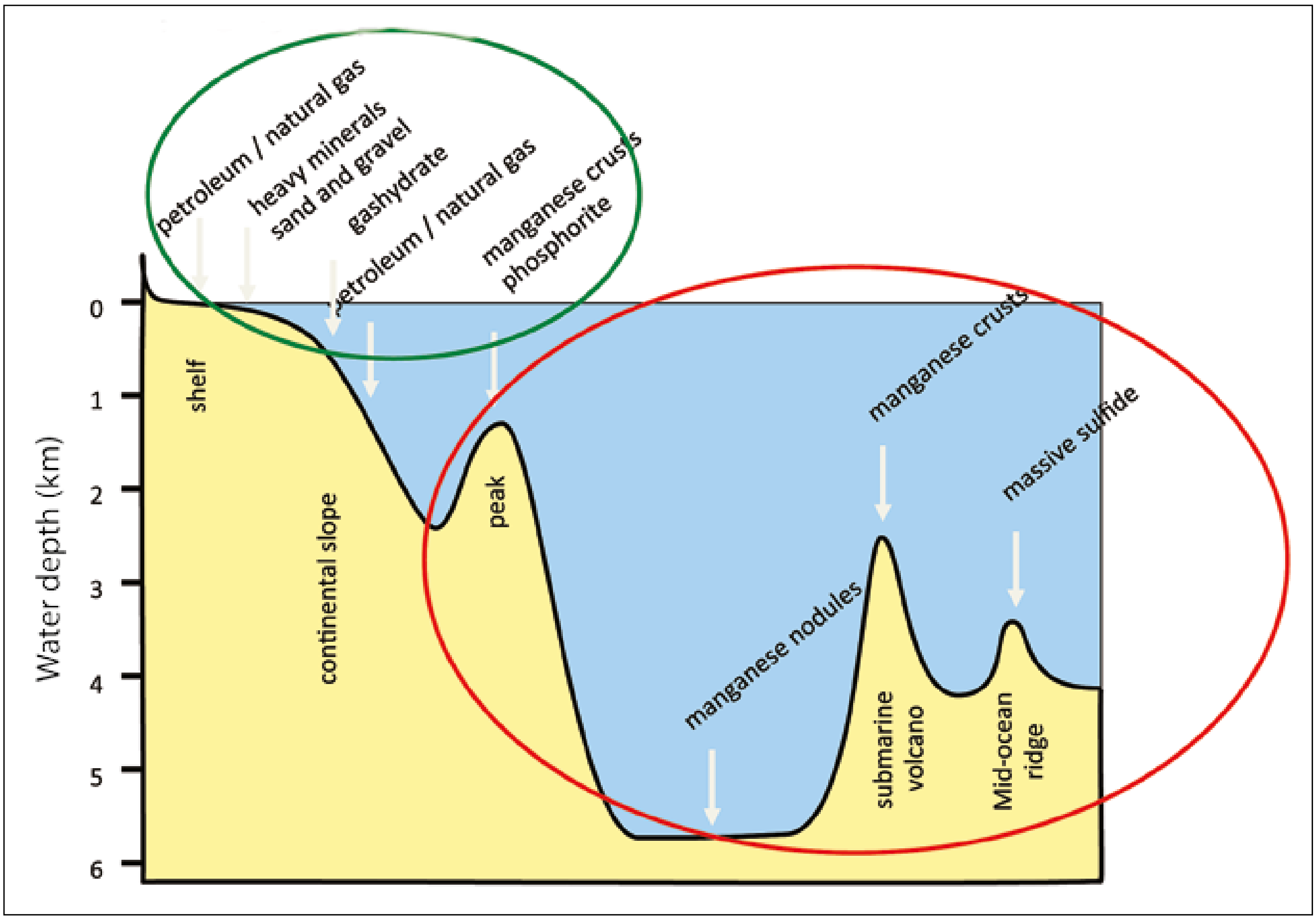
[38] https://www.isa.org.jm/deep-seabed-minerals-contractors?qt-contractors_tabs_alt=0#qt-contractors_tabs_alt

Credit: Image by Michael Tangherlini, credit Roberto Danovaro.

Fig. 3.14 Illustration of possible future exploitation of the chimneys of deep-sea hydrothermal vents and their potential restoration.



Credit: Andrea Koschinsky

Fig. 3.15 Sectors and depth of current resource exploitation (green) and of potential future exploitation (red). Many of these resources occur at a range of depths, this figure gives an indication in the depth trend of resource exploitation.

Although marine mineral mining is still in its infancy, by 2020 an expected 5% of the world's mineral supplies could be mined on the seabed, e.g. cobalt, copper, zinc and rare earth elements (EC, 2012). Although mining companies and investors are often non-European, the EU is strong in offshore technology developed for the oil and gas industry including in the building of ships, Remotely Operated Vehicles (ROV's), cutters and risers, as well as the management systems required to operate such industries in a safe and environmentally conscious way. Uncertainties and concerns linger in terms of the largely unknown environmental consequences and the outcomes of demonstration projects.

3.4.3.2 Resources

Seafloor massive sulphides (SMS or polymetallic sulphides) are deposits of metal-bearing minerals that form on and below the seabed as a consequence of the hydrothermal circulation of seawater in the oceanic crust (Hannington *et al.*, 2010). SMS are distributed mainly along mid oceanic ridges, and are also present in back arc basins and along submarine volcanic arcs (Hannington *et al.*, 2010). Depending on the geological setting, SMS predominantly comprise iron sulfides enriched in copper and zinc, associated with precious metals such as gold, silver, indium, or germanium (Petersen and Hein, 2013). The deposits are generally limited to areas of less than a km^2 and are situated between 800m to 5000m depth (Hannington *et al.*, 2010).

Polymetallic nodules are mineral concretions that are usually 1 to 12 cm in diameter (Hein *et al.*, 2013). The mechanisms of growth of these nodules is uncertain but may be induced by the presence of organic material or by microbial activity (Hein *et al.*, 2013). They are found in large areas (thousands of km^2) in the abyssal plain at 3000 to 6500m depth (Hein *et al.*, 2013). The greatest densities were discovered in 1973 in the Clarion Clipperton Fracture Zone (CCFZ) in the Pacific. Nodules comprise manganese and iron hydroxides, enriched in nickel, copper, and cobalt (Hein *et al.*, 2013). Traces of other valuable metals such as REEs including lithium, thallium, and molybdenum are also present (Hein *et al.*, 2013).

Metal-rich muds are formed in metal enriched ocean basins usually associated with mid-ocean ridges. Brines, formed by deep-sea water, leaching of the salt from surrounding evaporites and from hydrothermal fluids, collect in deep basins within the mid-axial valley and are efficient at trapping metals from the mineral-rich fluids exiting from hydrothermal systems (Laurila *et al.*, 2014). Some of the world´s largest metal deposits on land (banded iron formations) are thought to have formed by similar processes. One of the most well-cited studies of potential from deep-seafloor muds in the Pacific region suggests that an area of just one square kilometre in certain areas could provide one-fifth of the current annual world consumption of these elements (Kato*et al.*, 2011). At present such deposits have only being found in the Red Sea, with the largest known deposit, Atlantis II Deep, hosting approx 90 million tonne of ore with an estimated value of US$3.03 to US$5.29 (Bertram, *et al.*, 2011). The main metals of commercial interest that would be extracted from this deposit are zinc, copper, silver and gold (Bertram *et al.*, 2011). There is good reason to believe that these deposits have formed in the past during ocean opening in sub-tropical latitudes, making them a possible exploration target.

Cobalt-rich crusts are formed by the precipitation of iron hydroxides and manganese oxides on hard substrata, in areas of the deep ocean characterized by low sedimentation rate (Hein *et al.*, 2013). These polymetallic crusts can reach approximately 26cm thickness on large areas (greater than one km^2). They are formed between 400m to 7,000m depths on the flanks of seamounts (Hein *et al.*, 2013). These precipitates are highly enriched in cobalt, platinum, and tellurium, with the presence other minor elements such as titanium, thallium, zirconium, molybdenum, and other REEs (Hein *et al.*, 2013). The deposits with the highest potential seem to be situated in the Pacific.

Phosphate deposits are formed by precipitation where there are conditions of high surface productivity associated with upwelling of nutrient rich deep water and low oxygen concentrations in the underlying water mass (Nielsen *et al.*, 2014). Areas where these deposits are known include on the deep continental shelf and upper slope off Walvis Bay, South Africa at depths of 180m to 300m (Enviro Dynamics, 2012), and on the crest of the Chatham Rise to the east of New Zealand at depths of approximately 400m (Nielsen *et al.*, 2014). The Walvis Bay deposit comprises sediment enriched with pelletal phosphate with a concentration of between 18 to 20% phosphate. This requires processing to bring the phosphate concentration up to between 27 to 30% phosphorus pentoxide (P_2O_5) required for use as fertilizer (Enviro Dynamics, 2012). The Chatham Rise deposit is a limestone gravel-lag deposit (Nielsen *et al.*, 2014).

3.4.3.3 Associated ecosystems

These areas are characterized by diverse geological and geographical settings and are hosted by specific ecosystems, presenting significant spatial variability at different scales.

Hydrothermal vents were discovered in 1977 at the Galapagos Rift. Observations made by the submersible *Alvin* revealed the surprising presence of dense tubeworm communities in the vicinity of hot vents. These highly productive ecosystems rely on the presence of reduced chemicals in the vent fluid to fuel chemoautotrophic bacteria, often associated with a specialized fauna through symbiosis. The different micro-habitats provided by active hydrothermal vents are characterized by steep physico-chemical gradients and by the presence of potentially toxic compounds in hot fluids reaching approximately 400°C. They are colonized by a fauna with a high level of endemism, often adapted to tolerate these ‘extreme’ environments. The specific composition of the vent fauna is geographically variable and has been classified into up to 11 distinct faunal provinces (Rogers *et al.*, 2012). While the communities in the direct vicinity of active vents have been studied frequently since 1977, the communities at inactive hydrothermal vents are less well understood. They may have dynamics that are more representative of open-ocean deep-sea communities that are reliant on sinking flux but this is not yet known. Inactive SMS sites will have relatively larger portions of hard substrata, which can be relatively rare in the deep sea, where soft sediments dominate.

Polymetallic nodules occur widely on abyssal plains producing scattered hard substrata in this sediment covered area. Most work on nodule areas has taken place in the Clarion Clipperton Fracture Zone (CCFZ) in the eastern Pacific. The sediments in this region are dominated by meiofaunal species (about 0.025mm to 0.5 mm[39]) with high diversity but low biomass and are comparable to other abyssal plains with similar input of phytodetritus (e.g. nematodes; Brown *et al.*, 2001). Macrofaunal groups (sieve size 0.25mm to 1mm) have been less studied but the

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[39] For discussion of faunal size classes see Van Der Grient and Rogers, 2015.

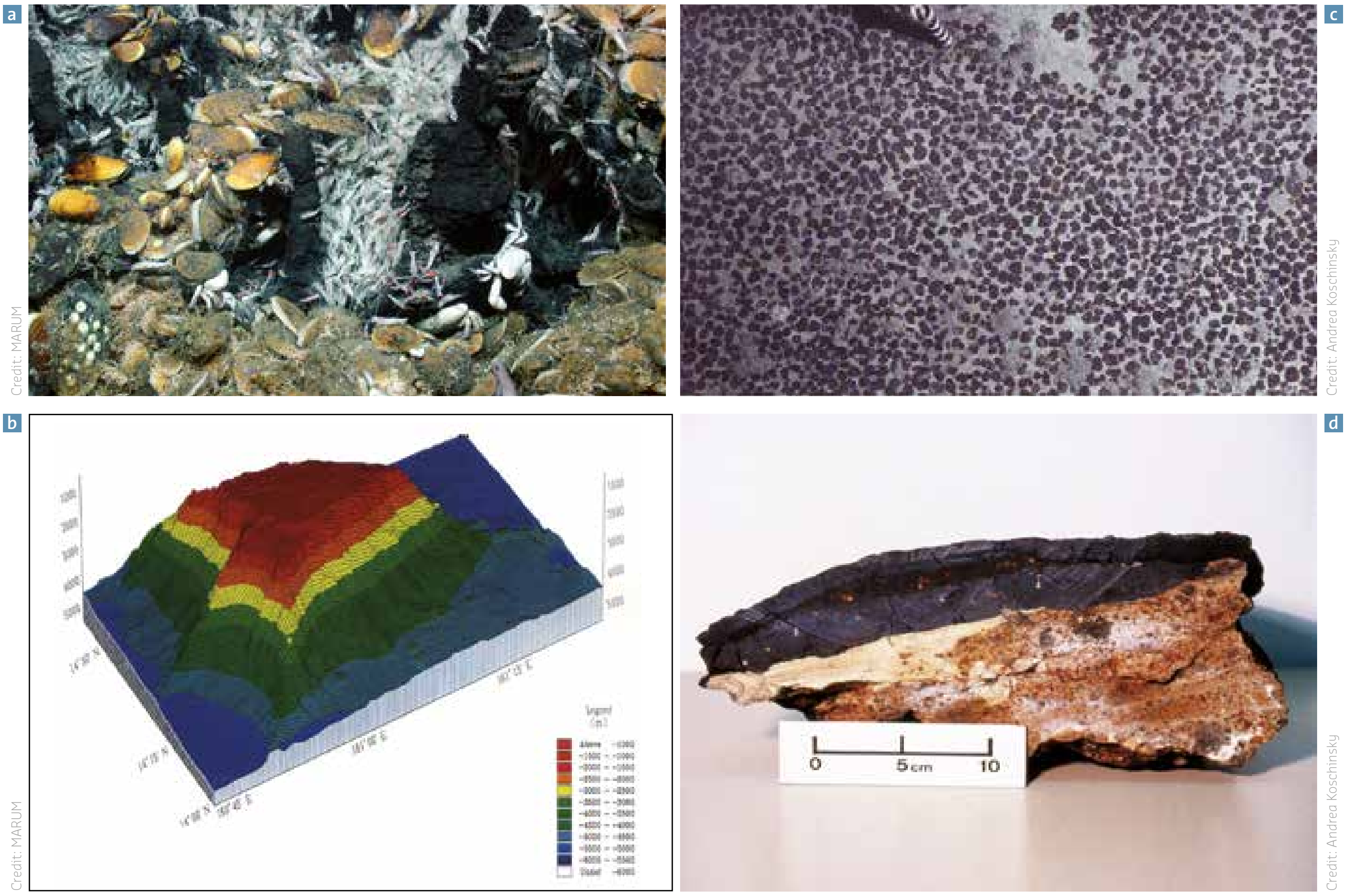
polychaetes and peracarid crustaceans are the most abundant groups as elsewhere in the deep sea (Janssen *et al.*, 2015). These groups appear to show relatively high turnover in species even over small distances, although some species are widely distributed (Janssen *et al.*, 2015). The nodules are colonized by specific sessile filter feeding communities (Veilette *et al.*, 2007). The megafauna differ between the soft sediment and the hard substrata represented by the nodules and rarer rocks, stones and whale skeletons. Soft sediment is dominated by various groups of echinoderms and crustaceans whilst hard substrata are colonized by sponges, crinoids, octocorals, black corals, and other sessile epifaunal species (Bluhm, 1994). The biomass and size distributions of these fauna occur in relation to food supplies from sinking particulate organic matter (marine snow) from the waters above (e.g. Brown *et al.*, 2001). Areas such as the CCFZ have such low biomass mainly as a consequence of low food inputs relative to more productive parts of the ocean, such as higher latitude temperate seas.

Metal-rich muds have so far been located in the Atlantis II Deep in the Red Sea. The deep Red Sea is not well studied but there has been a suggestion the fauna is largely derived from the Indian Ocean (Indo-Pacific) but has a high level of endemism (approximately 30%; Türkay, 1996) although biomass is extremely low (approximately 0.05g ~C/m^2; see refs. in Vestheim and Kaartvedt, 2015). The axial depressions in which metalliferous muds are deposited contain highly saline, acidic, and anoxic waters and thus represent an extreme and inhospitable environment for metazoans although chemoautotrophic prokaryotes occur in these brines (Vestheim and Kaartvedt, 2015). Sampling of the sediments and sulphur chimneys just above the brine layers within these depressions have identified the occurrence of several fish, shrimps, polychaetes, and mollusks (Vestheim and Kaartvedt, 2015). The latter include a new species of the bivalve family Corbulidae which forms a distinct band in distribution along the “shoreline” of the brine layer (Oliver *et al.*, 2015). This shoreline is thus associated with an increased biomass and diversity of species than the surrounding sediments, presumably deriving nutrition directly or indirectly from chemosynthesis (Vestheim and Kaartvedt, 2015).

Cobalt-rich crusts are distributed throughout the global oceans on the summits and flanks of seamounts, ridges, and plateaus. They form heterogeneous habitats colonized by habitat forming sessile organisms (e.g. sponges and corals) hosting a large diversity of species mainly dependent on feeding on suspended organic material. Communities are very different from those of the abyssal plains and can be related to the depth, substratum, and current flow (e.g. Rogers, 1994). In the region where crusts are most likely to be exploited, the central north Pacific, seamounts with cobalt crusts host communities of benthic invertebrates that significantly differ from those outside of the cobalt crust zone (Schlacher *et al.*, 2013). Differences are in the composition and relative abundance of species rather than in species richness itself (Schlacher *et al.*, 2013).

Phosphate deposits lie in high productivity waters or what were high productivity waters. The Walvis Bay mineral deposits lie in the rich Benguela Current large marine ecosystem which comprises rich fisheries resources and large concentrations of aquatic predators such as seabirds. In 2013 a moratorium on marine phosphate mining was put in place by the government of Namibia as a result of concerns raised by environmentalists and the fishing industry with respect to potential impacts on fish stocks. The Chatham Rise phosphate deposit lies partially within areas of the seabed protected from deep-sea trawling as a result of the presence of vulnerable marine ecosystems, namely cold-water coral reefs. The region lies in high productivity waters associated with the sub-tropical front and as a result comprises rich deep-water fisheries resources, a rich and complex benthic ecosystem associated with cold-water coral reefs and other habitats, and also significant concentrations of seabirds and marine mammals. As a result of the presence of the marine protected area and the risk of significant and permanent adverse impacts on the seabed ecosystems on the Chatham Rise, consent for mining was refused (NZ Government, 2015).

As can be seen mining consents for shallower water phosphate deposits have been put on hold or refused on environmental grounds. In the case of the Chatham Rise considerable knowledge exists on this area partially as a result of identification of vulnerable marine ecosystems on small seamounts and the potential risk from deep-sea fishing. The main common feature of the ecosystems where other forms of deep-sea minerals are found is the lack of knowledge concerning their fundamental ecology, functioning (e.g. life cycle, population dynamics, connectivity etc.), and ecosystem service provision.



Credit: MARUM

Credit: Andrea Koschinsky

Credit: MARUM

Credit: Andrea Koschinsky

Fig. 3.16 **a.** Living community at hydrothermal seeps on the Mid-Ocean Ridge at a water depth of 3,030m.
b. Dense nodule coverage of the seafloor.
c. Structure of typical seamount covered with crusts.
d. Cross section of a few cm thick manganese crust on volcanic rock.

3.4.3.4 Legal framework

The legal framework regulating deep-sea mining depends on the geographical location of the resources. The UNCLOS distinguishes two maritime zones relevant here (see Chapter 1, section 1.4; Box 1.4)). The first, the continental shelf and extended continental shelf, is subject to the exclusive jurisdiction of coastal States who can authorise any activity to be performed in relation to resources on the seabed and in the subsoil. Deep-sea mining is therefore regulated by the specific national legislation of coastal States in combination with relevant international law in the field of environmental protection (namely, pollution prevention and control, environmental impact assessment etc.) and of transboundary impact of the considered activity. National regulations for pollution control from seabed mining should be “no less effective” than international rules and regulations adopted by the ISA. Thus the regulatory framework for seabed mining currently under development by the ISA will set the bar for national regulations to come.

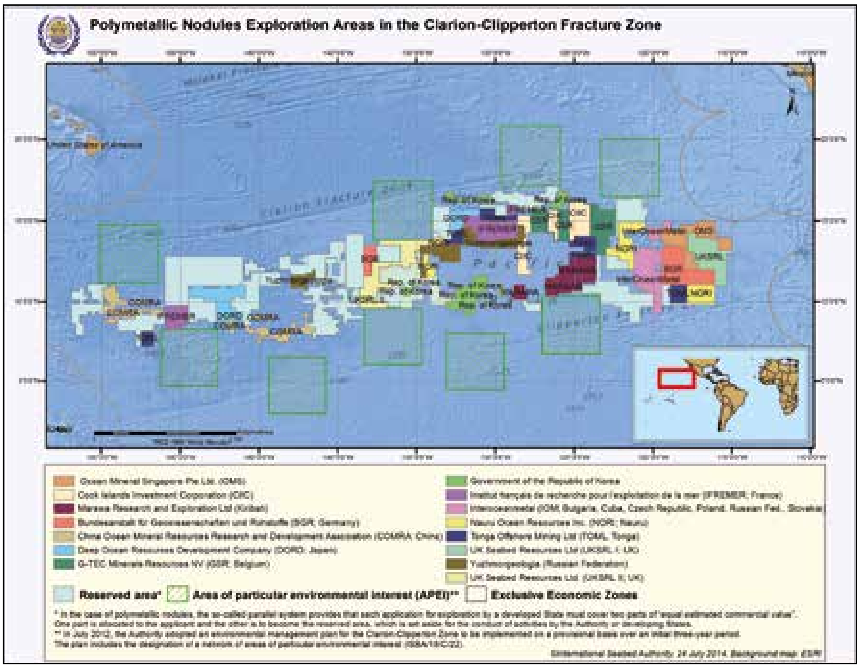


Fig. 3.17 Clarion-Clipperton Fracture Zone ISA exploration contracts (as of August 2015). See map in Figure for scale.

Credit: ISA

> *“Exploitation of deep-sea resources in the Area will be greatly assisted by contractors pooling their baseline data, and on the delivery of exploitation regulations to guide the permitting and mining process.”*
>
> Seabed mining industry stakeholder

The second zone is “the Area” for which the International Seabed Authority (ISA, based in Kingston Jamaica) is in charge of the organization and regulation of activities for exploration and exploitation linked to deep-sea mining. As previously mentioned, the ISA is to act “on behalf of mankind as a whole”, which is a broad remit that takes into consideration all stakeholders, including future generations (1994 Implementation Agreement on Part XI). The ISA has so far adopted the Regulations on Prospecting and Exploration for Polymetallic Nodules; the Regulations on Prospecting and Exploration for Polymetallic Sulphides and the Regulations on Prospecting and Exploration for Cobalt-Rich Crusts. These regulations together with the recommendations by the ISA Legal and Technical Commission for the guidance of contractors on the assessment of the environmental impacts of exploration for polymetallic nodules, form the so-called ‘Mining code’. The ISA is currently developing both the regulatory framework to guide future seabed mining as well as the financial mechanism for benefit sharing. This will also entail the development of more detailed standards for EIAs, SEAs and strategic/regional environmental plans that will need to be informed by new and improved scientific understanding. 22 exploration contracts are effective in the Area: 14 for polymetallic nodules, mainly in the Clarion-Clipperton Fracture Zone (Figure 3.17), 5 for sea-floor massive sulphides (Mid Atlantic Ridge and Indian Ocean) and 3 for cobalt-rich crusts (Western Pacific Ocean), with 4 awaiting signature. The first contracts were signed in 2001 and will expire in 2016.

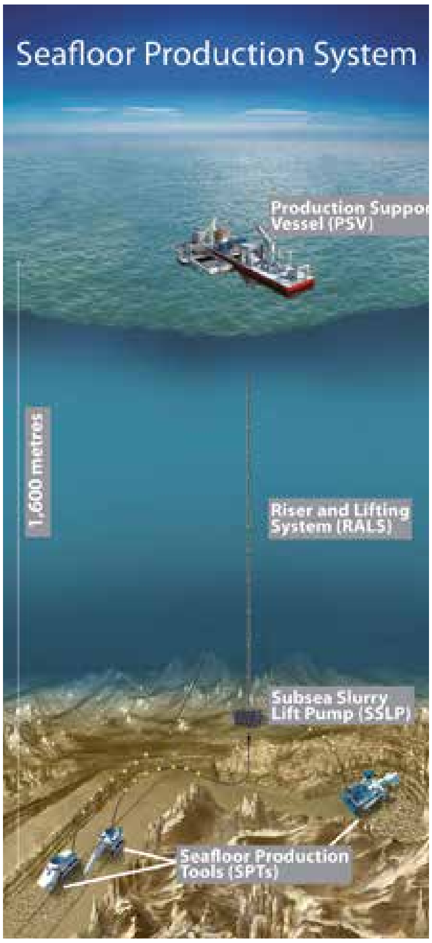
3.4.3.5 Exploitation strategy

Up until now, no industrial exploitation has started for deep-sea mineral resources and the current activities are linked to exploration rather than exploitation. Typically, the process of exploitation will comprise three stages. Nodules will be collected and separated from the sediment whereas sulphides and crusts will be excavated or scraped. Depending on the size and other factors, the material may then be crushed and lifted to the sea-surface with risers with the precise riser approach still being debated. It will likely involve seawater circulation. The solid ore would then be separated from the pumped liquid and stored on ships or platforms prior to transfer to the shore for processing. The way in which produced water might be handled is still under discussion.

All aspects of the exploitation process are still the focus of much research activity, ranging from the basic natural sciences through metallurgy and production processes.

The first industrial mining operation for seafloor massive sulphides is likely to begin within the EEZ of Papua New Guinea by 2018 (Figure 3.18). In order to be prepared for such interest in the Area, in 2014, the ISA took the first steps toward the development of an exploitation code. To kick-start reflection and discussion, the ISA held a public consultation of its wider stakeholder community to which forty one governments, NGOs, science and industry representatives responded. This was followed by two reports of the ISA's Legal and Technical Commission in March 2015 covering possible structures for an exploitation regulation and payment mechanism respectively (ISA, 2015a; ISA, 2015b). In addition, it announced three further reports addressing a mining inspectorate, ISA revenue management and the Enterprise. In late Spring 2015 forty-nine stakeholders responded to an invitation to comment on the exploitation report. Most recently, and on the basis of the stakeholder responses, the ISA published an update of the exploitation report in July 2015. Throughout the ISA reports and in many stakeholder submissions, the importance of science to the future of the deep-sea mining regime is repeatedly

Fig. 3.18
Left: Seafloor production system from Nautilus for SMS.
Right: Collecting Machine (CM), a robotic vehicle which collects cut material (sand, gravel, silt) with seawater with internal pumps and transfers the slurry to the rider and lifting system.
http://www.nautilusminerals.com/s/Projects-Solwara.asp



Credit: Nautilus

Credit: Nautilus

stressed. Specifically, the marine scientific community is expected to deliver the knowledge necessary to ensure high standards in exploitative activities as well as the knowledge to environmentally protect those areas mined as much as possible. The exchange of scientific data and information is also expected to contribute to the transparency and, thus, to the good governance of mining activities. In short, as with many other issues in the deep-seas, there is a demand for more science for both exploitative and protective measures.

3.4.3.6 Impact

A complete evaluation of the potential impacts of deep-sea mining, as well as their duration, is difficult to carry out with the current knowledge of the functioning and the recovery rate of the ecosystems. However, the main direct impacts linked to the extraction processes at sea (not including the ore processing on land or the possible leaks or accidents) concerning the different resources can be assessed.

'Pilot projects (such as pilot mining, demonstration and impact studies) are still needed.'

Seabed mining industry stakeholders, The Netherlands, Norway, Germany, Belgium

The first impact will be a nearly complete loss of the substrata and thus the fauna on the totality of the exploited area. Rapid recolonization processes have been hypothesized on the active parts of SMS but these are likely to depend on the locality of mining, the geological setting and resulting longevity and distribution of vent sites. For the mine off Papua New Guinea other vent sites are close to the site where mining will take place and so rapid recolonization of the site has been predicted but without any ground-truthing as of yet.

The excavation and crushing processes will inevitably produce a plume of particles at the seabed. The rising system and dewatering processes on board the storage vessels will produce a secondary plume(s) enriched in small particulate matter that may be eventually discharged at or near the bottom or discharged in the water column, current rules say below the thermocline. These discharge plumes will have physical (sedimentation) and biogeochemical (metal leaching) impacts on the pelagic and/or benthic fauna, depending on the depth of the discharge, the local or regional hydrodynamic conditions, and the sediment size, which makes the spatial scale difficult to evaluate. Sediment plume and settlement was also raised as an issue in consideration of phosphate mining on the Chatham Rise.

Indirect impacts can be also listed concerning, for example, the effect of the noise, light, or electromagnetic disturbances on the local fauna, and/or the increase in shipping activity in the exploited area.

Even though new work is being carried out (e.g. European Framework 7 MIDAS project, baseline assessments following ISA guidelines, draft ISA framework for the regulation of exploitation activities[40]) to refine the content of Environmental Impact Assessment (EIA) procedures related to deep-sea mining projects, it appears that the actual fundamental knowledge is not sufficient yet to propose an efficient EIA evaluation procedure. This is a particular issue where baseline knowledge on surrounding or connected ecosystems may be very poor leading to the issue that EIAs may have no context on which to judge significant adverse impacts. In other words, everything can be known about a potential mining site but without knowledge of surrounding similar ecosystems a judgement cannot be made on the rarity of species present, connectivity, (e.g. whether a site is a significant source population) or broader ecosystem functions. Environmental policies will have to be adjusted to the increasing knowledge using a collaborative approach involving scientists, industries, stake holders as well as the general public.

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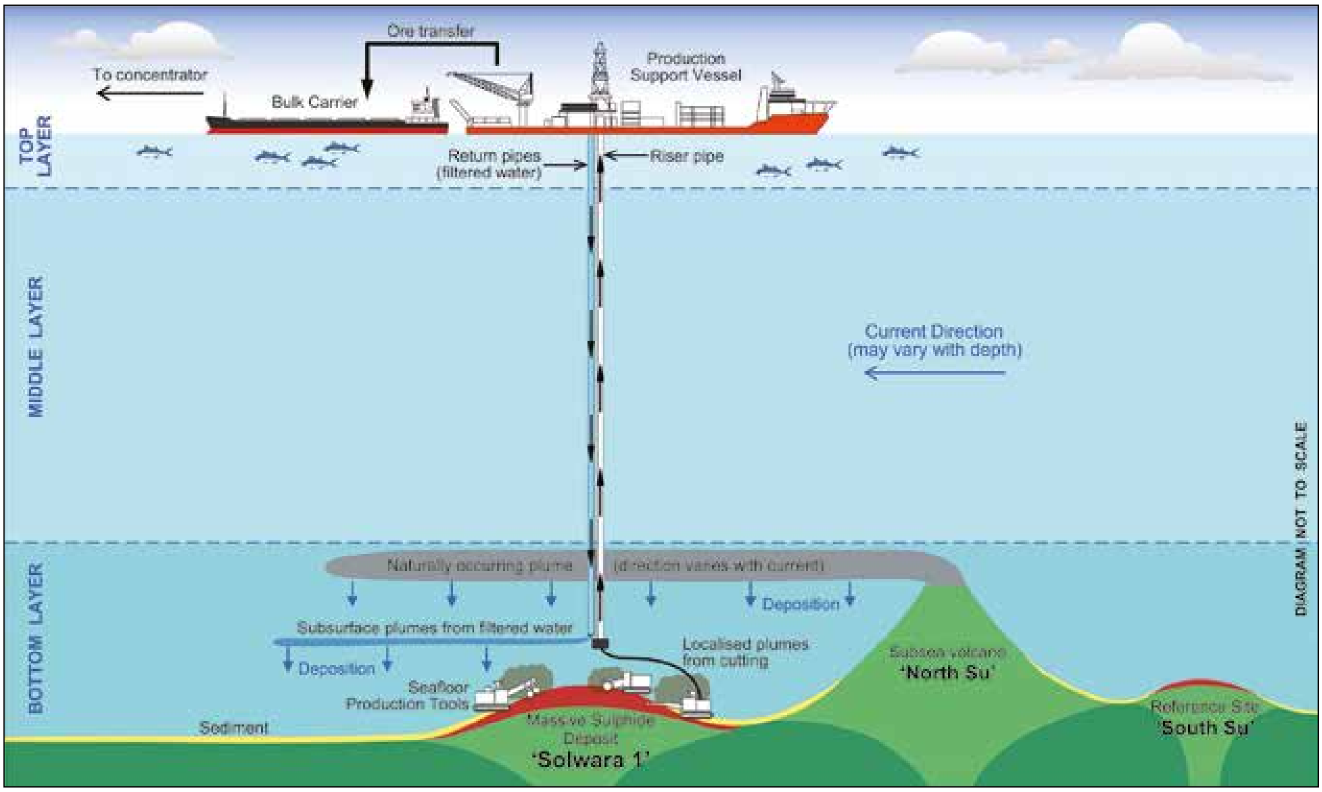
[40] https://www.isa.org.jm/survey/2015-exploitation-framework-survey



Credit: Nautilus

Fig. 3.19 Mitigation strategies for seabed mining.

3.4.3.7 European and International focus

At the G7 Summit, 7-8 June 2015, the Leader's Declaration noted the growing commercial interest in marine mining and the need to take a precautionary approach underpinned by scientific research. In turn, the European Commission has particularly focused on the opportunities of seabed mining, both in European waters and under European licenses in the Area, and have undertaken a number of studies to better determine the current knowledge, stakeholder involvement and future needs. In 2014 the European Commission launched a stakeholder consultation on seabed mining, to which EMB responded specifically to the section 'Mining in Deeper Water' with preliminary results of the Working Group activities[41]. There were 206 replies with a representative selection of private bodies, public authorities, researchers and other replies. Another 515 respondents, rather than replying to the questions, sent individual e-mails. The Joint Programming Initiative on Healthy and Productive Seas and Oceans (JPI-Oceans) is also facilitating a multinational pilot action, "Ecological aspects of deep-sea mining", led by German institutions, to survey and study the DISCOL site in the Peru Basin, southeastern Pacific (see chapter 7, footnote 76).

> *"We are committed to taking a precautionary approach in deep-sea mining activities, and to conducting environmental impact assessments and scientific research."*
> Leaders' Declaration, G7 Summit,
> 7-8 June 2015
> https://www.g7germany.de/Content/EN/_Anlagen/G7/2015-06-08-g7-abschluss-eng_en.pdf?__blob=publicationFile&v=1

There have also been a number of recent activities by the European Parliament e.g. through the Science and Technology Options Assessment (STOA) panel[42] and the Intergroup Seas, Rivers, Islands and Coastal Areas and Climate Change Biodiversity and Sustainability (CCBSD) which have included parliamentary briefings, and reports. For instance, in 2015, the STOA panel published a report assessing technology options for deep-seabed exploitation (European Parliament, 2015). Through an extensive literature review and interviews with 23 experts, the

[41] http://ec.europa.eu/dgs/maritimeaffairs_fisheries/consultations/seabed-mining/index_en.htm

[42] http://www.europarl.europa.eu/stoa/cms/home/publications/studies?reference=EPRS_STU%282015%29547401

panel outlined the knowledge gaps and risks, the legal framework at the EU and international level, the main technological, economic, environmental and societal aspects and impacts, and the next steps for the EU.

3.4.3.8 Knowledge Gaps and Research questions

The expanding interest deep-sea mining has highlighted a number of key research questions:

- Significant knowledge gaps need to be addressed in resource evaluation, study of the ore formation processes, exploration (infrastructure, and instruments) and mapping of the deep seabed;
- Fundamental knowledge to be acquired in terms of marine ecosystems;
  - Interaction between the geo and bioprocesses (geomicrobiology);
  - Baselines of biodiversity (species richness, abundance, biomass) and ecosystem functioning of the deep-sea ecosystems concerned;
  - Connectivity and life cycles of the species that live on and around potential mining areas;
  - Temporal dynamics (deep-sea observatories) of the ecosystems in which mining is likely to take place;
  - Bentho-pelagic coupling via food webs, life histories and other aspects of the ecology of deep-sea communities;
  - Ecotoxicology associated with exposure to resuspended metals and other materials associated with the mining process;
  - Identification of tracers to track mining plumes and transport of suspended metals etc. in the water column;
  - Modelling of deep-ocean currents, mixing, and the associated dispersal of deep-water sediment plumes;
- Transfer of knowledge to industry;
  - There is a need to develop efficient (scientifically and economically) impact assessment protocols;
  - There is a need for the development of management tools;
- Data sharing and funding of environmental Research;
  - Funding of baseline research should be Public at the national and international levels this is because the majority of funding by industry is mainly limited to resource evaluation, the environmental compartment being highly restricted in geographic scope and scientific detail;
  - It is critical to develop new systems for sharing of environmental data.

3.4.3.9 Pros

Growing human population is placing increasing demands on resources with the needs for sustainable energy and other forms of technology requiring increasing supplies of rare metals (Hein *et al.*, 2013). It has reached the point where land-based resources may not be sufficient to meet these demands (Hein *et al.*, 2013). Furthermore, geographically-limited sources of some of these metals means that strategic supply has become an issue (e.g. China is the major producer of 30 critical metals but more and more of this production is being used internally; Hein *et al.*, 2013). Grades of the ores produced by terrestrial mines are also in decline, for example an average copper ore now comprises only 0.5% Cu on land but SMS deposits vary from 1 to 12% (Hein *et al.*, 2013). Land-based mines also face the issue of removal of increasing quantities of overburden and have a large footprint in terms of processing facilities and roads etc., with serious environmental impacts on areas which may be important for food production, habitation or conservation of the Earth's biodiversity. Processing of some terrestrial ores, most notably those from China for rare earth elements (REEs; associated with radioactive thorium) can be particularly environmentally harmful. Marine mineral deposits, because they are richer and in some cases more easy to extract may pose a lower environmental risk (Hein *et al.*, 2013).

3.4.3.10 Cons

Deep-sea mining will herald a new industrialization of parts of the ocean that have previously not experienced direct human influence. The ecosystems involved are poorly explored and understood with limited knowledge on biodiversity, ecosystem function, ecosystem services and their spatial and temporal variation. The broader connectivity of these ecosystems, including with the wider ocean is also not understood. At present deep-sea mining is only in its exploratory phase. Despite extensive work prior to production by deep-sea mining companies (e.g. Nautilus) ultimately the effects and impacts of deep-sea mining operations will not be fully understood prior to them taking place. This is particularly the case in understanding the resilience of marine ecosystems (sensitivity to impacts and ability to recover from them) and the wider effects of sediment plumes on both the water column and seabed. The legal framework with respect to deep-sea mining is also yet to be refined, and the framework for benefit sharing of profits from such activities in the Area is unresolved. Regardless of the amount of legislation, implementation is always critical and is the area where international ocean governance has demonstrated failures in the past with respect to activities such as fishing.

3.4.3.11 Alternatives

The main alternative identified to marine mining is recycling, a key component of the European Union Circular Economy Roadmap[43]. Whilst the current level of recycling for metals such as copper is quite high (estimated end-of-life recycling rate [EOF-RR] of approximately 45%; Glöser *et al.*, 2013), that for REEs is extremely low and newly extracted metal is required to meet demand. At present there are a number of barriers to recycling of REEs namely inefficient systems of collection, technological issues and lack of incentives (Binnemans *et al.*, 2013). Development of efficient, fully integrated recycling routes for REEs might enable EOF-RRs in the region of 16.5 to 56% by 2020 depending on the type of REE and source of material (Binnemans *et al.*, 2013). The rate of growth in demand for REEs at present is about 1% and so it is estimated that even with a major improvement in recycling rates newly extracted material will still be required (Binnemans *et al.*, 2013). However, this, along with improved recovery rates for other metals may influence the economics of deep-sea mining, making it unviable. Furthermore new developments in the sourcing of minerals such as REEs may change the face of strategic supply (e.g. discovery of high REE concentrations in phosphate deposits; Emsbo *et al.*, 2015). Another option is substitution, for example, graphene may replace some REEs in the future.

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[43] http://ec.europa.eu/smart-regulation/impact/planned_ia/docs/2015_env_065_env+_032_circular_economy_en.pdf

3.4.4 Renewable energy

3.4.4.1 Introduction

The dynamic marine environment has considerable potential for renewable energy generation schemes. The less used coastal zone offers large fetch and open space for wind farm energy generation. Other parts of the ocean are endowed with large tidal currents or waves that can be harnessed for power generation. Other concepts involve deep-ocean currents, ocean thermal energy conversion, and farming of algae that could either directly produce hydrogen or are harvestable for biogas production. Currently most investment is focused on the surface ocean in coastal environments because of logistical and financial constraints. The European Commission has been actively involved in funding ocean energy research since the 2nd Framework Programme in the late 1980s.

> *"In order to develop in the deep sea, offshore renewable energy technologies would need to undergo significant technological developments. If in the future technologies are established that could work in these water depths, then environmental impact monitoring, risk analysis and education would all be needed."*
>
> Offshore wind industry stakeholder, UK

Europe has a strong position in ocean renewable energy (blue energy), which is still in an early stage of development and has a strong focus on R&D. Prospects are most promising for the development of tidal current energy, directly followed by wave energy. However, there are also renewable energy technologies that exploit the deep sea, most notably ocean thermal energy conversion (OTEC) and deep-ocean turbines. The key to the future success of blue energy relies upon the rapid development of technological advancements and the successful completion of demonstration projects. Fluctuations in oil prices and commitments to decarbonising the global economy will have a significant impact on the future of this activity. Long-term commitments from governments in the form of policy and regulations are also needed to make the landscape more inviting for investors.

3.4.4.2 OTEC (Ocean Thermal Energy Conversion)

Of all the marine renewable energy schemes currently under investigation, offshore ocean thermal energy conversion (OTEC) has the potential to impact the deep ocean the most as it produces electricity by utilizing the temperature difference between the cold deep ocean water and warm surface waters (the difference should be at least 20˚C). OTEC is therefore most suited to tropical regions and there is little potential at present for direct application in European waters, though some projects are being developed in European overseas territories located in the tropics (Gilmore *et al.*, 2014; Rajagopalan and Nihous, 2013). OTEC can be run in either a closed or open loop system. Closed loop OTEC uses a fluid with a low boiling point (e.g. ammonia) by cycling between evaporation at the warm side of the heat exchanger and condensing at the cold side, to drive a turbine to produce electricity. In the open loop system, warm ocean water is depressurised so that it boils and the resulting steam is used to drive a turbine producing electricity. The steam is then condensed by cooling by the cold deep water. A key advantage of OTEC is that it can provide continuous base-load power and is not subject to episodic variations. It is anticipated that the cold nutrient rich water brought to the surface may be used for air conditioning or aquaculture.

There are a growing number of industrial consortiums developing OTEC globally. The most successful OTEC plant to date is located in Hawaii, where a 250kW test plant was built in 1999. Development has been restricted since then because of high capital and commercialization costs of OTEC. More recently the French group DCNS has developed a land-based prototype on the French Island of La Réunion and is working on several onshore and offshore projects. A Dutch company called

Bluerise is also planning to build a 10kW demonstration plant in Curaçao. However the largest project currently is a 10MW OTEC plant under construction by Lockheed Martin in China and is due to be completed by 2017.

Investment by the European Union has sought to grow the capacity for OTEC in Europe in order to become the world leader and to bring in considerable funds from exporting this technology globally. In 2014, under the NER300 programme, EC Akuo energy and DCNS were funded (72M€) by the European Commission for NEMO "New Energy for Martinique and Overseas", a project for the development of an offshore pilot 16MW OTEC plant in Martinique. The NEMO project has also been strongly supported by the French government during its development.

3.4.4.3 Conduction of electrical power via undersea cables

A critical limiting factor in the development of deep-sea renewable energy will be transmission of electricity to the shore. High voltage direct current (HVDC) is typically used in submarine connections as for distances greater than 30km alternating current (AC) can no longer be used. Currently the longest submarine power cable in use transmits 700MW over 600km from Norway to the Netherlands. Infrastructure and expertise in submarine cables is thus an important part of the development of marine renewable energy. Submarine cables may alter the existing marine habitat and in the coastal zone are most commonly broken as a result of maritime activities (predominantly fishing). Infrastructures associated with new or existing submarine cables should also be utilized for linking to undersea observatories for monitoring of deep-water temperature or salinity. See section 3.5.7 for more information on cables.


Credit: OpenHydro

Fig. 3.20 Tidal turbine being prepared on land. The concept is being tested for use in the deep ocean.

3.4.4.4 Electricity from marine sediments

In many deep-sea sediments, a voltage gradient exists across the water-sediment interface resulting from microbial activity in the sediment because of the consumption of oxygen as they oxidize organic carbon that has sedimented out from the surface ocean (Nielsen *et al.*, 2010). This voltage gradient has been utilized as part of a fuel cell to generate electrical power *in situ* (Tender *et al.*, 2002) and this has been used to power sensors and acoustic modems at an underwater observatory (Schrader *et al.*, 2013). Presently microbial fuel cells derived from bacteria in deep-sea sediments show great promise as cheap low power sources of electricity, but are not yet commercialized.

3.4.4.5 Deep-ocean turbines

Deep-sea currents are often relatively sluggish compared to those in coastal waters but they are consistent. There are currently several projects in the planning or trials phases globally to test the operation of deep-water turbines[44] with the intention of deploying these systems to depths as great as 500m[45].

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[44] http://spectrum.ieee.org/tech-talk/energy/renewables/a-new-idea-for-green-energy-deep-ocean-current-power

[45] http://www.livescience.com/47188-ocean-turbines-renewable-energy.html

3.4.4.6 Research Technology Gaps and Needs

- Research is needed to understand the impacts of cold nutrient rich waters on surface productivity resulting from OTEC;
- Further development and implementation of submarine transmission links for electricity is required;
- Protection of deep-sea cables from fishing activities is a problem that is likely to require both mechanical solutions (burying or armouring of cables) and policy solutions (marine spatial planning);
- More research is required on microbial electricity generation;
- A greater understanding of deep-ocean currents and extreme events;
- Sediment loading, means of servicing.

3.4.4.7 Pros

As coastal areas become more competitive for marine spatial planning between tourism, aquaculture, wind farms etc., options to be able to move further offshore and into deeper water become more desirable. Renewable energy is also a more sustainable option than traditional energy sources such as oil, gas and methane hydrates, and is critical for the energy mix if the EU and Member States are going to meet their energy and carbon emission targets.

3.4.4.8 Cons

The majority of deep-sea renewable energy developments are in conceptual stage and therefore difficult to determine real and long term effects on the ocean system. There is also no proven technology, and so would need high levels of investment and technology development to reach a large scale stage. Kwiatkowski *et al.* (2015) used an Earth System Model (ESM) to evaluate the effects of increased vertical mixing in the upper ocean, as would potentially occur with the use of OTEC and ocean pipe technology. Their model found that increased vertical transport in the upper ocean decreases upward shortwave and longwave radiation at the top-of-the-atmosphere primarily because of the loss of clouds and sea-ice cover over the ocean. Within a century, this produces higher global mean surface temperature than would have occurred in the absence of increased vertical ocean transport. Closed loop systems for OTEC may help mitigate some of the negative effects related to the disruption of the ocean thermocline.

3.4.4.9 Alternatives

Currently, there are a number of renewable energy options that have proven technology on land and in shallow and coastal waters, such as wind, solar and tidal. For some of these, it is a case of adapting the technology for the deep sea to allow access to less competed-for space and potentially more energy, such as the use of floating platforms for wind energy, or adding wind turbines and solar panels to multiuse offshore deep-ocean platforms.

3.4.5 Geoengineering (climate engineering) in the ocean

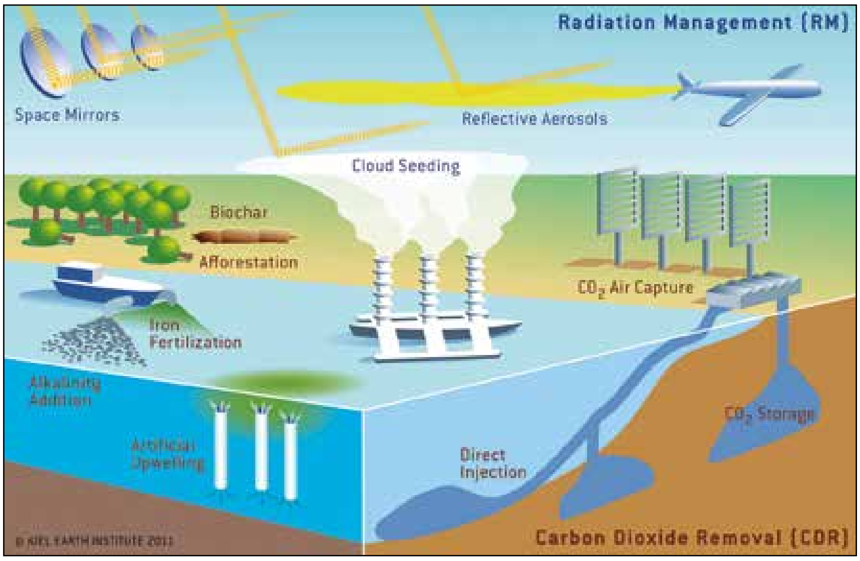


Fig. 3.21 Various geoengineering schemes, both terrestrial and oceanographic.

Credit: Kiel Earth Institute

3.4.5.1 Introduction

There is now widespread scientific consensus that the burning of fossil fuels and the resulting increase in atmospheric CO_2 has led to, and will continue to drive, a significant warming of the planet (IPCC, 2013). The warming surface ocean also results in the transport of heat into the intermediate (Chen and Tung, 2014; Durack *et al.*, 2014) and deep layers of the ocean (Fahrbach *et al.*, 2011). Enhanced thermal stratification of surface waters results in reduced ventilation of deep waters and reduced solubility of most gases with warmer surface temperatures potentially leading to less oceanic uptake of CO_2 and oxygen. The latter will also lead to deoxygenation of intermediate and deep waters through reduced oxygen supply, and a warming surface ocean will most likely increase ecosystem productivity and thus greater respiration (Gruber, 2011; Stramma *et al.*, 2008). In addition, increasing atmospheric CO_2 will directly lead to more uptake of CO_2 by the ocean, and through simple changes in ocean chemistry, to acidification with widespread impacts on ocean organisms (Orr *et al.*, 2005; Gattuso *et al.*, 2015).

The ocean is presently one of the major sinks for anthropogenic carbon (Sabine *et al.*, 2004) and since the start of the industrial revolution the oceans have taken up approximately 155Pg CO_2 from the atmosphere out of 530Pg CO_2 released through fossil fuel burning and land use change (Khatiwala *et al.*, 2013). The majority of this anthropogenic CO_2 resides in the upper ocean and has resulted in a decrease in the pH of the surface ocean of approximately 0.1. In the deep ocean where the anthropogenic CO_2 is yet to mix into, there has been no observed change in pH yet. Modelling studies predict that the oceans will take up most of the CO_2 released to the atmosphere over several centuries as the CO_2 is dissolved in surface waters and gradually mixed into the deep waters via the thermohaline circulation. Ocean mixing does limit the timescales over which anthropogenic CO_2 is stored in the ocean, as on millennial time scales the ocean will eventually equilibrate with the atmosphere (Archer *et al.*, 1997).

While adaptation and mitigation strategies are being explored and pursued across the globe to combat the problem of global warming, there is recent interest in potential geoengineering (climate engineering) solutions and this has prompted a number of high profile national reports (National Academy of Sciences, 2015a; National Academy of Sciences, 2015b; Royal Society, 2009) some of which involve ocean-based solutions.

Geoengineering schemes (Caldeira *et al.*, 2013) can be classed into two main categories:

(i) CO_2 removal (CDR) – technologies that seek to remove CO_2 from the atmosphere and store it long term;
(ii) Solar radiation management (SRM) – technologies that attempt to reduce the energy received at the surface from incoming solar radiation.

Many of the proposed CDR strategies directly involve the ocean (Rau *et al.*, 2012) and those with direct pertinence to the deep sea are examined in more detail below. In the case of SRM schemes (Robock *et al.*, 2009), while there is a developing community of modellers (Kravitz *et al.*, 2013), there are no reports as yet of studies looking at the impacts for the deep ocean on changing the incoming surface radiation. One proposed SRM scheme is the injection of sulphate aerosols into the atmosphere (Crutzen, 2006), and is often viewed as analogous to the natural eruption by volcanoes of SO_2 leading to climate cooling. Studies examining the impact of volcanic aerosols on climate have suggested that while there is cooling there is no change (Jones and Cox, 2001) or minimal changes (Tjiputra and Otterå, 2011) in the ocean uptake or release of CO_2. Additionally SRM schemes do not address ocean acidification (Williamson and Turley, 2012) and may indeed exacerbate the problem as a result of greater uptake of CO_2 by cooler surface waters (Kravitz *et al.*, 2013).

3.4.5.2 Nutrient (iron, nitrogen, phosphate) fertilization or nourishment of the surface ocean

Enhancing the primary productivity of specific crops for CDR is seen as a relatively simple mechanism to address the CO_2 imbalance from burning fossil fuels. Currently research is focused on three such CDR methods (Powell and Lenton, 2012):

- Biomass energy with carbon dioxide capture and storage (BECCS). Ocean nourishment or ocean fertilization is considered here as a form of BECCS;
- Biomass energy with CO_2 capture and storage (BECCS). In this process CO_2 is captured and stored from gasification, combustion, or fermentation of biomass (Fuss *et al.*, 2014). Seaweed has recently been put forward as a marine candidate crop for BECCS (Hughes *et al.*, 2012);
- Biochar production. Biochar is charcoal created by pyrolysis of biomass waste under low oxygen conditions with minimal release of CO_2. Furthermore this process is intended to render the resulting Biochar relatively inert to further microbial oxidation with no long term release of CO_2.

Primary productivity in the surface ocean is strongly limited by the availability of nitrogen or phosphorus in most oceanic regimes (Moore *et al.*, 2013). However, in upwelling zones and high latitude regions there is significant nitrogen and phosphorus available but phytoplankton growth is low because of the absence of the micronutrient iron (Martin *et al.*, 1990). Such regions are described as high nutrient low chlorophyll (HNLC) areas. Over the last 20 years there have been a number of mesoscale iron enrichment experiments performed in the ocean to test the hypothesis of iron limitation (Boyd *et al.*, 2007). While iron enrichment is an example of a BECCS strategy the long-term removal of CO_2 is thought to be poor and inefficient because of the subsequent remineralization of the sinking organic material in the surface ocean and the costs involved with transporting iron to HNLC regions (Williamson *et al.*, 2012). A further unintended consequence of widespread ocean fertilization is 'nutrient robbing' (Gnanadesikan and Marinov, 2008), a process in which nutrients which would normally up well in a coastal region after transport through the ocean conveyor system from HNLC areas, are removed by ocean fertilization and reduce the primary productivity elsewhere. However, one of the iron enrichment experiments (EIFeX) did see significant amounts of carbon export to deep-ocean sediments via fast sinking diatom aggregates (Smetacek *et al.*, 2012). Carbon transferred to such sediments may take some decades to hundreds of years to be respired and returned to the surface (Robinson *et al.*, 2014). This flux of carbon to the benthos will also enhance the benthic carbon cycle (Hughes *et al.*, 2007) as is seen in deep-sea communities influenced by natural iron fertilizations in the Southern Ocean (Wolff *et al.*, 2011).

While scientific interest in open ocean iron fertilization has waned as a possible BECCS scheme, a recent rogue experiment along the west coast of Canada (Tollefson, 2012) brought this approach again to the public's attention. This Canadian experiment was targeted at increasing Salmon numbers but it is unclear if it had the desired impact (Batten and Gower, 2014; Xiu *et al.*, 2014) or if it has had an impact on the deep ocean.

3.4.5.3 Ocean Storage of Biochar or crop residue (BECS)

While most studies involving biochar have examined its impact as landfill in terrestrial environments, some groups have proposed to store it in the deep ocean as part of a range of mitigation strategies. At present there are no reports on the effects that high concentrations of biochar may have on the deep ocean. Recent work has focused on the transport of 'black carbon' or charcoal particles from soils to rivers and ultimately the coastal ocean (Jaffé *et al.*, 2013) and sequestration in continental shelf sediments (Sánchez-García *et al.*, 2012).

A related approach that has also been suggested is the carbon sequestration of terrestrial crop residue in the ocean by burial in the deep sea (Strand and Benford, 2009). Initial laboratory experiments have indicated that terrestrial crop residues (e.g. soy stalk, maize stover) in seawater were only slightly remineralized (Keil *et al.*, 2010) and much less so than marine phytoplankton material. However, at present there are no studies on the impact of this material on other biogeochemical cycles (e.g. Nitrogen or Oxygen) or benthic communities.

3.4.5.4 Direct CO_2 sequestration in the deep ocean

The pressure and temperature regime in the ocean can induce changes in the chemical properties of CO_2 in seawater which have been utilized to sequester CO_2 in deep-ocean waters. In seawater below 500m, pure CO_2 will undergo a phase change from gas to liquid because of the effects of pressure and temperature. This liquid CO_2 will be positively buoyant (rising) in deep seawater until it is below approximately 3,000m, but negatively buoyant (sinking) below that depth. Below approximately 3,700m, the liquid CO_2 becomes negatively buoyant compared to seawater saturated with CO_2. Importantly solid CO_2 hydrates (CO_2•nH_2O, $6<n<8$)

can also form exothermically below about 500m depth. While the solid hydrate is denser than seawater, the inclusion of gas and liquid in the hydrate can cause newly formed hydrates to rise.

The idea of injecting CO_2 into the deep ocean was first proposed by Marchetti in 1977 (Marchetti, 1977) and the idea has been developed further by other scientists since that time. The rational for this approach is that the large size of the ocean and the geochemical buffering provided by seawater alkalinity and carbonate sediments will result in the injected CO_2 being removed from the atmosphere for 300-1000 years before released back to the atmosphere (Ridgwell *et al.*, 2011).

The first small scale scientific tests were carried out in Monterey Bay, California in 1998 (Brewer *et al.*, 1999). In the small scale experiments performed so far, benthic fauna have been found to be seriously impacted by the plume of CO_2 from the release site (Barry *et al.*, 2004). Immediate mortality was seen close to injection points, though some species could survive limited exposures to high CO_2 levels but the long-term chronic effects have not yet been studied in deep-sea organisms. While it is anticipated that the impacts on benthic ecosystems will increase with increasing CO_2 concentrations, as yet no environmental thresholds or tipping points have been identified. Modelling studies indicate that if pursued as a climate change mitigation strategy deep waters would become more acidic and would impact benthic organisms particularly those benthic calcifiers (e.g. cold water corals) (Ridgwell *et al.*, 2011).

3.4.5.5 Ocean pipe technology

There are two ways ocean pipe technology has been proposed to mitigate the effects of climate change. The first is by using the pipes to increase ocean carbon uptake by bringing nutrient rich deeper waters into nutrient limited surface regions, hypothetically increasing primary production (Kwiatkowski *et al*. 2015; Lovelock and Rapley, 2007). The second is using ocean pipes to store thermal energy in the deep ocean.

3.4.5.6 Pros

Between renewable energy options and carbon sequestration, the deep sea may be important in helping the EU meet its sustainable energy targets, including reducing its emissions to 20% below 1990 levels by 2020 and 80% below 1990 levels by 2050. Coal, gas and oil currently supply 80% of the world's energy needs (ZEP, 2013) and though renewable energies are improving, we cannot rely solely on them in the near term. Many options exist to reduce GHG emissions, one of which is carbon dioxide capture and storage (CCS), which needs to be used in concert with greater energy efficiency and renewable energy (ZEP, 2013). CCS has the potential to capture half the world's CO_2 emissions overall and reduce global CO_2 emissions by 19% (ZEP, 2013). Deploying CCS, alongside renewable and nuclear energy options, could deliver electricity prices around 15% lower in 2030 than decarbonising without CCS (CCSa, 2015). The International Energy Agency (IEA) states that fighting climate change could cost 70% more without CCS. Captured CO_2 could be used for Enhanced Oil Recovery (CO_2 EOR) in the Central North Sea, lowering the cost of CCS, increasing the proportion of recoverable oil and extending the life of oil and gas infrastructure (CCSa, 2015). A clear regulatory framework is thus required for a commercial scale, integrated system, and the EU's CCS Directive provides this. (EC Climate Action).

To make this transition the EU would need to invest additional €270 billion, or 1.5% of its GDP annually, on average, over the next four decades. To meet these targets, and in addition to other measures, CCS would need to be deployed on a broad scale after 2035, notably to capture industrial process emissions. This would entail an annual investment of more than €10 billion (see Roadmap, EC, 2011). In a world of global climate action, this would not raise competitiveness concerns. The Commission's proposal for a 2030 climate and energy policy framework acknowledges the role of CCS in reaching the EU's long-term emissions reduction goal. However, to ensure that CCS can be deployed in the 2030 timeframe, increased Research and Development is required.

One of the side effects of climate change and ocean warming is an increase in extreme weather events because of the increase in thermal energy. Ocean pipe technology could therefore be used to limit the impact of extreme events such as hurricanes.

3.4.5.7 Cons

While a number of geoengineering approaches have been proposed, each introduces uncertainties, complications and unintended consequences that have only begun to be explored (MacCracken, 2009). The majority of options need significant technological advances and current capacity is limited and costs high.
Barriers to large-scale deployment of CCS technologies include concerns about the operational safety and long-term integrity of CO_2 storage as well as transport risks and the potential environmental consequences of leakage into the environment (IPCC AR5, WG3 Ch.7). As of mid-2013, CCS has not yet been applied at scale to a large, commercial fossil-fired power generation facility. However, all the components of integrated CCS systems exist and are in use today for hydrocarbon exploration, production, and transport, as well as the petrochemical refining sectors (IPCC AR5). The CCS chain consists of three parts: capturing the carbon dioxide, transporting the CO_2, and securely storing the CO_2 emissions, underground in depleted oil and gas fields or deep saline aquifer formations (ZEP, 2013). Currently, the main cost element in the CCS value chain is 'capture' (STATOIL).

SRM technologies such as atmospheric aerosols and ocean albedo modification do not address the ocean acidification issue and are therefore of limited value in mitigating climate change impacts on the ocean.

Vertical ocean pipes could drastically alter the ocean thermocline. Prolonged application of ocean pipe technologies, rather than avoiding global warming, could exacerbate long-term warming of the climate system (Kwiatkowski *et al.*, 2015). See chapter 7 for a more in depth description as similar effects as OTEC.

3.4.5.8 Legal framework

The London Convention/London Protocol Annex 6 urges precaution in the use of geoengineering technologies but only covers ocean fertilization at present. In 2010 parties agreed to continue working towards a global, transparent and effective control and regulatory mechanism for ocean fertilization and other activities that have the potential to harm the marine environment (CBD, 2012). New types of ocean engineering can be classed as emerging activities that fall within this remit but they must still fall within the purview of the London Convention/ London Protocol. In some cases, such as the use of ocean pipe technology the approach may not be covered by the London Convention / London Protocol. There is also an argument under international law that placement of materials into the ocean for purposes other than disposal may mean that geoengineering schemes cannot be classed as dumping at all (CBD, 2012). Likewise, other aspects of specific types of geoengineering targeted at the ocean may be covered by existing legislation (e.g. harm to the marine environment and UNCLOS). In the case of CCS in European waters, the legal framework that should be considered in the selection of storage sites and the planning of environmental risk assessments and monitoring studies includes not only the EU directive on CO_2 capture and storage (CCS) but related legislations including the EU Emission Trading Scheme, the Environmental Liability Directive, the Environmental Impacts Assessment Directive, the Strategic Environmental Assessment Directive, the London Protocol, OSPAR Convention, and Aarhus Convention. Public involvement in the planning and development of CCS projects is required by legislation. However, the CBD COP 11 noted:

> *"The lack of science-based, global, transparent and effective control and regulatory mechanisms for climate-related geoengineering, the need for a precautionary approach, and that such mechanisms may be most necessary for those geoengineering activities that have a potential to cause significant adverse transboundary effects, and those deployed in areas beyond national jurisdiction and the atmosphere, noting that there is no common understanding on where such mechanisms would be best placed (XI/20, paragraph 8)"*[46].

There is clearly a need for the development of a global framework to address the potential environmental and social consequences of proposed climate engineering technologies.

3.4.5.8 Research questions

Pilot projects are key to learn more about marine CO_2 sequestration including to test technology, reduce costs, and improve safety (see Box 3.4; Statoil, 2015). The following research priorities are suggested:

- Several CDR technologies require further technological development and testing including an appraisal of technical and economic feasibility;
- Improved technologies and "know-how" for CO_2 seabed injection or injection into disused oil / gas well. CO_2 injection into the seabed has already been found to have negative impacts on deep-sea ecosystems and is likely to impact deep ocean chemistry if undertaken at a large scale;
- A more thorough understanding of the broader ecosystem impacts of several geoengineering methods proposed for deployment in the ocean;
  - Further understanding of the biogeochemical and ecological implications of ocean fertilization;
  - An understanding of the impacts of deposition of biochar or crop residues in the deep ocean;
  - Biogeochemical and Earth-system implications of ocean-pipe technology;
- Strong baseline research is needed to underpin good governance and the development of regulations.

[46] https://www.cbd.int/decisions/cop/?m=cop-11

BOX 3.4 ECO2 PROJECT

One EU project that assessed the environmental risks associated with the sub-seabed storage of CO_2 and provided guidance on environmental practices was ECO_2 Opoczky, 2015. The ECO_2 project compared existing CO_2 storage sites in Norway Sleipner, 1996; Snøhvit 2008 at water depths of 250-350m with several natural seepage sites in order to identify potential pathways for CO_2 leakage through overburden. The project monitored seep sites at the seabed, tracking and tracing the spread of CO_2 in ambient bottom waters, and studying the response of the benthic biota to CO_2. The project's observations at natural seeps, release experiments and numerical modeling have revealed that the footprint at the seabed where organisms would be impacted by CO_2 is small for realistic leakage scenarios. These data match the 2005 Special Report on CCS by the IPCC which concluded that appropriately selected and managed geological reservoirs are 'very likely' to retain over 99% of the sequestered CO_2 for longer than 100 years and 'likely' to retain 99% of it for longer than 1000 years (EC Climate Action).

Based on these observations, the project created guidelines and recommendations for environmental practices, which includes a generic approach for assessing consequences, probability and risk associated with sub-seabed CO_2 storage based on the assessment of i) the environmental value of local organisms and biological resources, ii) the potentially affected fraction of population or habitat, iii) the vulnerability of, and the impact on the valued environmental resource, iv) consequences (based on steps i – iii), v) propensity to leak, vi) environmental risk (based on steps iv and v). The major new element of this approach is the propensity to leak factor which has been developed by ECO2 since it is not possible to simulate all relevant geological features, processes and events in the storage complex including the multitude of seepage-related structures in the overburden and at the seabed with currently available reservoir modelling software. The leakage propensity is thus estimated applying a compact description of the storage complex and more heuristic techniques accommodating for the large number of parameter uncertainties related to e.g. the permeability of potential leakage structures. (Opoczky 2015). Following ECO_2, a new H2020 project, STEMM-CCS , is due to start in 2016, coordinated by the National Oceanography Centre, UK.

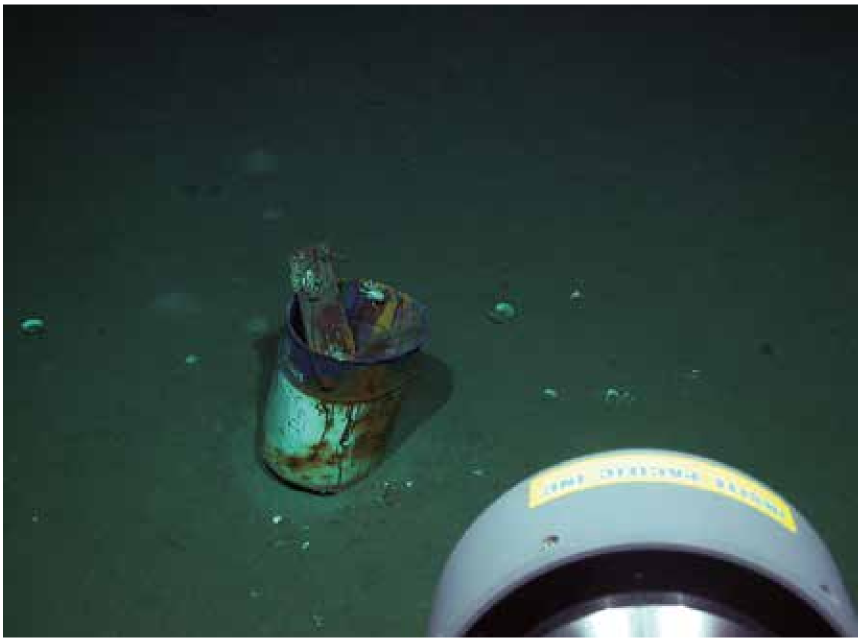
http://www.eco2-project.eu/

Strong research and investment is also needed at the national level. The UK government launched the CCS competition in 2011 and the two 'preferred bidder' projects are making good progress on their engineering studies and permitting activities. The competition remains on track to enable final investment decisions to be made by early 2016 with the aim to develop CCS at scale in the 2020s. The Energy Technologies Institute (ETI) has calculated through its energy systems modeling that without CCS the cost of reaching the UK decarbonization goals in 2050 could double, costing the UK economy an additional £32 billion per year or 1% of the GDP in 2050. No other technology has such a dramatic impact on the costs of achieving a low-carbon economy (CCSa, 2015). As well as keeping energy bills as low as possible, the development of CCS can help to maintain future competitiveness of UK industry e.g. steel, cement, and chemicals, as it is the only technology available to decarbonize these essential sectors. The UK has one of the most advanced policy and regulatory frameworks in the world to support CCS. The combination of the CCS competition and the recent reforms of the electricity market mean that the UK is now well-placed to make CCS a reality (CCSa, 2015).

The potential effectiveness and environmental impacts of other forms of geoengineering are not well understood and there is clearly a need for more research on these aspects for any proposed schemes that may impact the deep ocean.

3.5 Other activities

3.5.1 Waste disposal and legacy materials



Credit: MARUM

Fig. 3.22 Paint can, one example of waste from human activities that ends up on the deep-sea floor.

Ocean disposal of waste materials from land-based sources is regulated by the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter—London Convention 1972 (LC-72). A separate treaty addressing the issue of wastes disposed of from vessels is the International Convention for the Prevention of Pollution from Ships, 1973 (MARPOL), adopted in 1973. Also, national and regional legislation is critically important here, such as the OSPAR Convention for the North East Atlantic and the Barcelona Convention for the Mediterranean.

Prior to the implementation of the London Convention, there was considerable dumping of waste materials in the deep ocean and the legacy of these actions remains with us today and in the future (e.g. Ramirez-Llodra, 2011). For example, approximately 120,000 tonnes of radioactive waste was disposed in the deep north east Atlantic before a moratorium was declared in 1983 in the revised London Convention.

3.5.1.2 Radioactive wastes

The disposal of high level radioactive wastes, which require cooling because of their high heat production, is prohibited in the deep ocean under the London Convention. Lower level radioactive wastes that require shields and special handling techniques, however, were dumped previously in the deep north east Atlantic from 1949-1982 at 9 dumpsites (all below 2000m, and most below 4000m) under the surveillance of the Nuclear Energy Agency (NEA). Approximately 120,000 tonnes of radioactive waste was disposed of during this period. The United States also dumped radioactive waste during this period in the north-west Atlantic and in the Pacific Ocean. In 1983 a moratorium on the disposal of low level radioactive wastes in the deep ocean was declared in the revised London Convention.

3.5.1.3 Munitions

Vast amounts of war materials have been disposed of into the ocean over the last hundred years, most notably after the end of the second world war, and is still ongoing today though at a significantly reduced level. While the majority of the dump sites have been situated on the continental slope, there was significant dumping in the deep ocean (e.g. off Hawaii). The exact locations and extent of many of these dump sites is often poorly known. Recent investigations of contamination of deep-sea biota by chemicals associated with dumped weapons indicated that accumulation appeared to be insignificant (Koide *et al.*, 2015).

Fig. 3.23 Plastic bag on the deep-sea floor.

Credit: MARUM

3.5.1.4 Land based / sourced pollutants

The impact of anthropogenic activities on the deep ocean (Ramirez-Llodra *et al.*, 2011) is now more clearly seen because of the combination of increasing human activities and developments in ocean going technology and analytical capabilities. The most visual pollution is marine litter, and it is found throughout the European seas, including shelves and the deep basins (Pham *et al.*, 2014; Ramirez-Llodra *et al.*, 2013). Marine litter ranges over a variety of sizes from kilometre long ghost nets drifting in the deep ocean to colloids or nanoparticles dispersed in seawater. Other pollutants are derived from human activities on land and are transferred to the deep ocean via riverine runoff, atmospheric deposition and ocean mixing. One prominent example is plastics, which are predominantly sourced from the land and are long lasting in the marine environment due to their low chemical reactivity and biodegradability. Larger items may sink quickly to the depths or be ground up in the surf zone into smaller pieces, known as microplastics (Barnes *et al.*, 2009), that are then transported throughout the globe by the ocean currents (Cózar *et al.*, 2014). Indeed recent evidence indicates that the deep ocean is a major sink for microplastics (Woodall *et al.*, 2014). Microplastics are important as they can have physical impacts on marine organisms (Wright *et al.*, 2013) and may facilitate the transport of organic pollutants (Mato *et al.*, 2000) and heavy metals (Holmes *et al.*, 2012) through the marine environment. Microplastics may also provide a niche for novel bacterial assemblages (Zettler *et al.*, 2013).

3.5.1.5 Persistent Organic Pollutants (POPs)

POPs is a generic term for several groups of man-made chemicals that persist in the environment and are highly toxic as they interfere with many biochemical processes (Farrington and Takada, 2014) and are bioaccumulated through the food web via trophic transfer (Webster *et al.*, 2014). They are typically transported long distances from their source and can thus pose problems to all regions of the globe. POPS are typically found at highest concentrations in surface waters of the world oceans because of their deposition from the atmosphere (Jurado *et al.*, 2004; Nizzetto *et al.*, 2010). Chemically they are typically highly lipophilic and while sparingly soluble in water they are easily adsorbed by suspended particles (Schulz-Bull *et al.*, 1998). However, POPs can be transported relatively rapidly into the deep sea in regions where there is active deep water formation such as the Antarctic and the North Atlantic (Lohmann *et al.*, 2006), or via incorporation into sinking particles from the euphotic zone (Scheringer *et al.*, 2004). The majority of PCBs (polychlorobiphenyls – a subset of POPs) have been found to accumulate in continental shelf sediments (Jönsson *et al.*, 2002) posing a threat to benthic organisms. Organochlorine compounds have also been found to accumulate in pelagic deep-sea organisms (Looser *et al.*, 2000).

3.5.1.6 Heavy Metals

Since the dumping of sewage and dredge material to the deep sea has been reduced the supply of heavy metals by human activities has decreased significantly. An exception to this may be the increased use of the ocean for disposal of mine tailings (see 3.5.1.8). Atmospheric deposition of some heavy metals to the ocean is still elevated over pre-industrial values despite global reductions in the release to the atmosphere (e.g. removal of lead from petrol). Mercury (Hg) is found at very low concentrations in deep ocean waters (Cossa *et al.*, 2004) but it is strongly bioaccumulated by organisms as all of the chemical forms found in seawater, elemental mercury, methyl mercury, and dimethyl mercury are strongly lipophilic. Thus predators at the top of the food chain are most susceptible to Hg toxicity (Koenig *et al.*, 2013).

3.5.1.7 Disposal of dredge spoils and mine tailings

In general dredge spoils are deposited in shallow waters although there are exceptions, most notably around oceanic islands such as Hawaii (Tomlinson and De Carlo, 2015). These materials can be associated with elevated concentrations of toxic materials such as arsenic (Tomlinson and De Carlo, 2015). Increased demand for metals globally is driving pressure to mine both on land and in the oceans (Ramirez-Llodra *et al.*, 2015). Mining produces very large quantities (millions of tonnes per annum in some cases) of waste material comprising a mix of unprocessed rock from overburden and processed material which comprises of pulverized and chemically-treated rock in the form of fine particulate material from which the target mineral has been extracted (Ramirez-Llodra *et al.*, 2015). On land tailings are stored behind dams where the tailings slurry is pumped to settle on the bottom of a natural depression. This has been associated with severe environmental and societal impacts as the slurry often contains heavy metals and processing chemicals which may leach into local waterways or be released through failure of the retaining dam (Ramirez-Llodra *et al.*, 2015). This has led to a rising trend of disposal of mine tailings in the ocean, either in shallow water or through submarine tailing disposal (STD) or deep-sea tailing placement (DSTP; Ramirez-Llodra *et al.*, 2015). The latter two forms of disposal have deposited mine tailings into the deep sea via gravity flows. Impacts include: smothering of the benthic fauna; toxic effects arising from heavy metals or process chemicals within the tailings; changes in the physical characteristics of sediments as well as their organic content (food value); sediment plumes in the water column and re-suspension or upwelling of tailing particles or slope failure leading to wide dispersal of tailings (Ramirez-Llodra *et al.*, 2015).

Submarine tailing disposals have been mainly used in Norway as a result of unsuitable terrains for damming and retention of mine tailings. This is followed by Papua New Guinea and other countries including Indonesia, France, Greece, and Turkey, and STDs and DSTPs have also been used in Greenland and Canada. In Indonesia the Batu Hijau copper and gold mine deposits tailings as deep as 4,000m via the Sennu Canyon (Ramirez-Llodra *et al.*, 2015). Many STDs and DSTPs are located on continental and island margins where a variety of complex habitats such as canyons, cold-water coral reefs, sponge reefs, seeps and seamounts exist. These habitats are known to be hotspots of biodiversity and biological activity but in general baseline knowledge on ecosystems likely to be impacted are lacking, especially in the Indo-Pacific (Ramirez-Llodra *et al.*, 2015). Such baseline data should include not only knowledge of the biota present but also the physical characteristics of disposal sites including seabed bathymetry, ocean currents, and biogeochemistry (Ramirez-Llodra *et al.*, 2015). This has led to incidents whereby mining tailings have spread beyond predicted dispersal areas and where unanticipated issues with toxicity of tailings have arisen (Ramirez-Llodra *et al.*, 2015).

The London Dumping Convention permits the release of inert mining materials into the ocean under permit. However, the lack of understanding of the behavior of mine tailings in the deep ocean and their biological impacts is a significant cause for concern. The London Convention / London Protocol has undertaken a fact gathering mission which has culminated in a report which includes consideration of marine disposal of mine tailings (Vogt, 2013). Other efforts are underway to try and gain a better understanding of the issues that require assessment in DSTP (Ramirez-Llodra *et al.*, 2015) including by IMO and GESAMP (Group of Experts on Scientific Assessment of Marine Environmental Protection). In Europe the EU Directive on Management of Waste from Extractive Industries (2006/21/EC) is drawing up new guidelines for best practice in marine disposal of mine tailings. At state level, as in Norway, marine disposal of mine tailings is subject to a permitting process which involves a significant EIA component prior to operations being approved (Ramirez-Llodra *et al.*, 2015).

3.5.1.8 Illegal dumping, industrial accidents (shipwrecks, oil spills, radionuclides, conflict)

Despite the protection provided to the deep sea by the London Convention, illegal dumping of waste does still occur and could impact the deep sea. Accidents in the maritime environment, such as the *Deepwater Horizon* event, can release vast amounts of hydrocarbons to deep waters, impacting communities in the water column (Ortmann *et al.*, 2012) and the benthos (Montagna *et al.*, 2013; Valentine *et al.*, 2014). Industrial accidents involving radionuclides such as occurred at Fukushima can also contaminate vast regions of the deep sea (Buesseler *et al.*, 2012; Charette *et al.*, 2013). It should also be borne in mind that there have been enormous losses of shipping in the deep ocean as a result of the naval battles of the two world wars containing oil, chemicals and unexploded ordinance. In the Pacific and East Asian region alone it is estimated that there is 13 million tonnes of sunken shipping from World War 2 posing a significant pollution risk to the marine environment (Monfils *et al.*, 2006) and globally there may be 34 million tonnes from the same conflict (Monfils, 2005).

3.5.1.9 Waste disposal research technology gaps and needs

The first challenge in dealing with legacy materials in the deep ocean is simply understanding where they are located. Following this, routes of entry into and transport through deep-sea ecosystems are also poorly understood. For example, the discovery of microplastic and other man-made fibres in the deep ocean suggests that these materials are transported from shallow water via the sinking of particulate organic carbon (marine snow) but this is as yet unproven (Woodall *et al.*, 2014). How these materials degrade over time and what the fate of degradation products are is also largely unknown. Impacts of large and obvious human debris, such as shipwrecks, are not sufficiently studied at the present time.

The increasing use of the ocean for disposal of mine tailings has not received the international attention it deserves. Improving the prediction of the behaviour of mine tailings in marine ecosystems and their biological impacts is a scientific priority with direct relevance also to deep-sea mining. Ramirez-Llodra *et al.* (2015) list in detail the scientific research needs to achieve this but to summarise:

- Improved understanding of the dispersal and deposition of mine tailings in the deep sea;
  - Bathymetry;
  - Hydrodynamics, including annual variation and extreme events;
  - Improved modelling of tailings dispersal;
  - Aspects of the behaviour of particulates associated with tailings once they are released into the environment;
  - Biogeochemical effects;
- Understanding of the species richness, abundance and biomass of deep-sea benthic and pelagic communities likely to be effected by mine tailings;
  - Baseline data collection on biodiversity;
  - Monitoring changes in faunal composition over time;
- Understanding of the impacts on the biota of mine tailings;
  - Accumulation of particulates, metals and other chemicals by deep-sea fauna;

  - Ecotoxicological effects of heavy metals and chemicals, potential biomagnification up the food chain;
  - Interactions with other human impacts (climate change, invasive species);
- Understanding of the recovery potential of impact sites;
  - Connectivity of populations of the deep-sea fauna;
  - Effects of changed substratum on community composition after mining has ceased;
- Improvements in engineering associated with mining and tailings disposal;
  - Research on best practice;
  - Improving the performance of mining in terms of reducing quantities of tailings produced;
- Improved mechanisms of communication and data transparency between the mining industry, government, scientists and civil society.

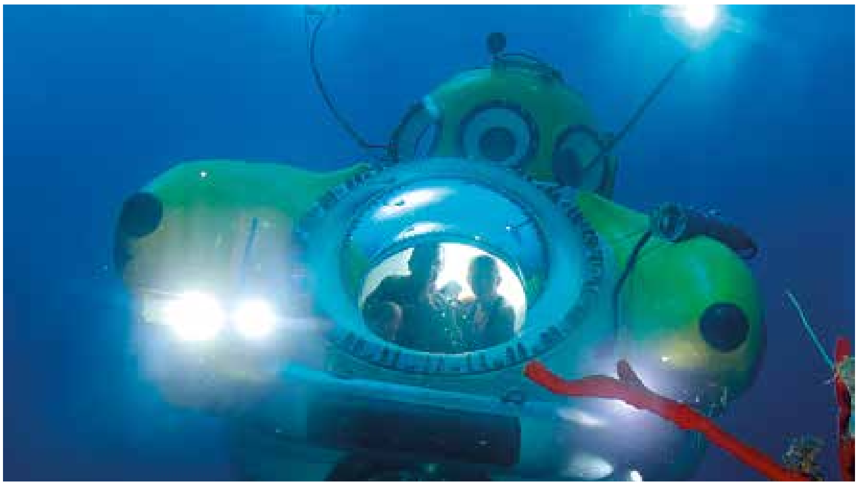
The ecotoxicology of many pollutants in deep-sea species is also an area of science that is poorly understood in many of the impacts discussed above. Many deep-sea species, especially larger animals, are long lived and thus may be exposed to cumulative pollutants over very long periods of time with unknown effects on physiology and fitness. It is also notable that as well as legacy materials in the deep ocean there is a whole new range of products in use by humankind that potentially end up in the ocean including everything from new-generation flame retardants, personal care products and even pharmaceuticals and recreational drugs. Scientific investigation has a long way to go to address these issues.

A further challenge in understanding such human impacts on the deep sea is the lack of understanding of what even represents good environmental status in the deep ocean in the context of the Marine Strategy Framework Directive (MSFD; see section 4.5). We would suggest the following as priority research questions in this context:

- What are the ecosystem features of a healthy deep-sea ecosystem in terms of species richness, abundance, biomass, connectivity, food webs, biogeochemical cycling and ecosystem services? Such investigations require the intensive study of areas of the ocean that have a relatively low level of human impact;
- Where are legacy and new generation contaminants / pollutants located in the deep sea, what are their routes of entry into and transport through the deep ocean, including both physical and biological pathways?
- What are the effects of such materials on deep-sea species, communities and ecosystems and how do they influence ecosystem function and ultimately ecosystem services?
- Is the remediation of such materials possible in the deep ocean?

Such questions demand multidisciplinary science involving advanced methods in seabed and water column biological survey and monitoring, chemistry and ecotoxicology. Geographically large surveys are required to understand the extent of these problems whilst constrained intensive studies are required to understand the mechanistics of how such materials interact with the environment.

3.5.2 Tourism



Credit: Karl Stanley www.stanleysubmarines.com

Fig. 3.24 Submersible *Idabel* on deep-sea tourism expedition, Cayman Trench wall, Roatan Honduras.

3.5.2.1 Growth opportunities for tourism in the deep sea

One of the sectors highlighted by the European Commission's Blue Growth strategy is coastal and maritime tourism. Coastal and maritime tourism represents over one third of the maritime economy and has become the largest maritime economic activity with projected trends only increasing. Deep-sea tourism is an under-utilized resource that could help mitigate many of the challenges to coastal and maritime tourism highlighted by various EC communications. The 'sun and beach mass-tourism' business model is no longer a successful model because of increased competition from cheap international alternatives, the high seasonality, and the enormous strain it puts on the environment. In addition, with the internet, technological advances and social media, citizens are becoming more engaged in our "inner space" which may inspire adventure seeking or science stewardship (ECORYS, 2013).

Deep-sea tourism has the potential to provide an alternative or supplement this business model, by expanding the geographic area in which tourism can occur (thereby decreasing environmental pressures on coasts), adding niche and innovative activities to make Europe more competitive and expanding the traditional tourism season. Lack of innovation and diversification was seen as a challenge for maritime and coastal tourism, which deep-sea tourism could help change. It would also help highlight and create an incentive to keep deep-sea waters clean, even though they are not seen by tourists. Healthy ecosystems are key for deep-sea tourism sectors such as nature based tourism and recreational fishing (EC, 2012a).

3.5.2.2 Current Sectors

Offshore and Deep-sea fishing

Recreational sea angling is a big business in Europe, with an annual socio-economic value estimated at €8-10 billion and involving 8-10 million anglers (ECORYS, 2013). Deep-sea fishing has a much longer season than traditional coastal opportunities, and can therefore be used to extend the tourism season in many coastal nations. Even for recreational fishing that occurs in areas less than 200m, many of the species rely on deeper water for food sources or part of their life cycle development. This activity may be particularly important for some islands within the EU (e.g. the Canary Islands, Azores).

BOX 3.5 CASE STUDIES OF DEEP-SEA FISHING TOURISM

It is noted that deep-sea tourism is occurring across Europe from the Azores to the Mediterranean and Norwegian Sea. Two examples are further detailed below.

Tourism Norway

Tourism Norway has worked with sea fishing tourism for over 8 years and it has proven incredibly popular. Providers are fully occupied in the summer, so much so that Tourism Norway have focused much of their campaign on the spring/ autumn season when suppliers still have capacity. Unlike freshwater fishing, there are no licenses required for sea fishing and therefore theoretically it can take place year round, however, weather can be a limiting factor in the winter (personal communication).

As there are no licenses required for deep-sea fishing, it needs to be regulated in other ways to ensure sustainability. The Directorate of Fisheries in Norway have a number of regulations for recreational fishing to ensure it remains sustainable, including minimum sizes for salt water fish, export quotas, banned or highly regulated species, equipment limitations, and minimum distances from fish farms.

MalinWaters

MalinWaters is a network primarily between Northern Ireland and Scotland which supports a variety of deep-sea tourism options including boat charters, sailing, cruise ships, sea angling, and nature based tourism such as whale watching. Sail cruising is the most popular.

Gaps in data and knowledge were highlighted as a challenge to marine and coastal tourism, especially as the sector is dominated by SMEs (90% of organizations employ less than 10 people). Networks such as the MalinWaters brand and the Sail West project can help promote dialogue, as well as access to information and funding, and make advice and support available. MalinWaters had not noticed increase in activity or funding since the Blue Growth strategy was released (private communication). There is a need for public sector involvement for the development of infrastructure such as pontoons and slipways to help promote the industry.

Whale and shark watching

Whale and shark watching are growing industries in Europe and have the opportunity to expand the traditional tourist season, as well as educate visitors on the importance of the deep sea. In this respect, there is the potential for collaboration with marine researchers, both to help educate the public and to initiate citizen science projects to promote involvement. In the Azores, in the 20 years between 1991 and 2011, the number of whale watchers grew from approximately 50 to 12,000, showing a staggering rate of increase and effectively replacing the old whaling industry on the islands in economic importance (Silva, 2015).

Shark watching is also a growth industry with operations occurring across European coastal waters from the Azores to the coastal waters of the U.K. Although observation of sharks usually occurs in shallow waters these animals are dependent on the open ocean for at least part of their life cycle, particularly in oceanic islands such as the Azores. In the Azores shark diving is a relatively new industry focused on three species, blue sharks, shortfin mako and whale sharks (Bentz *et al.*, 2014). Tourists pay up to €165 per dive to see sharks and favoured localities include the Formigas MPA, and several seamounts around the islands (Bentz *et al.*, 2014). There is a notable conflict between shark fishing and shark diving with recent opening of Azorean waters to European shark-fishing fleets having been reported to have resulted in a sharp decline in the probability of encountering sharks on dives (Bentz *et al.*, 2014).

Exploration and adventure trips to the deep

Credit: Karl Stanley www.stanleysubmarines.com

Fig. 3.25 Six-gill sharks approach the *Idabel* submersible, 610m down, lured in by bait.

There is increasing interest and activity in private enterprises exploring the ocean depths. This new era of deep-sea exploration poses an opportunity for deep-sea research in terms of technology and infrastructure to access the deep sea and to engage with society to promote citizen science to add valuable data and knowledge. For example, in 2013 the Triton submarine caught the giant squid on camera during an expedition to the bottom of the North Pacific. The Roatan Institute of Deep-Sea Exploration (RIDE) has a three-person submarine which takes visitors to depths of 610m to explore the upper reaches of the Cayman Trench (see Fig. 3.24 and 3.25). RIDE has a two-fold mission: to explore deep waters, and to do so without relying upon grant money, by offering affordable trips to the public. It is located in Half-Moon Bay, Honduras, where there is a steep trench wall close to shore. Prices range from $500 (305m) to $1500 (six-gill shark expedition/460m+) depending on the length and depth of the expedition. For comparison, a single dive to a maximum of 305m with DeepSea Hunters in the Cocos and Malpelo Islands is $1850. Lover's Deep, a private luxury submarine capable of diving to depths around 200m, from £1,750,000 per night for a minimum of two nights, is also based in the Caribbean.

Currently, the cost, limited number of operations, and travel time are limiting factors for deep-sea submersible tourism. For example, for RIDE's six-gill shark expedition, passengers must be willing to spend up to a total time of 9 hours inside a submarine at temperatures as low as 10°C. Many of the more luxurious and well known submarine tours only go to depths of 30m so they can maintain space and comfort (e.g. Submarine Safaris, Lanzarote). However, as technology develops and interest increases, submersible tourism may grow to tourism for the masses, further engaging the public with the deep-sea and creating new opportunities for citizen science. Europe can take advantage of this growth through a number of ways, for example, by having themed World War One and World War Two dives to visit wrecks such as the World War Two battleship *Bismarck*.

3.5.2.3 Potential for the future?

In any area with the potential for socio-economic growth, there needs to be regulations in place that are capable of adapting as the sector grows to ensure sustainable development. There is the opportunity for deep-sea tourism to collaborate with different industry and research sectors, for example, the training of tourism operators to help monitor and promote marine science (e.g. PADI's Project AWARE), and the use of multipurpose offshore platforms or artificial islands created by dredging companies that can be used as hubs for fishing, boats, and submarines, as well as potential offshore nature reserves. Deep-sea tourism has a large potential for eco-tourism, bringing tourists to pristine, relatively undisturbed natural areas and using the opportunity to educate them on sustainability and social responsibility.

There are a number of popular walking networks around Europe, such as the West Highland Way and the Camino de Santiago. Similar networks could be created for boat charters and sailing across sea basins, such as a multinational North Sea trail that links walking and sailing. This would require strong cooperation and communication between the different countries which border the North Sea, and could be expanded to other sea basins in Europe. The different sea basins of Europe offer different opportunities and challenges, and therefore tailor made approaches for deep-sea tourism opportunities are needed.

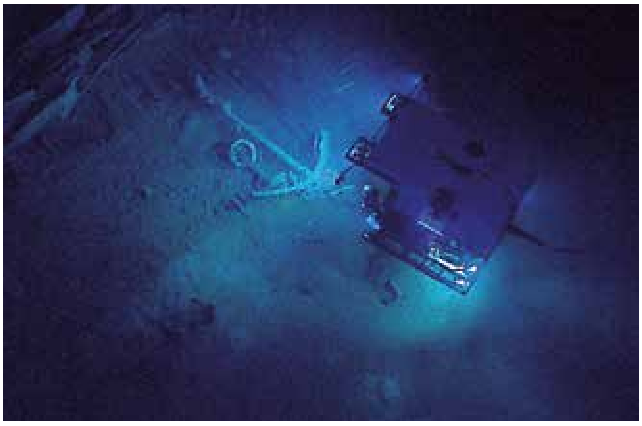
Deep sea tourism has the opportunity to relieve some of the stress currently on coastal areas but only if it is well managed with other economic and environmental activity. Therefore, there is a great need for proactive Marine Spatial Planning, especially at this early stage before too much development has occurred. This need has been highlighted by the European Commission, including 'the importance of long term joint planning to take into account future uses of the seas and their impact on marine ecosystems.' This requires strong scientific knowledge, both to help determine the optimum locations for the different activities and to ensure an accurate baseline on which long term monitoring and environmental impact assessments can be based.

Fig. 3.26 Planet Ocean Underwater Hotel, currently in the concept and investment phase.

Credit: Planet Ocean Underwater Hotel

3.5.3 Maritime archaeology and deep-sea treasure hunting

Credit: Institute for Exploration, URI GSO and the URI Institute for Archaeological Oceanography.



Credit: NOAA Okeanos Explorer Programme

Fig. 3.27 Deck-mounted gun, Destroyer of the Black Sea Fleet, Dzerzhynsky, sunk in 1942. NOAA Ocean Explorer Aegean and Black Sea 2006 expedition.

Fig. 3.28 ROV *Deep Discoverer* investigates Monterrey Shipwreck C's anchor and the associated fauna and artifacts in the area.

3.5.3.1. Introduction

According to UNESCO, the seabed hosts three million shipwrecks such as *Titanic, Belitung* and the 4,000 shipwrecks of the sunken fleet of Kublai Khan. Moreover, sunken ruins and cities, like the remains of the Pharos of Alexandria, Egypt, and thousands of submerged prehistoric sites are also located on the bottom of the oceans. In the deep sea, the cultural heritage mainly consists of shipwrecks and artifacts transported thereto[47]. The advent of modern deep-sea exploration technology including ROVs and AUVs has opened up approximately 98% of the seafloor to maritime archaeology that previously was largely out of reach (Foley and Mindel, 2002). Using ROV and subsequently AUV technology (e.g. the SeaBED AUV; Bingham *et al.*, 2010), in combination with high resolution multibeam and sidescan sonar mapping scientists have demonstrated the efficacy of maritime archaeology in the deep sea. The focus of this work has been in the Mediterranean and Black Seas with early successes including the demonstration of a likely trade route between Carthage and the port of Ostia (Rome; Ballard *et al.*, 2000) and increased knowledge on ancient ship construction methods (Ward and Ballard, 2004).

Commercial exploitation of historic ship wrecks has been extremely controversial with salvage companies claiming it is the only way to fund and execute maritime archaeology, and opponents suggesting it is nothing short of treasure hunting. In 1985, the famous US oceanographer Robert Ballard discovered the remains of the *RMS Titanic* in international waters at a depth of 3,800m. Unfortunately, the recovery of artefacts from the *RMS Titanic* also led to a series of disputes concerning the salvage rights, namely the rights of possession over the recovered goods that the salvor, the owner, and the territorial and/or national state can assert[48]. These disputes concerning competing salvage rights are quite common in the field of underwater cultural heritage[49]. Those issues have not been entirely solved by the existing international legal framework.

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[47] http://www.unesco.org/new/en/culture/themes/underwater-cultural-heritage/the-underwater-heritage/

[48] For an overview of the RMS Titanic disputes, see http://www.gc.noaa.gov/gcil_titanic-salvage.html.

[49] Concerning the different types of ownership that can be claimed in relation to recovered underwater cultural heritage, see inter alia S. Dromgoole (2015) Underwater Cultural Heritage and International Law (CUP) 96 ff.

3.5.3.2 Underwater Archaeology and Protection of the Underwater Cultural Heritage

"Underwater cultural heritage" means all traces of human existence having a cultural, historical or archaeological character which have been partially or totally under water, periodically or continuously. According to the UNESCO, this includes wrecks and ruins but also submerged landscapes (areas of human development which are now submerged), submerged wells and caves, and traces of marine exploitation, fish-trapsfences and ports[50].

Pursuant to UNCLOS all States have *"the duty to protect objects of an archaeological and historical nature found at sea and shall cooperate for this purpose"* (art. 303.1). UNCLOS does not provide much more in relation to marine archaeology. It is still unclear under UNCLOS what are the powers of the coastal state when the objects are not removed but simply destroyed within the same area. A specific provision of the UNCLOS, art. 149, deals with underwater cultural heritage found in the deep seabed Area: *"All objects of an archaeological and historical nature found in the Area shall be preserved or disposed of for the benefit of mankind as a whole, particular regard being paid to the preferential rights of the State or country of origin, or the State of cultural origin, or the State of historical and archaeological origin."* The vagueness of this provision raises many questions concerning the meaning of "benefit of mankind as a whole" and who should be in charge of implementing it. This has been addressed by the 2001 UNESCO Convention on the Protection of the Underwater Cultural Heritage [51], which provides that States Parties shall notify the Director-General and the Secretary-General of the International Seabed Authority concerning any activity or discovery which has been reported to them by their nationals or by vessels flying their flags (art. 11.2).

3.5.3.3. Research Questions

Deep water can make archeological research problematic because of the additional challenges, resources needed, and costs. Large numbers of well-preserved sites and landscapes in deeper waters remain largely unexplored despite the fact they can provide crucial information. Direct evidence of human presence within these landscapes is difficult to obtain primarily because of the water depth but also to the less favourable conditions for investigating such as strong currents; silting, low or zero visibility and because sites may be buried by sediment (Fleming *et al.*, 2014). Interdisciplinary cooperation between archaeology, science and engineering is required to explore the vast archive of deep-water domains (Fleming *et al.*, 2014).

Underwater expeditions with HOVs, ROVs and AUVs have yielded spectacular findings on the seafloor and produced high quality results particularly in deep-water shipwreck archaeology. An important challenge for the future is to advance their use from visual surveys and incidental salvage to real excavations. Visualization of the seabed is a field that has improved rapidly in recent years with the emergence of computer-based 3D visualization methods from acoustic or image data (e.g. structure-from-motion photogrammetry; e.g. McCarthy and Benjamin, 2014). However, advances are required in the ability to identify objects, especially if they are small, on the seabed from video or acoustic imagery (Fleming *et al.*, 2014). As yet, the technology has not been developed for the excavation of sites on the seabed using ROVs or HOVs, and the recovery of large undisturbed blocks of sediment from the seabed remains problematic (Fleming *et al.*, 2014). Advances in ROV and HOV

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[50] http://www.unesco.org/new/en/culture/themes/underwater-cultural-heritage/

[51] 50 States are currently parties to the Convention http://www.unesco.org/new/en/culture/themes/underwater-cultural-heritage/2001-convention/

technology are required to perfect finer control and maneuverability to enable the ability for deep-water excavation.

3.5.4 Maritime consultancy

There is a growing interest in deep-sea data, expert advice (scientific and legal) and services. This is shown by the increasing appearance of companies such as McKinsey and Company and Price Waterhouse Coopers advising governments (including those in Europe) on blue growth opportunities and also advising other organizations with respect to the oceans, particularly on economic matters (e.g. Global Ocean Commission). Europe has an opportunity to develop a service sector in maritime consultancy to respond to these needs. There are already large companies operating in this sector but there is clearly a growing need for individual experts from the marine science, law, engineering, shipping, security and other communities to provide expert advice. At present it is difficult to place a value on the maritime consulting industry.

3.5.5 Military activities

Credit: Eirik Grønningsoeter/ WildNature.no/3SProject/FFI

Fig. 3.29 Tagging attempt on a bottlenose whale using a hand held pole with a v3 DTAG on June 23 2012.

The increase in human activity in the oceans is increasing the amount of marine noise and subsequent marine pollution in the deep sea. The deep sea is important militarily as the theatre of operation for submarines such as the UK's *Vanguard* and *Astute* classes and French *Triumphant* class which have depth capabilities of several hundred metres. Submarine detection and countermeasures are thus also important, and application of active acoustic techniques is a key component of naval warfare. High-intensity naval sonars and geological (oil and gas) survey sonars have been implicated in mass–strandings of whales and dolphins in numerous locations around the world (e.g. Frantzis 1998), possibly because startling and pain-inducing sudden and loud sound provokes rapid ascent and consequent decompression sickness (Fahlman *et al.* 2014) (See Fig. 3.30). Cause-and-effect has not always been established, however, so whereas statistically-significant correlations have been demonstrated between strandings and naval activity in the Mediterranean and Caribbean Seas, they have not for stranding events off Japan and Southern California (Filadelfo *et al.* 2009).

The Canary Islands were a particular ‘hotspot’ (Fernández *et al.* 2013) for mass strandings of beaked whales (14 in 2002, Jepson *et al.* 2003; 4 in 2004, Fernández *et al.* 2012). This prompted the Spanish government to impose in 2004 a moratorium on naval exercises in waters around the Canaries, and there have been no strandings there since (Fernández *et al.* 2013). The European Parliament (2004) issued a non-binding resolution in 2004 to stop the deployment of high-intensity sonar pending completion of an assessment of its effects on marine life.

Despite the European Parliament Resolution, strandings are still occurring in European waters. For example, in April 2014 at least 5 beaked whales stranded on southeast Crete at the same time as an Israeli/Greek/US naval exercise was underway in the area (Frantzis 2014). Strandings also continue to occur outside European waters. For example, in 2008 approximately 100 melon-headed whales stranded in the Loza Lagoon system in Madagascar (Southall *et al.* 2013). Although the link is not proven, these strandings coincided with an offshore survey that was using seismic airguns and a ‘powerful’ multibeam echosounder.

European waters come under the jurisdiction of the EU Habitats Directive (92/43/EEC, Article 12), which requires member states to establish a system of strict protection for all cetaceans and other animal species listed in Annex IV. There is also a growing body of work on the possible negating effects that gradual ramp-up of signal strength can have versus immediate insonification at full intensity (Paul Wensveen, pers. comm., 2014). These measures may have local benefits, but in the case of the Madagascar stranding described above the survey was c. 65 km off shore: survey activity there might have caused the animals initially to enter the lagoon, but not the strandings themselves. This well-illustrates one aspect of the lack of clarity surrounding strandings, the lack of robust cause-and-effect data. Another is the secrecy associated with military acoustic equipment: many of the equipment specifications, including source level and frequency range, are classified. What is more, some killer whales show avoidance responses at received sound pressure levels below thresholds assumed by the U.S. Navy (Miller *et al.* 2014), suggesting that present-day assumed standards may be inappropriate.

Challenges remain with prevention of harm to mammals by sound at sea. The thirst for oil and gas continues – stimulating prospecting activities in to deeper and more remote regions – and global geopolitical instability would seem to render it unlikely that military activity on the high seas will cease. The potential for harm by military activities is well acknowledged, however. The US Office of Naval Research funds research in to the effects of sound on marine life, and NATO runs an Active Sonar Risk Mitigation program. According to their web site (http://www.cmre.nato.int/research/marine-mammal-risk-mitigation) “A systems architecture is being developed that will combine all pertinent factors into a decision aid that can be used to help plan active sonar maritime activities to mitigate risk to marine mammals. Over time, this decision aid will be expanded to cover the additional NATO operational areas.” It remains to be seen how widespread and effective such a system might be.

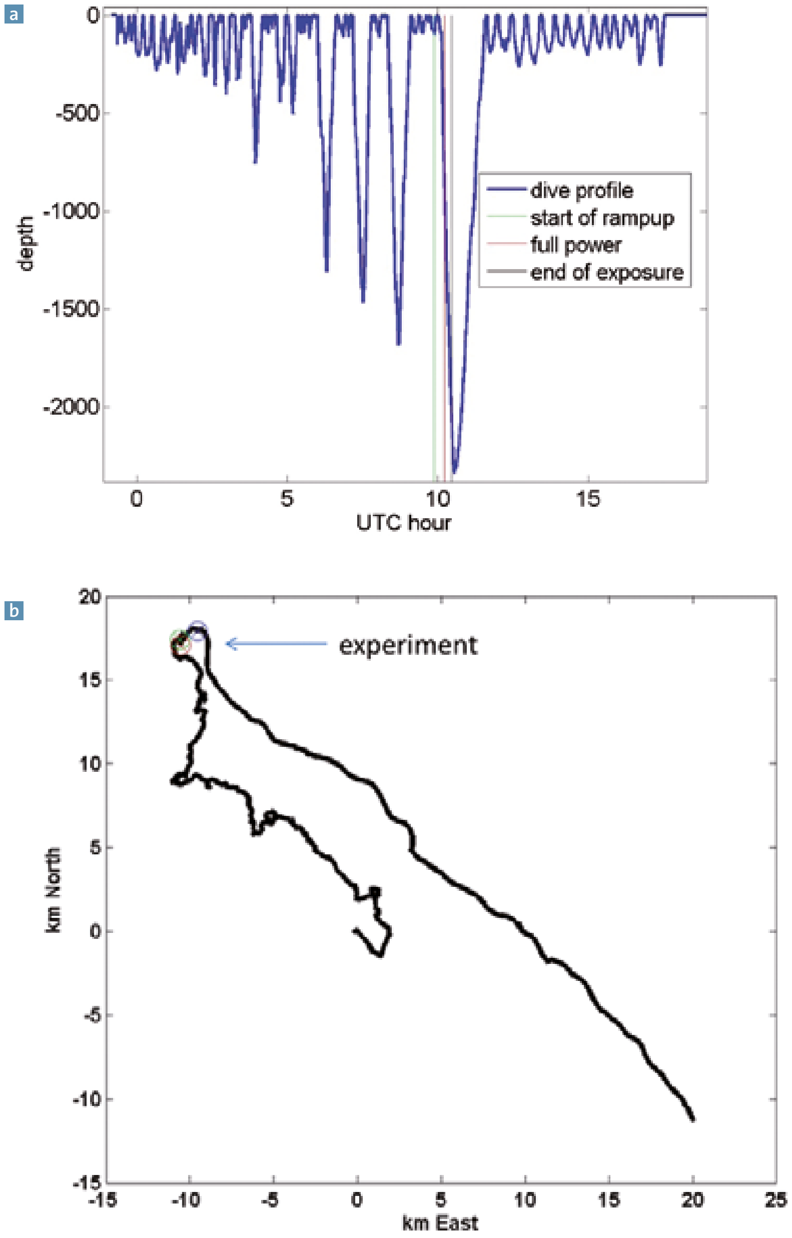

Fig. 3.30 Results from a sonar exposure experiment on bottlenose whale Ha13_176. The dive record showed that the tagged animal performed an unusual deep dive down to 2,400m during the sonar exposure (Fig. 3.27a) and the dead-reckoned track showed that during this dive the animal moved out of the area on an unusually straight course (Fig. 3.27b)

a: The 17 hr dive record of bottlenose whale Ha13_176

b: Non-georeferenced pseudotrack of tagged bottlenose whale Ha13_176. The location of the sonar exposure experiments is indicated. During the exposure the animal became very directional and moved away from the area on a straight course until the tag released 7 hrs later.

Credit: Kvadsheim *et al.*, 2014

3.5.6 Shipping

Deep-sea shipping refers to the maritime transport of goods on intercontinental routes, crossing oceans; as opposed to short-sea shipping over relatively short distances (EC Eurostat). There has been a large rise in global trade which has, in turn, driven an enormous growth in the shipping industry. It is estimated that global deep-sea shipping has a GVA of €98 billion and provides 1.2 million jobs (Ecorys *et al.*, 2012 . In: EEA, 2015). Deep-sea shipping, however, has been identified as one of the marine and maritime economic activities considered to have the highest risk in relation to environmental impact. This is because of the carbon-intensive nature of the fossil fuels burnt by merchant fleets (heavy fuel oil), but there are also other issues including waste disposal, noise pollution, direct collision with marine life and the introduction of non-indigenous and potentially invasive species.

Whilst dumping at sea is largely banned by the London Dumping Convention recent observations of deep-sea litter in the North Atlantic revealed a predominance of items such as food packaging, plastic and glass (Woodall *et al.*, 2015). Whilst a proportion of this will come from land a significant fraction is likely to originate from shipping. The main pathway of non-indigenous species (NIS) introduction in European seas is shipping (51%). In the Baltic Sea, nearly half (49%) of the non-indigenous species come from shipping activities. Noise pollution in the form of low frequency continuous sound (ambient sound), such as that emitted by shipping, can lead to communication difficulties and can cause long-term stress in marine organisms, although studies are confined to shallow water species.

The International Maritime Organization (IMO) is responsible for regulating shipping, including aspects related to navigation, safety at sea and vessel source pollution, and it has adopted a number of legally binding and non-legally binding instruments to address these issues, such as the *International Convention for the Control and Management of Ships' Ballast Water and Sediments (BMWC)*(2004) targeted at reducing the transfer of harmful and invasive species. The IMO has also adopted guidelines of relevance to the conservation and management of deep-sea resources. PSSA (Particularly Sensitive Sea Areas) is an area of the sea that needs special protection through action of IMO. The concept of PSSA has developed through IMO practice since the 1970s and adopted on the basis of Guidelines[52]. In 2002 IMO approved Guidelines for Ships operating in Arctic ice-covered waters[53]. In 2009 they were modified and made applicable also in the ice-covered areas of the Antarctic. The IMO has initiated the development of a mandatory polar shipping code to be adopted in 2015.

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[52] Revised Guidelines for the Identification and Designation of Particularly Sensitive Sea Areas (IMO Assembly Resolution A.982(24)).

[53] Guidelines for Ships operating in Arctic Ice-Covered Waters", IMODOC. MSC/Circ. 1056- MEPC/Circ. 399, of 23 December 2002.

Mitigation measures/research for these impacts include:

- The 2004 International Convention for Control and Management of Ships' Ballast Water and Sediments (BWM Convention) under the International Maritime Organization (IMO) is the global instrument to regulate the management, treatment, and release of ballast water. However, it has not yet entered into force as it needs to be ratified by more countries (HELCOM, 2014). As yet there is little understanding of the potential of ballast to introduce deep-water species to non-native waters;
- Measures to avoid areas of the ocean that contain species that are sensitive to shipping (e.g. va der Hoop *et al.*, 2014). This should involve an expansion of IMO PSSA network through consideration of evidence of impacts from shipping activities;
- Shipping can benefit from increased seabed mapping through improved maritime awareness and safety, which can be measured through the reduction of risk management costs and insurance premiums for deep-sea shipping.

3.5.7 Cables

Communication cables now span a great number of seabed areas worldwide providing critical connections for voice and data communication. This spans from personal communication and internet traffic, to news, and ultimately to global market sensitive high speed financial transaction information. These cables are often buried a metre or more below the seabed when close to land or on continental shelves, but can often rest on top of the seafloor at abyssal depths. Despite the cost of this infrastructure, they are still faster and cheaper than satellite communications for most applications. Improvements in milliseconds can have important implications for high-speed trading profits and such minute improvements often drive the sector.

In addition to basic communication utility there are examples of cables being used to make scientific measurements dependent on how currents affect cable voltages and to provide data and power to instruments on the seafloor or moored above it. Indeed multiple ocean observatory networks are now operational around the world that use cables dedicated for scientific use. The critical requirements for timelines and time synchronisation for geohazard research and early warning often drive the development of such systems. Cables have also been deployed for the study of neutrino particles, where time synchronisation of observations and powering a broad array of optical detectors is also critical. However, cables also offer rare opportunities to convey data to shore in real time, even for high bandwidth data like photographs or video, and even the remote control of instruments on the seafloor.

There has been an effort to take better advantage of commercial seafloor cables for scientific research, particularly when they are no longer commercially used. Numbers vary, but there are more than 300 cables worldwide with more than 20 being 'dark' and no longer in use. Several examples now exist where disused cables have been repurposed for scientific use, such as the ALOHA Cabled Observatory offshore Hawaii. A Joint Task Force , formed by the International Telecommunication Union (ITU), the Intergovernmental Oceanographic Commission of the United Nations Educational, Scientific and Cultural Organization (UNESCO/IOC), and the

World Meteorological Organization (WMO), was set up to investigate the use of submarine telecommunications cables for ocean and climate monitoring and disaster warning. This effort now seeks to promote such efforts as the costs related to repurposing cable networks is substantially lower than building them from scratch.

Seafloor communication cables of any type face a number of risks including damage from anchors and fishing, severing from geological events such as earthquakes and/or submarine sediment flows and landslides, and even shark bites. One particularly notable sediment flow event occurred offshore Taiwan in 2006 severing numerous cables and disrupting communications across Asia. The consequences for damage usually not only include costly repairs requiring efforts similar to laying sections of cable, but can also span into lost data, costs to financial markets from uncertainty introduced by missing data, and even costs to life where hazard warning might fail. The International Cable Protection Committee (ICPC) is the lead international authority on submarine cable security and reliability. The cable industry works to overcome those risks through raising awareness of cable locations to mariners and protecting shallower assets through burial. There is, however, still scope for better understanding risks particularly for geo-hazards when laying cables at or near slopes or other areas particularly prone to geological activity.

Opportunities for progress in taking better advantage of cable infrastructure for science are clear as the deep ocean remains woefully under sampled. Better coordination of efforts in the future could see more cables transitioned to scientific use when they are no longer commercially used, and adding some simple observation capability to elements of new cables, such as measuring and reporting temperature and salinity, can have major scientific value. This can be done for example in repeater infrastructure, where the signals are maintained at certain points along the cable path. A major hindrance to this at present is the requirement to de-install the cable after use. This means that by acquiring a cable from a telecommunications operator for re-purposing for science, the scientists also inherit the liability for de-commissioning and removal.

3.5.8 Scientific activities

Credit: Alex Rogers

Fig. 3.31 ROV *Kiel 6000* using a push corer to sample sediment on seamounts of the SW Indian Ridge.

The fundamental understanding of the uniqueness and complexity of deep-sea ecosystems can only be achieved through scientific research which is therefore an integral and necessary part of effective resource management, sustainable use and protection of these marine systems. Nonetheless, scientific activities result in local physical impacts to the deep-sea environment, particularly to the seabed, as a result of sampling and surveying. However, such activity is noted to be an order of magnitude lower than most commercial activities e.g. commercial bottom-trawling. In addition, scientific research and field work is planned to minimize these impacts both to maximize the accuracy and repeatability of observations and for conservation and deontological reasons (UNEP, 2007). Several deep-sea species and habitats can be vulnerable to disturbance and may have a lower resilience than shallower nearshore areas (OSPAR List of Threatened and/or Declining Species and Habitats, Reference Number: 2008-6) and as most forms of observation and investigation involve some disturbance of the natural systems being studied, it is well recognized that scientific activities can adversely affect individual organisms, communities and study sites. Moreover, the number of deep-sea research cruises has been increasing continually. Some deep-sea study sites are frequently revisited and repeatedly sampled for a wide variety of disciplines, sometimes with multiple conflicting effects, enhancing the potential for a significant impact of scientific activities.

Intrusive samplers (e.g. box-cores, grabs, dredges) collect organisms and leave a physical footprint in habitats that are comparable in type, but not duration, spatial scale or magnitude of the disturbance to that caused by industrial removal of seafloor resources (Ramirez-Llodra *et al.* 2011). More specialized collection equipment (frequently operated from research submersibles or ROVs), targeting specific organisms, may substantially reduce the number of individuals in local populations. Discarding sampled materials outside the area of collection and more specifically the experimental transplanting of biota or geological material between sites can lead to changes in the environment, populations (risks of disrupting genetic integrity) or the composition of communities. At sites where scientific activity is intense, light (e.g. from manned submersibles, ROVs, observatories with video footage) may alter behaviour and impair the sensitive light detection mechanisms of invertebrates (Herring *et al.* 1999) or fish and the effects of noise (e.g. underwater vehicles, geophysical instruments) range from direct physical injury in fish, to behavioural disturbance and interference in audibility and communication in mammals (Richardson *et al.* 1984). The use of chemical tracers or expendable devices which contain hazardous materials may be seldom used in deep-sea experimentation but lost gear, ballast weights, site markers, plastic, ropes and other materials left on the seafloor during observations and experiments are unfortunately much more common. Although these additions are thought to have a minor and local scale impact they still deserve further evaluation (Ramirez-Llodra *et al.* 2011).

The potential impact of natural events (e.g. climate change, submarine slumps, seismic and volcanic activity) or other anthropogenic sources of disturbance (e.g. trawling, mining) is several orders of magnitude higher but nevertheless, the scientific community is in general well aware of unwanted negative side-effects of scientific activities in deep-sea ecosystems. In most cases, scientists adopt responsible research practices by carefully planning and executing research programmes, avoiding unnecessary deleterious impacts on the studied sites, optimising the multidisciplinary use of samples and facilitating data-sharing. Besides the provisions and entitlements of the General Principles for the Conduct of Marine Scientific Research set out in UNCLOS, a voluntary code of conduct has been established specifically for research on deep-sea hydrothermal vents (Devey *et al.* 2007) and this was followed by the OSPAR Code of Conduct for Responsible Marine Research in the Deep Seas and High Seas of the OSPAR Maritime Area (OSPAR, 2008) which incorporates comments from several institutions (e.g. ICES, ESF). These documents define the best practices and guidelines for an environmentally friendly deep-sea research approach so that the protection and sustainable use of the oceans continues to be supported by strong scientific evidence.

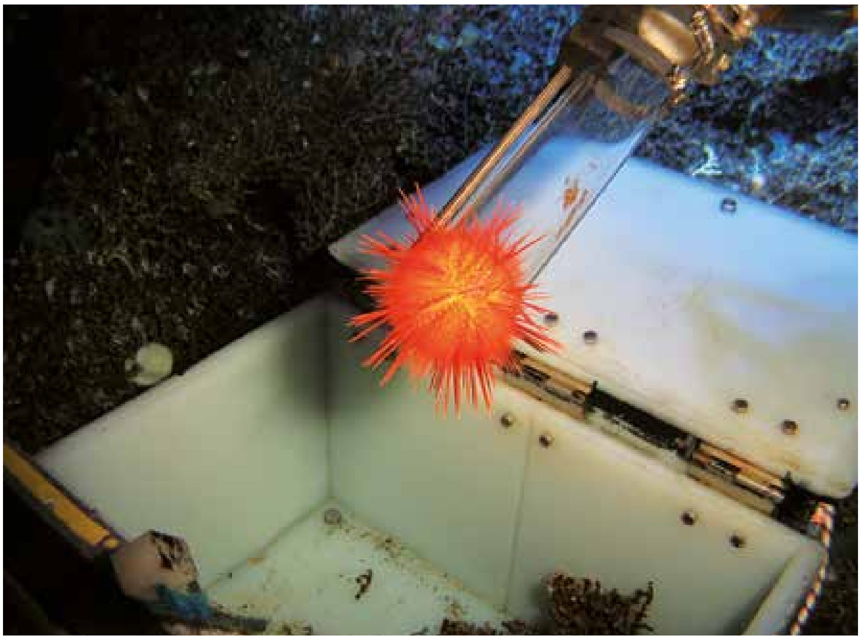


Fig. 3.32 ROV *Kiel 6000* using a slurp gun to collect an echinoid on seamounts of the SW Indian Ridge

Credit: Alex Rogers 2011

Credit: Fabien Roquet

Fig. 3.33 Preparing an Southern elephant seal for animal tagging. Such animals typically dive below 200m.

Credit: H. Robert, RBINS

Fig. 3.34 Lara Macheriotou and Ann Vanreusel (University of Ghent, Belgium) working on a deep-sea sediment multi-corer sample from the Clarion-Clipperton Fracture Zone (CCFZ), Pacific onboard the RV Sonne (SO239) in 2015. Field work was conducted as part of the JPI-Oceans pilot action 'ecological aspects of deep-sea mining'.

4

Conservation and management of deep-sea ecosystems

Credit: MARUM

4.1 Introduction

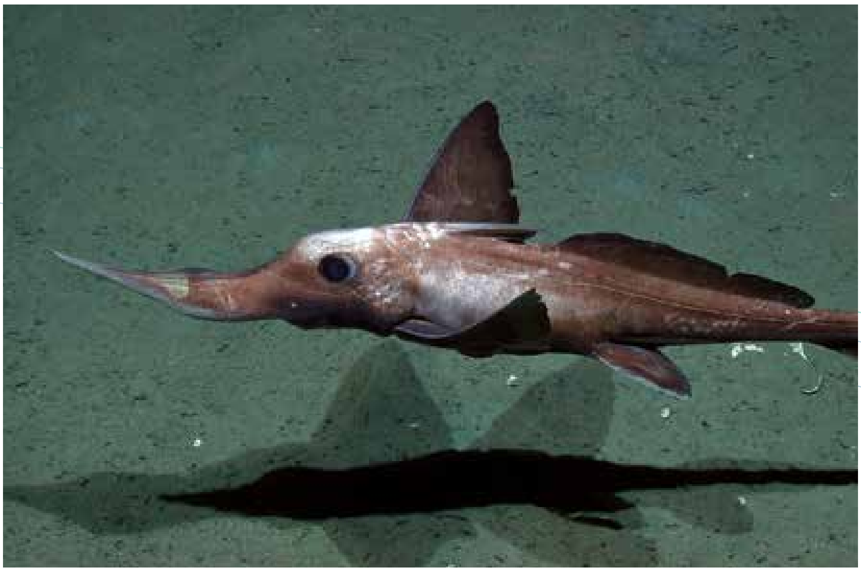


Image: MARUM

Fig. 4.1 Long-nosed chimaera in the Arabian Sea at a depth of 1,975m.

The conservation and management of deep-sea resources is carried out in a complex institutional environment. A number of global instruments, of which the 1982 Law of the Sea Convention is the most important, provides the global framework for management, while regional instruments in the North Atlantic provides for an additional layer of international governance. The actual implementation of management occurs at the domestic level of governance, as it is national governments, and the EU in many cases concerning EU members, that possess the legal, administrative and financial means to actually develop, adopt and implement management measures.

Conservation is achieved through the management of human activities, to prevent harm to the marine environment and overexploitation of marine living resources. These areas are dealt with largely in the preceding sections and so will not be addressed specifically here. Conservation is also achieved through specific conservation measures aimed at protection of species and spatial conservation measures aimed to protect habitats or species. Here we will largely address the latter as the use of marine protected areas (MPAs) and marine reserves (no-take MPAs) has been an area subject to significant controversy both in Europe and globally. It should be noted, however, that area-based measures such as MPAs are just one of several tools in the management toolkit, and that conservation objectives can be achieved in many ways.

The conservation of deep-sea ecosystems may seem a strange concept given the distance of these ecosystems from human population and their sheer size. It is tempting to think that damage in a small geographic area is simply compensated by large areas of habitat elsewhere. Furthermore, the deep sea suffers from an “out of sight out of mind” syndrome where the public simply do not consider it and policy makers have little idea of the biodiversity it harbours or the ecosystem services it provides. Yet work carried out over the last two decades in particular indicate that if anything, many deep-sea ecosystems are more vulnerable to human activities

Chapter 4 cover image: Deep-sea crab, *Paraloa cuvieri* on reef-forming cold-water corals in 800m of water in the Menez Gwen Hydrothermal Field southwest of the Azores

Credit: ONC

Fig. 4.2 Corky the Octopus, observed inhabiting the Circulation Obviation Retrofit Kit (CORK) drillhead in the North Pacific.

than shallow-water ones. The deep sea turns out to be more heterogeneous than previously considered with some habitats and species restricted to specific physical conditions and thus having a narrow geographic distribution and some occurring as islands surrounded by unsuitable environment (e.g. chemosynthetic ecosystems). Deep-sea species live in a relatively low-disturbance environment and hence by virtue of their specific biological attributes (i.e. slow growing, long lived, slow to reproduce, mechanically fragile) they show low resilience to direct human disturbance. Examples include cold-water coral reefs, coral gardens, sponge habitats, other habitats formed by sessile species, long lived deep-sea teleost fish and sharks. Because of their reliance on *ex-situ* primary production (with the exception of chemosynthetic production) deep-sea species are also likely to be affected by climate change impacts acting through changes in the abundance, biomass and composition of phytoplankton communities in the euphotic zone. Management of human activities in the deep sea, as emphasized through much of this report, is currently undertaken with low levels of scientific knowledge and understanding of the species and ecosystems subject to exploitation or potential impacts. It therefore has to be precautionary to give large margins of safety to conserve species and habitats. Spatial conservation measures are particularly important in this context as they provide direct protection to species with a low resilience to exploitation and other human impacts but also act as an insurance mechanism preserving the structure and function of deep-sea ecosystems. In some circumstances, such as the protection of fragile habitat-forming benthic invertebrates from the impacts of deep-sea bottom trawling, spatial protection measures are essential.

4.2 Protection of the Marine Environment

UNCLOS provides an international framework for protection and preservation of the marine environment. Part XII of the Convention contains general obligations to protect and preserve the marine environment, including obligations to address imminent pollution damage and contingency planning and to carry out environmental monitoring and environmental impact assessment. There is a general obligation for all States to protect and preserve the marine environment and to take all measures necessary to prevent, reduce and control pollution from any source. The following sources are addressed more specifically: land-based activities, offshore seabed activities, activities in the Area, dumping, and vessels, as well as pollution from or through the atmosphere, and pollution resulting from the use of technologies under national jurisdiction or control. States are also obligated to address the intentional or accidental introduction of alien species which may cause significant or harmful changes to a particular part of the marine environment. There is also an obligation for States to cooperate in formulating and elaborating further rules and standards at global and regional levels, and there are provisions regarding enforcement rights and obligations on the part of flag States, coastal States and port States. It is important to note that a coastal State's sovereign right to exploit its natural resources must be carried out in accordance with duties to protect and preserve the marine environment (Art. 193 UNCLOS). States' measures to protect and preserve the marine environment under Part XII must include those necessary to protect and preserve rare or fragile ecosystems and habitats of depleted, threatened or endangered species (Art. 194 UNCLOS).

Credit: Alex Rogers

Fig. 4.3 Photographs of cold-water coral reef habitat from Coral Seamount, South West Indian Ocean, at approximately 1,000m depth. The coral framework is comprised mainly of *Solenosmilia variabilis* and hosts a high diversity of other organisms including glass sponges, urchins, gastropod molluscs, zoantharians and squat lobsters.

Numerous global and regional agreements build on the environmental provisions of the Convention, notably conventions on vessels negotiated under the auspices of IMO and the regional seas agreements developed under the auspices of UNEP. Moreover, the Convention requires that national measures adopted by States either be “no less effective than”, “at least have the same effect as”, or “take into account” internationally-agreed rules and standards and, in some cases, *recommended* practices and procedures depending on the type of activity or source of pollution.

4.2.1 Living marine resources

In its territorial sea, a coastal state has sovereignty over marine resources. The Law of the Sea Convention also codifies the coastal State´s sovereign rights for the purpose of exploring and exploiting, conserving and managing the fish stocks in the EEZ. These rights are subject to a number of restrictions/duties, among them: to have due regard to the rights and duties of other States and act in a manner compatible with the provisions of the convention (Art. 56(2) UNCLOS), and, taking into account the best scientific evidence available to it, to ensure through proper conservation and management measures that the maintenance of the living resources in the exclusive economic zone is not endangered by over-exploitation (Art. 61 (2) UNCLOS). As appropriate, the coastal State and competent international organizations, whether sub-regional, regional or global, shall co-operate to this end. In taking conservation measures the coastal State shall take into consideration the interdependence of stocks and the effects on species associated with or dependent upon harvested species with a view to maintaining or restoring populations of such associated or dependent species above levels at which their reproduction may become seriously threatened (Art. 61 (4) UNCLOS). It shall also take into account any generally recommended international minimum standards, whether sub-regional, regional or global (Art. 61 (4) UNCLOS).

Although the coastal state has sovereign rights over living marine resources the Law of the Sea Convention requires the optimum utilization of such resources (Art. 62 (1) UNCLOS). This implies that if a coastal state does not have the ability or

Credit: Australian Maritime College

Fig. 4.4 Orange roughy and bycatch on the deck of a research trawler. Intensive exploitation of orange roughy in past decades has greatly decreased populations. Management of the orange roughy fishery in New Zealand and Australia is good, but unregulated landings by other countries continue. These were caught aboard the FTV *Bluefin* off East Coast of Tasmania.

does not wish to target a particular living resource (i.e. fish stock) then other states may do so. The coastal State is given a broad discretion in deciding which other States´ fishermen are to be given access to its fisheries resources. The Convention also contains provisions regarding enforcement of laws and regulations of the coastal State (Art 73 UNCLOS).

On the high seas, the flag states of the fishing vessels are to respect certain conditions, primarily the duty to take such measures for their respective nationals as may be necessary for the conservation of living resources and the duty to cooperate with other states in the conservation and management of living resources (Art 117 and 118 UNCLOS). In determining conservation measures, States are to take into account the same criteria noted above for coastal State fisheries (interdependence of stocks, associated or dependent species, generally recommended international minimum standards). These provisions established a foundation for further developments in the United Nations Fish Stocks Agreement (UNFSA; Art 117-119 UNCLOS). The UNFSA was adopted in 1995 and entered into force in 2001. It is an implementing agreement of the provisions in the Law of the Sea Convention regarding the conservation and management of straddling and highly migratory fish stocks (stocks that move between EEZs and the high seas). The principles in the agreement include the precautionary approach (Art 6 and 7 UNFSA) as well as the application of ecosystem-based management (Art. 5 (e) UNFSA). The UNFSA also affirms the duty of states to cooperate in the management of straddling and highly migratory fish stocks. Where an organization or arrangement (RFMO/RFMA) already exists (such as NEAFC and NAFO), it is to be used (see Box 4.1 of existing deep-sea relevant RFMOs) . Where a fishery occurs and no organisation or arrangement exists, States fishing on the high seas are directed to establish one. The flag State has a duty to ensure compliance by its vessels with subregional and regional conservation and management measures for straddling and highly migratory fish stocks. States cooperating through RFMOs and regional arrangements should also establish appropriate cooperative mechanisms for effective monitoring, control, surveillance and enforcement. After years of debate, the UNGA has recognized that the provisions of the UNFSA should also apply to discrete high seas fish stocks, including deep-sea fisheries in the high seas.

BOX 4.1 REGIONAL FISHERIES MANAGEMENT ORGANISATIONS WITH RESPONSIBILITY FOR DEEP-SEA LIVING RESOURCES IN THE HIGH SEAS

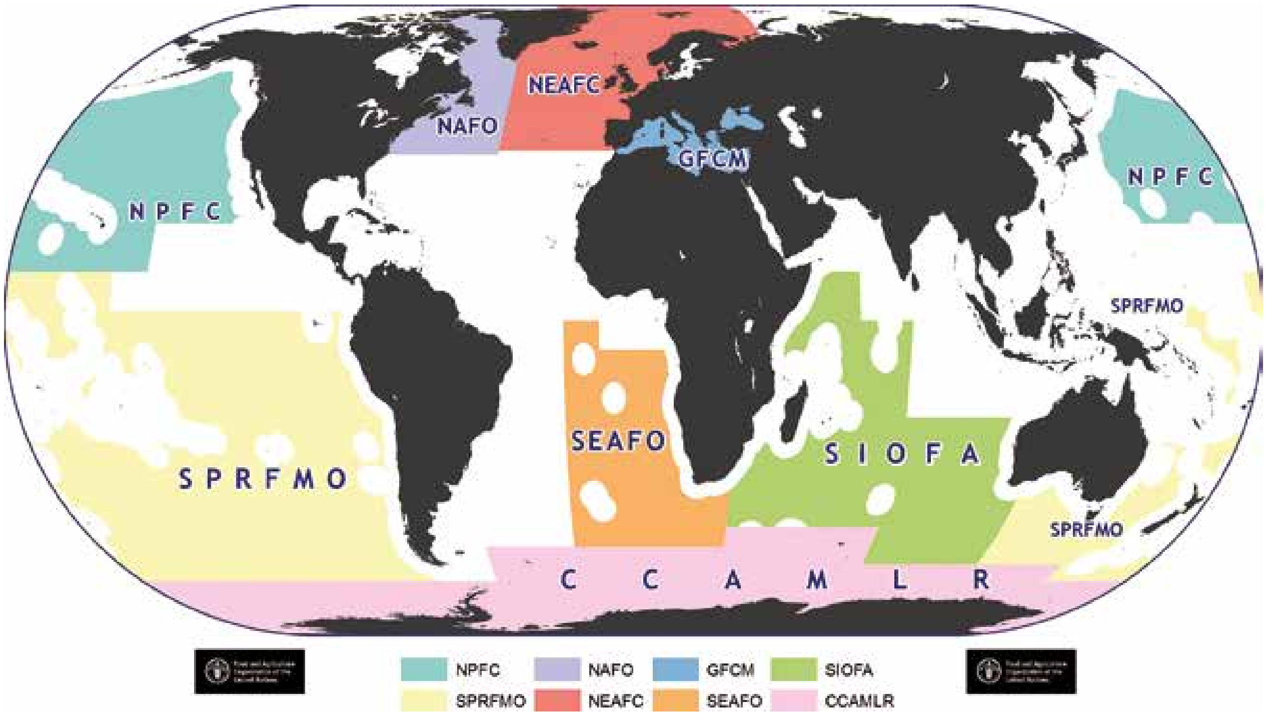


Fig. 4.5 A map of world areas of competence of regional fisheries management for low productivity, deep-sea species (a subset of RFMOs). Source: FAO.

North East Atlantic Fisheries Commission (NEAFC)

Geographic area: NE Atlantic
Important deep-sea species (Catch >200t): Ling *(Molva molva)*, Greenland halibut *(Reinhardtius hippoglossoides)*, greater silver smelt *(Argentina silus)*, tusk *(Brosme brosme)*, conger eel *(Conger conger)*, blue ling *(Molva dypterygia)*, black scabbardfish *(Aphanopus carbo)*, roundnose grenadier *(Coryphaenoides rupestris)*, bluemouth *(Helicolenus dactylopterus)*, forkbeards *(Phycis spp)*, rough head grenadier *(Macrourus berglax)*, black-spot sea bream *(Pagellus bogaraveo)*, Baird's smoothhead *(Alepocephalus bairdii)*, silver scabbard fish *(Lepidopus caudatus)*, rabbitfish *(Chimaera monstrosa, Hydrolagus* spp.), Norway haddock *(Sebastes marinus)*, wreckfish *(Polyprion americanus)*, alfonsinos *(Beryx splendens, B. decadactylus*; NEAFC, 2013). Redfish *(Sebastes* spp.) are managed more as a high productivity stock and are not included in the NEAFC list of "deep-water" species.

North West Atlantic Fisheries Organisation (NAFO)

Geographic area: NW Atlantic
Important deep-sea species: main commercial species are roundnose grenadier and rough head grenadier although the catches of Greenland halibut have been increasing. Other species are not taken in directed fisheries or are subject to smaller-scale fisheries including blue antimora *(Antimora rostrata)*, wolfish *(Anarhicas lupus, A. minor, A. denticulatus)*, skates, sharks and rabbitfish. Reporting of catches for these are unreliable and/or aggregated above the species level (Rogers and Gianni, 2010). As with NEAFC redfish are also taken in the NAFO area but are managed as high productivity fish stocks.

General Fisheries Council for the Mediterranean (GFCM)

Geographic area: Mediterranean
Important deep-sea species: The deep-sea species targeted for fishing are generally high productivity species including hake (*Merluccius merluccius)* and deep-sea shrimps *(Aristeus antennatus, Aristeomorpha foliacea)*. However, many of these fisheries are multispecies and other species captured include blue whiting *(Micromesistius poutassou)*, greater forkbeard *(Phycis blennoides)*, angler fish *(Lophius sp.)*, conger eel, blackspot seabream, megrims *(Lepidorhombus spp.)*, bluemouth, other shrimps *(Parapenaeus longirostris, Pasiphaea* spp., *Acanthephyra eximia, Plesionika* spp.), Norway lobster *(Nephrops norvegicus)* and crabs *(Geryon longipes, Paramola cuvieri)* (Cartes *et al.*, 2004; GFCM, 2014). By-catch of deep-water sharks (e.g. *Squatina* spp., *Etmopterus spinax*, *Hexanchus griseus*) and rabbitfish (*Chimaera monstrosa*; Cavanagh and Gibson, 2007; Saidi and Bradai, 2008; Bradai *et al.*, 2012) occur in these fisheries.

South East Atlantic Fisheries Organisation (SEAFO)

Geographic area: Southeastern Atlantic
Important deep-sea species: Pelagic armourhead *(Pseudopentaceros wheeleri)*; Patagonian toothfish *(Dissostichus eleginoides)*; alfonsino *(Beryx spendens)*; deep-sea red crab *(Chaceon erytheiae*; SEAFO, 2014).

Convention for the Conservation of Antarctic Marine Living Resources (CCAMLR)

Geographic area: Antarctic / Southern Ocean
Important deep-sea species: Patagonian toothfish, Antarctic toothfish *(Dissostichus mawsoni)*, grenadiers *(Macrourus carinatus, Macrourus holotrachys, Macrourus whitsoni, Coryphaenoides armatus, Caelorhynchus marinii)*, blue antimora.

Southern Indian Ocean Fisheries Agreement (SIOFA)

Geographic area: Southern and western Indian Ocean
Important deep-sea species: Orange roughy *(Hoplostethus atlanticus)*, pelagic armourhead, alfonsino *(Beryx splendens, B. decadactylus)*, spiky oreo *(Neocyttus rhomboidalis)*, smooth oreo *(Pseudocyttus maculatus)*, cardinal fish *(Epigonus* spp.), ocean blue eye *(Schedophilus labyrinthica)*, blue-eyed trevalla *(Hyperoglyphe antarctica)*, gem fish *(Rexea solandri)*, hapuku *(Polyprion oxygeneios)*, ocean perch *(Helicolenus percoides)*, ribaldo *(Mora moro)*, seabass *(Lutjanus* spp), jackass morwong *(Nemadactylus marcopterus*; Williams *et al.*, 2011), emperors (Letherinidae (SWIOFC, 2009), long-tail red snapper *(Etelis coruscans)*, sharks, lobster (*Palinurus* spp.; Bensch *et al.*, 2008).

North Pacific Fisheries Commission (NPFC)

Geographic area: North Pacific
Important deep-sea species: Pelagic armourhead, alfonsino *(Beryx splendens, B. decadactylus)*, cardinal fish *(Epigonus denticulatus, E. atherinoides)*, warty oreo *(Allocyttus verrucosus)*, mirror dory *(Zenopsis nebulosa)*, rockfish *(Helicolenus* spp), skilfish *(Erilepis zonifera)*, grenadiers *(Coryphaenoides* spp), deep-water sharks, tanner crabs *(Chionioecetes tanneri)*, red crabs *(Chaceon* spp.), snow crabs *(Paralomis* spp), precious coral *(Corallium* spp and others; Rogers and Gianni, 2010).

South Pacific Regional Fisheries Management Organisation (SPRFMO)

Geographic area: South Pacific
Important deep-sea species: Orange roughy, black oreo *(Allocyttus niger)*, smooth oreo, spikey oreo, warty oreo, cardinal fish *(Epigonus telescopus)*, alfonsino *(Beryx splendens, Beryx decadactylus)*, blue-eyed trevalla, ribaldo, grenadiers (Macrouridae), deep-sea sharks *(Dalatias licha, Squalus* spp., other spp.), wreckfish *(Polyprion oxygeneios, P. americanus)*, morwong *(Nemadactylus* spp.), gemfish, kingfish *(Seriola lalandi)*, Foundation lobster *(Jasus caveorum)*.

Credit: Alex Rogers

Fig. 4.6 Plelagic armourhead (*Pseudopentaceros wheeleri*) top and alfonsino (*Beryx spendens*) bottom, taken from above Atlantis Seamount SW Indian Ocean.

Despite the provisions of UNCLOS and its implementing agreement, the UN Fish Stocks Agreement, issues have remained leading to overexploitation of living resources in EEZ and on the high seas, as well as environmental impacts such as bycatch and habitat destruction. The international community has responded to these issues through a number of agreements, voluntary guidelines, and codes of practice implemented to varying degree by States, Regional Fisheries Management Organisations, and Agreements.

The first of these was the UN Food and Agricultural Organisation's Code of Conduct for Responsible Fisheries (CCRF; FAO 1995). It sets out "principles and international standards of behaviour for responsible practices with a view to ensuring the effective conservation, management and development of living aquatic resources, with due respect for the ecosystem and biodiversity." The Code reinforces the provisions of UNCLOS, its implementing agreements and also national laws with respect to sustainable management of fishing. There is a strong emphasis on effective management and conservation of marine living resources for present and future generations. This is not only to prevent overfishing of target species for fisheries but also to conserve species belonging to the same ecosystem or which are dependent or associated with the target species (Art. 6.2 CCRF). There is also a requirement to base conservation and management decisions on the best available scientific evidence (Art 6.4 and 6.5 CCRF) and to apply the precautionary principle, which may be the case where lack of scientific information may be an issue, such as in the deep sea (Art. 6.5 CCRF). The CCRF also specifically states that all critical habitats (i.e. spawning grounds) should be protected and rehabilitated as far as possible and where necessary (Art. 6.8 CCRF). There are also provisions relating to exercise of effective control over fishing vessels (Art 6.11CCRF) and in terms of cooperation to achieve the objectives of sustainable management and conservation of marine living resources (Ar. 6.11 and 6.12 CCRF).

As a response to increasing evidence of overfishing and depletion of stocks of low-productivity deep-sea fish and of significant adverse impacts (SAI; see Box 2.2) to vulnerable marine ecosystems from bottom-trawl fisheries, the UN General Assembly made several resolutions calling on states and RFMOs to improve the management of such fisheries on the high seas (UNGA Resolutions 59/25 2004 and 61/105 2006; Rogers and Gianni, 2010). The FAO's Committee on Fisheries (COFI) requested that FAO develop new guidelines to assist states and RFMOs to sustainably manage such fisheries and to take measures to identify vulnerable marine ecosystems and prevent damage to them from bottom trawling. The International Guidelines for Management of Deep-Sea Fisheries in the High Seas were developed through a series of expert workshops and agreed at the FAO in Rome in 2008. The Guidelines define low productivity deep-sea species, vulnerable marine ecosystems (VMEs) and significant adverse impacts. They also outline a series of recommendations to prevent overfishing or depletion of low productivity deep-sea species, for the identification of VMEs and assessment of SAIs, of appropriate management measures to prevent such SAIs, and for the initiation of environmental impact assessments for deep-sea fisheries. Examples of VMEs are also outlined in an Annex to the Guidelines.

More recently the FAO developed International Guidelines on Bycatch Management and Reduction of Discards (FAO, 2010). These were also produced in response to a Resolution from the UNGA (UNGA Resolution 64/72 which also comprised provisions relating to management of deep-sea fisheries) and are aimed at minimizing the capture and mortality of species and sizes which are not going to be used in a manner that is consistent with the CCRF. These Guidelines are relevant to deep-sea fisheries as bycatch has been identified as a particular threat to non-target species, reducing some to levels where they may be regarded as critically endangered (e.g. Devine *et al.*, 2006). Other relevant international action addressing bycatch issues that may be considered in terms of deep-sea fisheries include the 1999 International Plan of Action for Reducing Incidental Catch of Seabirds in Longline Fisheries (IPOA-Seabirds) and the 1999 International Plan of Action of the Conservation and Management of Sharks (IPOA-Sharks).

Illegal, unreported and unregulated fishing (IUU fishing) is a threat to all marine fisheries but especially those in waters distant from land, such as deep-sea fisheries, or those in remote parts of the world's oceans (i.e. the Southern Ocean). Deep-sea fisheries also target relatively small stocks that are localised to specific features (e.g. seamounts) in remote areas, exacerbating issues of detecting such activities and also adding to the expense of their management relative to the value of catches. Specific efforts by the international community to reduce / eliminate IUU fishing include the International Plan of Action to Prevent, Deter and Eliminate Illegal, Unreported and Unregulated Fishing (IPOA-IUU) and the Agreement on Port State Measures to Prevent, Deter and Eliminate Illegal, Unreported and Unregulated Fishing, which is not yet in force as it is still going through a process of ratification by states. There are now 13 out of the 25 ratifications necessary to bring the treaty into force. St. Kitts and Nevis and Iceland are two of the most recent. In 2014 FAO also adopted guidelines to strengthen Flag State performance (FAO, 2015), building on the previous 1993 FAO Agreement to Promote Compliance with International Conservation and Management Measures by Fishing Vessels on the High Seas which are also relevant relevant to prevention of IUU fishing.

Credit: Copyright National Oceanography Centre Southampton

Fig. 4.7 Northern Rockall Bank, showing coral rubble and trawl marks (taken on research cruise JC060).

4.2.2 Non-living marine resources

The oil and gas industry has been the main activity located in the deep waters of continental margins to date. This is likely to continue as there is a trend for oil wells over recent times to increase in depth (Sähll *et al.,* 2015). In the near future, a new industrial activity in the deep ocean, exploitation of deep-sea mineral resources, is likely to take place and forecasts are for significant growth in this industry with the EC predicting that by 2020 5% of mineral supplies will come from deep-sea mining (EC, 2012). Regulations for deep-seabed mining in the Area are currently under development by the ISA.

The evolution of regulation of the oil and gas industry has largely occurred over time in response to accidents involving loss of human life or substantial environmental damage (Bennear, 2015). In the USA the latter has been the main driver (e.g. the damage caused by the *Exxon Valdez*) but in Europe the former has probably been more important (e.g. the *Piper-Alpha* disaster; Bennear, 2015). Regulation of the oil industry is now achieved through a combination of a liability system (the polluter pays for environmental damage), top-down regulatory control and management-based approaches where management plans, be they safety or environmental, are aimed at assessing risks and acting to prevent them from occurring (Bennear *et al.,* 2015). Here we focus on Europe, where planning of activities that may cause significant damage to the marine environment, such as oil and gas extraction, falls under a number of different Directives, namely the European Habitats Directive (1992/43/EEC), the Strategic Environmental Assessment Directive (2001/42/EC), and the Environmental Impact Assessment Directive (2011/92/EU; amended 2014/52/EU).

The Habitats Directive is aimed at halting biodiversity loss through the conservation of habitats and species in European territory. The Directive has the aim of setting up a coherent network of Special Areas of Conservation (SACs) hosting the habitats and species of conservation priority listed. Article 6 of the Habitats Directive specifically deals with protection of SACs from disturbance and outlines the procedures for assessment of whether or not plans or projects would have a significant negative impact on SACs (De Santo, 2007). Such plans and projects should only take place where there is overriding public interest and otherwise alternatives should be adopted or the activity prevented from going ahead (De Santo, 2007). Initially the Habitats Directive included maritime areas under the jurisdiction of Member States but this provision was dropped in the final version of the Directive for reasons that remain obscure (De Santo, 2007). As a result, the Habitats Directive dealt largely with terrestrial ecosystems and only three marine habitats (sand banks, reefs, submarine structures formed by leaking gas) and seven species (harbor porpoise, grey seal, common seal, sturgeon, shad, lamprey, loggerhead turtle) were included (De Santo, 2007). In 1999 the High Court of the UK, following a legal challenge from Greenpeace, extended the Habitats Directive from 12nm offshore to the edge of the 200nm Exclusive Fisheries Zone (EFZ) which effectively became the entire UK continental shelf, including extended continental shelf and slope under its jurisdiction (the Greenpeace Judgement; De Santo, 2007). Although this change in the law occurred at a national level the application of the Habitats Directive to the edge of the EEZ is now viewed to be the case for all Member States (De Santo, 2007). This means that projects or plans by governments or industry that potentially effect offshore SACs must undergo a specific assessment as to likely impacts (e.g. the Darwin Mounds SAC, an area south of the Wyville-Thomson Ridge with low-relief mounds on which the coral *Lophelia pertusa* occurs).

The Strategic Environmental Assessment Directive (SEA) and the Environmental Impact Assessment Directive (EIA) in Europe both involve the assessment of plans or projects on the environment. Although these clearly overlap (and overlap with the Habitats Directive), and both apply to deep-sea areas within national jurisdiction, they largely apply at different scales. The SEAs tend to be undertaken by Member States with a view to considering the environmental effects of large-scale plans, projects or policy. EIAs tend to apply to specific projects undertaken by the public or private sector. Thus the SEAs may be viewed as "upstream", perhaps as part of large-scale marine spatial planning, whereas the EIAs tend to apply "downstream" at a later stage, within the framework of a SEA. EIAs, certainly for the oil and gas sector, are more frequently referring to SEA Reports for information on environmental baselines (Barker and Jones, 2013). In either case, where significant environmental impacts are identified in these assessments then alternatives to the project should be assessed or appropriate measures taken to avoid, reduce or offset environmental damage.

Both the SEA and EIA Directives have driven improvements in the assessment of environmental impacts of industrial activities in European waters, including in the deep sea. Both also have weaknesses. For SEAs issues identified have included problems with identifying the scale or detail of environmental data required for baselines, lack of data, lack of standard criteria for environment and sustainability against which projects are judged, difficulties in identifying alternatives to plans and programmes and lack of monitoring programmes to identify unforeseen effects (EC, 2009). A review of standards for EIAs in the North Sea oil and gas sector has also identified problems which lead to deficiencies in a significant number of Environmental Statements (Barker and Jones, 2013). Whilst many EIAs described projects well, environmental baselines were largely based on existing data and of variable quality (Barker and Jones, 2013). Where new data were collected it was done well but with insufficient replication. Other issues included: difficulties in predicting the significance of environmental impacts, even where these were identified, provision of evidence of effectiveness of mitigation measures, identification of project alternatives, and on the monitoring of projects (Barker and Jones, 2013). The issues of lack of baseline data and identification of environmental impacts arising from human activities are picked up upon later in the report.

Within EEZs the management of marine mining activities will fall under the same regulations as other industrial activities. In the case of Europe, they are likely to be regulated under the SEA, EIAs Directive and Habitats Directives. In areas beyond national jurisdiction the United Nations International Seabed Authority (ISA) is the regulatory authority. Under UNCLOS the ISA is required to establish regulations and procedures to ensure the protection of the marine environment from harmful effects that may arise from exploration or production of minerals (ISA LTC, 2013). Industrial interests with an intention to explore for mineral resources in the Area must have a sponsoring State and have to apply to the ISA to undertake exploration activities (ISA LTC, 2013). The lack of data for areas where deep-sea mineral resources may reside, including mid-ocean ridges, seamounts and the abyssal plain, is a particularly challenging aspect of potential exploration, test mining and production in terms of environmental impacts. Therefore the ISA has a basic requirement for gathering of data on the environment where exploration is taking place, including both physical and chemical parameters and biological communities (ISA LTC, 2013). This is so that an assessment can be made of the likely impacts of any test mining activity, and also that monitoring can be undertaken against environmental baselines during and after test mining (ISA LTC, 2013). During this phase specific EIAs are required for rock sampling, test mining, drilling and biological sampling using destructive methods such as trawls or sledges (ISA LTC, 2013). Some additional requirements are also made with respect to the individual types of deposit including polymetallic nodules (ISA Assembly, 2013), polymetallic sulphides (seabed massive sulphides; ISA Assembly, 2010) and cobalt-rich ferromanganese crusts (ISA Assembly, 2012).

The ISA has, in consultation with scientists, looked at the potential use of spatial conservation measures to protect areas of the CCFZ from mining for polymetallic nodules. This has taken the form of an Environmental Management Plan and has included the provisional designation of nine areas of particular environmental interest (ISA Council, 2012). It is of note that all of these lie outside of the areas for mineral exploitation. A consultation process is now underway to develop a Regulatory Framework for management of the actual exploitation phase for deep-sea mining in the Area (ISA, 2014).

4.3. The provisions of the Convention regarding marine science

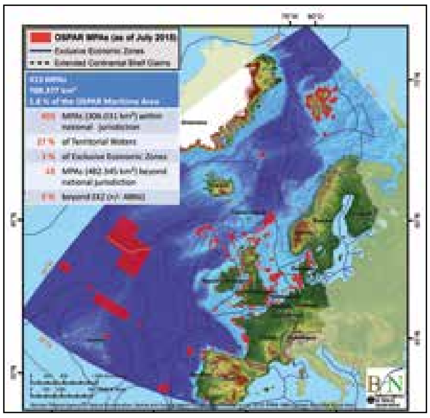
The Law of the Sea Convention contains provisions that address the rights and obligations with respect to the conduct of marine scientific research in the different maritime zones. Part XIII of the Convention covers the right of all states to conduct marine scientific research and the competence of the coastal State to regulate, authorize and conduct this activity within its jurisdiction. Marine scientific research is a freedom of the high seas. States likewise have a duty to promote and facilitate the development and conduct of marine scientific research (UNCLOS Art 239). The Convention also sets forth general principles that shall apply in the conduct of marine scientific research, including that it shall be conducted in compliance with all relevant regulations adopted in conformity with the Convention, including those for the preservation and protection of the marine environment (UNCLOS Art. 240). In terms of implementation it is notable, as outlined above, that the ISA requires EIAs for specific types of scientific research associated with exploration of potential mining areas and the gathering of environmental data within them. Evidence that scientific activities have had or potentially had impacts on deep-sea ecosystems is documented for chemosynthetic ecosystems, especially hydrothermal vents (Van Dover, 2014). Concerns raised over such impacts led to the development by the InterRidge (http://www.interridge.org/) international network of vent researchers of a voluntary code of conduct for marine research around hydrothermal vent ecosystems. This was known as the InterRidge Statement of Commitment to Responsible Research Practices at Deep-Sea Hydrothermal Vents (ISRRP; Devey *et al.* 2007). A subsequent study has suggested that scientists in general are aware of the ISRRP but there is a lack of clarity over how widely it is adhered to (Godet *et al.,* 2011). Deep-sea hydrothermal vents are relatively small, island-like habitats supporting an endemic biota surrounded by non-vent deep-sea ecosystems. For this reason they are particularly prone to localized damage by human activities, although in some cases they may show a high level of resilience to disturbances (e.g. vents on fast-spreading ridges which are subject to a high frequency of natural disturbance). Other deep-sea ecosystems, especially those with a small areal extent or which are classed as vulnerable marine ecosystems may also be prone to damage from scientific activities, especially the use of indiscriminate sampling gear such as trawls or sledges.

4.4 Spatial conservation measures in European waters and beyond

The European Habitats Directive (92(43)EEC) was previously the main mechanism for the establishment of Special Areas of Conservation (SAC) for deep waters off the European margin within national jurisdiction (e.g. the Banco D. Joao de Castro in the Azores and the Darwin Mounds). However, limitations to the deep-sea habitats listed in the Habitats Directive has resulted in more recent deep-water designations being driven by Regional Sea Commissions. For instance, in 2008 OSPAR produced a list of species and habitats of concern including deep-sea species and habitats, e.g. deep-water sponges, sharks, orange roughy, coral gardens etc. In addition, the interpretation manual of European Union habitats (EC, 2007) re-defines categories such as "reefs" to allow for the diversity of deep-sea habitats from biogenic to abiogenic reefs including seamounts and hydrothermal vents.

The application of such protected areas within a Member States' jurisdiction requires the Member State to first nominate a potential site of community importance (pSCI) before this can be legalized by the EC allowing the Member state to transform this into a SAC (within a six year time limit). Through this mechanism, a number of deep-sea MPAs have been established within EEZs (e.g. Rockall Bank, Anton Dohrn Seamount and areas of the Porcupine Bank). Furthermore, Portugal and the UK have established unilaterally MPAs on their respective extended continental shelves (Rainbow Hydrothermal Vent Field MPA and Hatton Bank SAC, respectively).

However, beyond national jurisdiction, there is no globally-binding legal framework for the establishment of MPAs or marine reserves. Spatial management measures have been established through cooperation amongst States within the umbrella of regional bodies which also seek independent expert advice from scientific networks, e.g. ICES). For example, OSPAR has the legal competence within its maritime area to designate MPAs in Areas Beyond National Jurisdiction (ABNJ) within its maritime area, and binding only its Contracting Parties. This has led to the establishment of two MPAs that are entirely located in ABNJ (Charlie-Gibbs South MPA and Milne Seamount Complex MPA) and several MPAs covering the High Seas over areas of claim for extended continental shelf (Antialtair Seamount High Seas MPA, MAR North of the Azores MPA, Altair Seamount High Seas MPA, Josephine Seamount Complex High Seas MPA) (Fig. 4.6; see also Olsen *et al.* 2013 for further information).



Credit: OSPAR 2015 (compiled by the German Federal Agency for Nature Conservation (BfN))

Fig. 4.6 Map of the OSPAR network of marine protected areas (as of 2014) (OSPAR, 2015), www.ospar.org

Fisheries were identified as the one of the key threats within the areas that have been designated. However, it is an explicit exclusion in the mandate of the OSPAR Commission to manage issues relating to fisheries. Therefore, to regulate such human activities in protected areas, OSPAR must cooperate with the appropriate competent organization (s) (e.g. RFMOs, including NEAFC; see Box 4.1).

To foster this cooperation, the OSPAR Commission and the NEAFC entered into a *Memorandum of Understanding (MoU)* in 2008[54], the objective of which was to promote cooperation on the conservation and sustainable use of marine biological diversity in the North-East Atlantic. Measures have included exchange of information, discussions of the management of human activities that impact on the marine environment, and development of common understanding of the application of the precautionary approach and to encourage the funding and conduct of marine science.

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[54] http://www.ospar.org/documents?d=32804

In parallel, the establishment of specific fishing controls (e.g. area based ban on bottom fishing) has been initiated by NEAFC in response to UN General Assembly Resolutions calling for sustainable management of deep-sea bottom fisheries in ABNJ and the FAO's International Guidelines for the Management of Deep-Sea Fisheries on the High Seas. Further closed areas are in place for fisheries management purposes (i.e. the Haddock Box on Rockall Bank). In the Mediterranean, the General Fisheries Commission for the Mediterranean (GFCM) has stipulated that bottom trawling is banned below 1000m depth and in the three selected sites above. (see also section 3.2.1.2 for current proposals for a EU ban on bottom trawling below 800m).

4.5. Towards Good Environmental Status (GES) of Europe's deep sea

The Marine Strategy Framework Directive (MSFD; 2008/56/EC) represents the environmental pillar of the EU's Integrated Maritime Policy and aims to achieve Good Environmental Status of the EU's marine waters by 2020 and to protect the resource base upon which marine-related economic and social activities depend (Figure 4.7). The Directive defines Good Environmental Status (GES) as:

"The environmental status of marine waters where these provide ecologically diverse and dynamic oceans and seas which are clean, healthy and productive... within their intrinsic condition, and the use of the marine environment is at a level that is sustainable, thus safeguarding the potential for users and activities by current and future generations."
Article 3 (5) of MSFD (2008/56/EC).

The Directive enshrines in a legislative framework the ecosystem approach to the management of human activities having an impact on the marine environment, integrating the concepts of environmental protection and sustainable use.

Credit: European Commission, DG

Fig. 4.7 MSFD policy cycle: Achieving GES by 2020.

The MSFD applies to the area of marine waters over which a Member State exercises jurisdictional rights in accordance with the UNCLOS. This includes a substantial component of deep-sea waters within European EEZs (see Introduction, Fig. 1.7 on EEZs) and includes, as defined by the MSFD, the seabed and subsoil under the water column. It should be noted that the applications of some States to assume their Sovereign rights and responsibilities also over the extended continental shelf means that national jurisdiction can, in some cases, extend beyond the EEZ (for the sea floor only). Member states are required to implement the MSFD by developing a marine strategy with assessment, monitoring programmes and programmes of measures for achieving the GES of the marine environment.

The MSFD sets out 11 qualitative descriptors of the marine environment, all of which are relevant to the deep sea (e.g. biodiversity, non-indigenous species, fish, health of food webs, contaminants, litter, underwater noise). However, successful assessment of ecosystem status and effective management requires a considerable scientific knowledge base. This is a particular challenge for the deep sea which is the most under-sampled region of the ocean and lacks systematic long-term monitoring in many key locations. A review of the initial assessment report by the EC and reports of various MSFD Descriptor Task Groups and National reports concluded there is a lack of data, especially for the deep-sea regions of the assessment. Additional efforts for a coherent classification of marine habitats, supported by adequate mapping, are essential for assessment at habitat level, taking into account variations along the gradient of distance from the coast and depth (e.g. coastal, shelf and deep sea). The appropriate sampling strategy for the deep and open sea should be discussed and established as currently there is a lack of standards for offshore and deep waters and a harmonized methodology at EU level is lacking.

Specific examples from MSFD Task Group reports of 'data-poor categories' from Europe's deep sea include:

- Descriptor 3 (commercial fish): Deep-water fish stocks and information on causes of declines e.g. in diadromous fish species and highly migratory fish, such as oceanic sharks (MSCC);
- Descriptors 8 and 9 (concentrations of contaminants in mraine waters and seafood): Only 3 Member States out of 20 were able to define partially baselines on Contaminants and none of the countries were able to establish thresholds (except one MS that did partially). Data on deep and offshore waters are overall very scarce and effort should be made to increase knowledge on this subject;
- Descriptor 10 (marine litter): Change in the nature, presence or abundance of anthropogenic debris on the deep seafloor is much less widely investigated than on the surface or on continental shelves. Research into the deeper seabed, which forms about half the planet's surface, is restricted by sampling difficulties and cost. Despite the presence of greater amounts of debris in deeper shelf waters than in coastal waters.

Among the three different categories of impacts considered in the Initial Assessments (on marine animals, water column habitats and seabed habitats), in general only impacts on marine animals were reported. Just one Member State (MS) included information about impacts on water column habitats, while none of the countries reported impacts on seabed habitats. Of the predominant habitat types reported by MSs, oceanic, shelf, and abyssal sediments were only reported by 1 out of 19 MSs. The MS reporting on each species' functional groups was consistently low, especially for certain deep-sea species.

Furthermore, a National example from the UK Marine Strategy noted that *"Current understanding of deep-sea habitats is limited"* and limited data availability for deep-sea species meant that some species have so far been excluded from the assessment of GES, as *"it is not possible to set appropriate, technically defined indicators and targets for these species due to the lack of survey data to support assessments.....For the short term development the fish component group have identified spatial gaps in monitoring for pelagic, deep-sea and coastal fish species."* To address these issues, the UK is currently developing indicators for the status of deep-water fish based on existing surveys.

Such data and knowledge are crucial to strengthen future MSFD reporting in deep-sea regions, e.g. to:

- Produce high resolution maps of habitat and baseline research on biodiversity and ecosystem functioning which is fundamentally lacking for the deep sea;
- Understand resilience, which is especially important in the deep sea as account must be taken of growing industrial interests, as well as changes related to CO_2 emissions;
- Effectively and holistically assess the spatial distribution and levels of pressures and impacts to establish environmental targets and associated indicators for their marine waters so as to guide progress towards achieving good environmental status in the marine environment.

4.6 Barriers to sustainable management and conservation

Whilst the establishment of deep-sea marine protected areas in European and adjacent waters is encouraging, significant problems remain in the conservation of deep-sea species and communities. Many of the protected areas specifically address benthic ecosystems and therefore there are no effective mechanisms to protect pelagic or demersal species that are of conservation concern other than more effective fisheries management. In particular, sharks are of a strong concern given their vulnerability to overexploitation both through targeted fishing and bycatch. The Mediterranean, for example, remains one of the regions of greatest threat to sharks and rays globally (42% of species Critically Endangered, Endangered or Vulnerable, including deep-sea species; Cavanagh and Gibson, 2007) pointing to the weakness of implementation of management of fisheries in the region to achieve sustainable levels of exploitation whilst limiting environmental impact.

Despite the success in establishing MPAs in European and adjacent deep seas there is little idea of whether these comprise a representative network providing protection for the full range of species and habitats threatened by human activities (mainly fishing at present; Fenberg *et al.,* 2012). A systematic approach to conservation that ensures the protection of the full range of species and habitats becomes vital to address some of the direct and regional-scale impacts of seabed mining (Wedding *et al.,* 2015). Again, as with many other areas in the present report, lack of data on bathymetry, habitat maps and information on species distributions as well as distribution and level of threat from human activities are a significant barrier to establishing a comprehensive range of spatial and other management measures to ensure conservation of deep-sea ecosystems (Fenberg *et al.,* 2012). Coupled with the presence of powerful industry sector interests (e.g. fisheries) the lack of information on deep-sea ecosystems becomes particularly problematic (Fenberg *et al.,* 2012). In the case of the CCFZ a combination of geospatial analysis and expert knowledge on benthic ecology led to a network of protected areas being proposed (Wedding *et al.,* 2013) and subsequently adopted as a management plan by the International Seabed Authority. Such efforts could be repeated in the context of deep-sea mining and other activities elsewhere. It should also be borne in mind here that the EU has signed up to Aichi Target 11 to protect using spatial conservation measures at least

10% of the entire marine environment by 2020.

Another significant issue particularly with respect to spatial conservation measures but also for other forms of sustainable management is monitoring, control, surveillance (MCS) and enforcement of regulations. Improvements in satellite remote sensing and other technologies are providing solutions to the MCS issue but further research and development is required to move such systems to an effective system of surveillance and enforcement (see 3.2.1.7).

4.7 Knowledge-based management and conservation of deep-sea ecosystems

Clearly baseline knowledge is required to increase the effectiveness of management of deep-sea ecosystems including for conservation purposes. These needs include:

- Better knowledge of species distribution, abundance and biomass in deep-sea ecosystems especially for threatened species;
- Better understanding of the connectivity of deep-sea populations and interrelationships between species;
- Understanding of ecosystem functions and services;
- Understanding of temporal variation in deep-sea communities;
- Better understanding of the spatial and temporal patterns of risk to deep-sea species and ecosystems posed by human activities;
- Understanding the role of deep-sea ventilation as a carrier of pollutants and contaminants, through the processes connecting coast/shelf areas and deep-sea and identify their preferred pathways (e.g. canyons);
- More knowledge on the effectiveness of deep-sea marine protected areas and other forms of conservation management;
- A better understanding of optimal design of networks of MPAs for the deep sea.

With respect to enforcement of management measures in the deep ocean clearly there are two areas which require attention. These are cooperation between institutions responsible for different industrial sectors as well as regional institutions such as OSPAR and States to achieve management and conservation objectives. Such cooperation has to go beyond European waters (as demonstrated by collaboration between EU States, OSPAR, NEAFC and ICES) and cross jurisdictional boundaries to achieve the knowledge driven and comprehensive management and conservation framework required for deep-sea ecosystems. There is also a need to apply new technological solutions to enforcement of management and conservation measures including:

- Development of new surveillance technologies (see 3.2.1.7) and the infrastructure to ensure effective enforcement;
- Effective port-state and market-based measures to ensure traceability of fish.

To conclude, great strides have been made in the conservation of deep-sea ecosystems from deep-sea fishing activities in European and adjacent waters but much more needs to be done to build upon these successes. New technologies and approaches will be needed to monitor the impacts of seabed mining.

5

Deep-sea research; current status in Europe and future requirements

Credit: IOW Baltic

5.1 Where is Europe positioned in deep-sea research?

The European contribution to deep-sea science is world leading. The history of this can be traced back to the 19th century (see section 1.1., Box 1.1). The renewed interest in deep blue economic growth raises the question of whether Europe has maintained momentum in deep-sea research. An analysis of trends in deep-sea publications by country and theme was conducted based on the ISI Web of Knowledge databases focused on the period from 1993 to the end of 2014. Search terms included the words "deep-sea or deep sea" in combination with a series of selective options including geographic region or state, period of investigation and topic investigated.

The temporal trend of deep-sea ISI publications led by European researchers from 1993 to 2014 is reported in Fig. 5.1. During the period of 20 years of the study the number of publications increased from 379 to 1556 per year, a 310% increase. However, as evident from Fig. 5.1, the increase during the first decade was much smaller (only approximately 83% with respect to the second decade) indicating that huge progress has been made recently. Deep-sea research is one component of the wider "marine research" carried out in Europe, which has profited from an important phase of growth stimulated by investment through the European 6th and 7th Framework Programmes and most recently Horizon 2020. A comparative analysis with the publications on the overall "marine" topic in Europe has shown the increase in the number of ISI publications in the Topic "Marine" has increased by 54% (Fig. 5.2), suggesting that the topic "deep sea" has increased at a very fast rate.

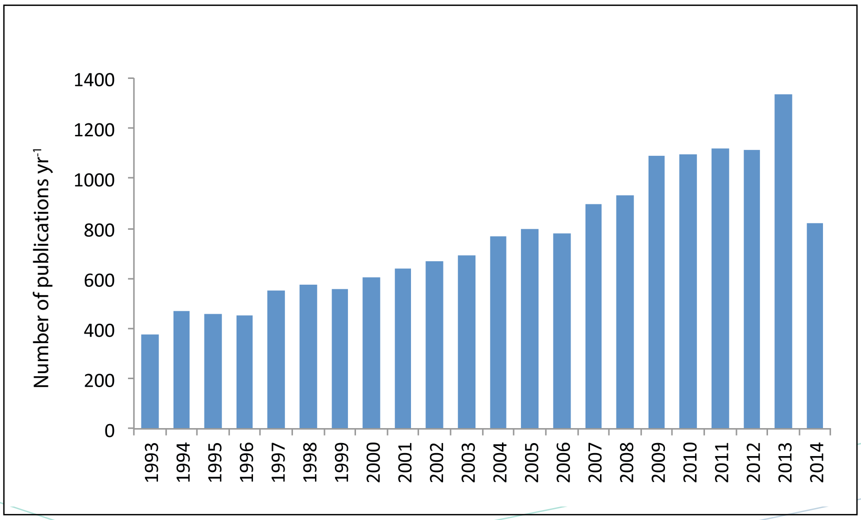
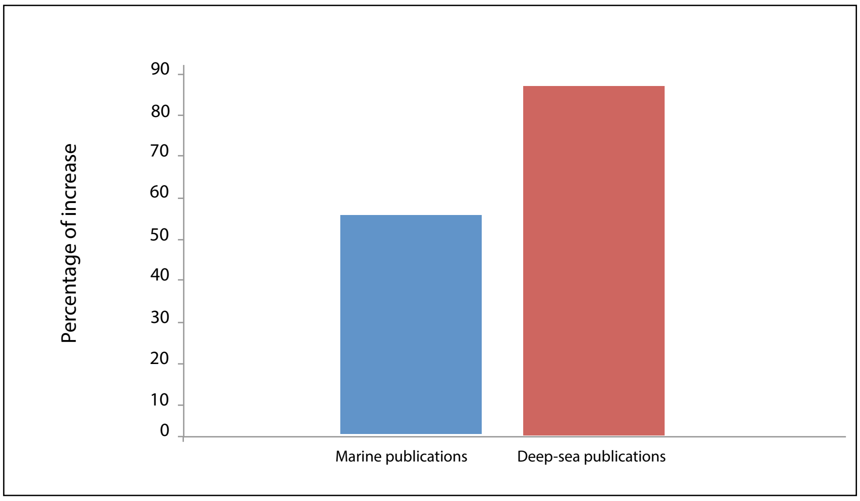


Fig. 5.1 Temporal trend in the number of deep-sea publications per year with a European lead-author 1993 to 2014. Data sourced from ISI Web of Knowledge.

Chapter 5 cover image: Forecastle deck of R/V *Meteor*

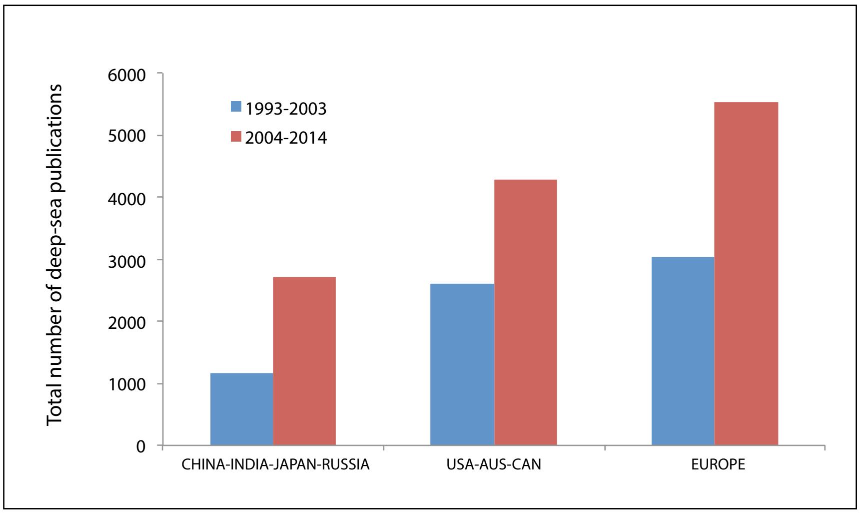
Fig. 5.2 Comparison between the percentage increase of ISI publications between the decade 1993-2003 and 2004-2014 in the topic «Marine» (blue) and «Deep-sea» (red). Data sourced from ISI Web of Knowledge.



Credit: Roberto Danovaro.

A comparison of the overall scientific productivity (here expressed as total number of ISI papers) in three geographic macro-regions at a global scale is reported in Fig. 5.3. This analysis reveals that Europe countries lead in both decades (1993-2003 and 2004-2014) and that this leadership has increased over time, and especially evident in the last decade. At the same time, these data point out that the rate of growth of the scientific production is highest for Eastern Countries (i.e. China, India, Russia and Japan), which together increased by 135% from the decade 1993-2003 to the decade 2004-2014, followed by Europe (83%), and with the US, Canada and Australia together increasing their overall production only by 65% between the first and the second decade.

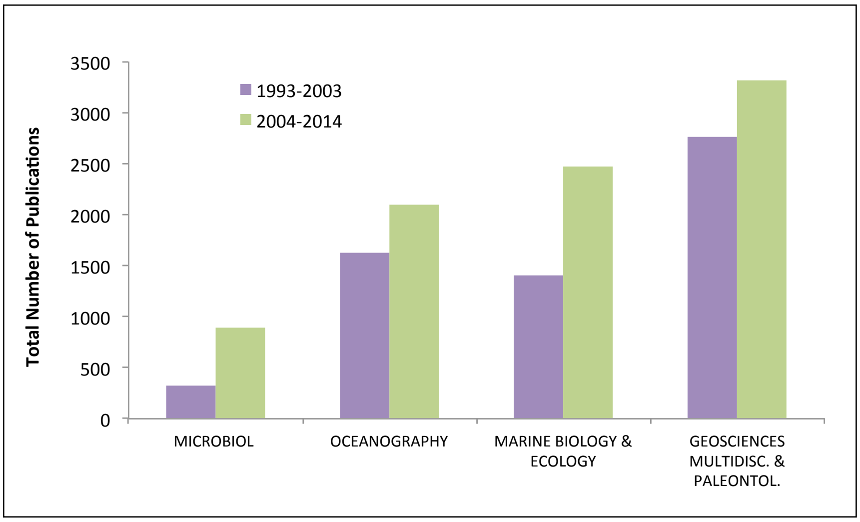
Fig. 5.3 Comparative analysis of total scientific publications (as number of ISI papers) in three macro-regions at global scale: 1. China, India, Russia and Japan, 2. USA, Canada (CAN) and Australia (AUS) and 3. Europe. Reported are only changes over time comparing the decade 1993-2003 and 2004-2014 for each macro-region. Data sourced from ISI Web of Knowledge.



Credit: Roberto Danovaro.

The analysis of trends of publication amongst research areas revealed that the main area in terms of number of scientific publication in both decades is the "Geosciences multidisciplinary and paleontology", followed by "Marine biology and ecology", "Oceanography" and "Microbiology".

All study areas have shown a substantial increase over time (Fig. 5.4; Danovaro In submission) but although the rank has not changed over the two decades studied "Geosciences" and "Oceanography" have increased only by 20-30% between the first and second decade whereas Marine biology and ecology", and "Microbiology" have increased by ca 80-170%, respectively (Fig. 5.4). These data indicate that although the largest number of deep-sea scientists are working in the Geological/ Oceanographic research areas, a significant portion of the new generation of scientists are focusing on the "biological" topics.



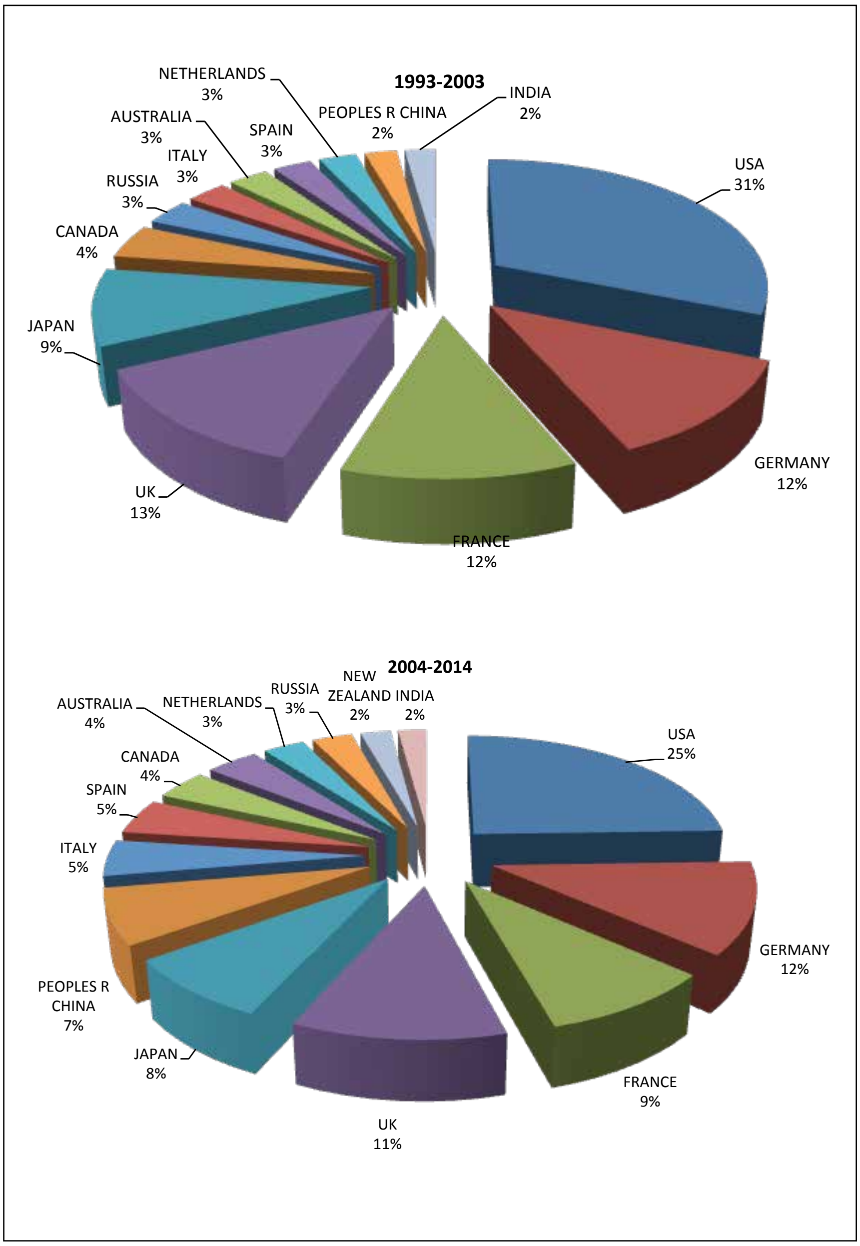
Credit: Roberto Danovaro.

Fig. 5.4 Comparative analysis of decadal scientific production (as number of ISI papers) within the four main research areas in European countries. Reported are changes over time comparing the decade 1993-2003 and 2004-2014 for the topics "Microbiology", "Oceanography", Marine biology and ecology" and "Geoscience multidisciplinary". Data sourced from ISI Web of Knowledge.

Finally, a comparative analysis was conducted on the contribution of the countries contributing more to the overall scientific production in the deep sea (Fig. 5.5). In this case the analysis used a cut off of 2% so that the countries contributing less than 2% are not included. This analysis shows that the individual leadership of the US is decreasing over time, passing from an overall contribution of 32% (ISI papers over the total) in the decade 1993-2003 to 26% in the decade 2004-2014. A minor decline in the relative importance between the two decades can be noted also for France and UK (reduction of 2%), and Japan (reduction of 1%). This contrasts with the notable increase of China from 2 to 8% and increase of Italy and Spain (increase of 2%), whilst the contribution of the other main countries remained almost unvaried between the 2 decades.

We can conclude that deep-sea research publications (as number of publication ISI - WoS) in Europe are increasing at a rate comparable or higher than that observed for broader "marine" science that has also seen a very significant increase over the last decade. Europe shows a consolidated leadership in both decades and has apparently the potential to consolidate this leadership for the next decade, even though the relative contribution of the different countries is changing over time as a result of the increasing investment by emerging large economies (e.g. China) and of European countries with a consolidated expertise in marine research that are now placing more effort in deep-sea research (Italy and Spain).

Fig. 5.5 Comparative analysis of the contribution of the main countries (i.e. those contributing for more than 2%) in deep-sea research over the last two decades. The comparison is based in terms of number of scientific papers produced. Reported are data from the decade 1993-2003 (top) and 2004-2014 (bottom). Data sourced from ISI Web of Knowledge.



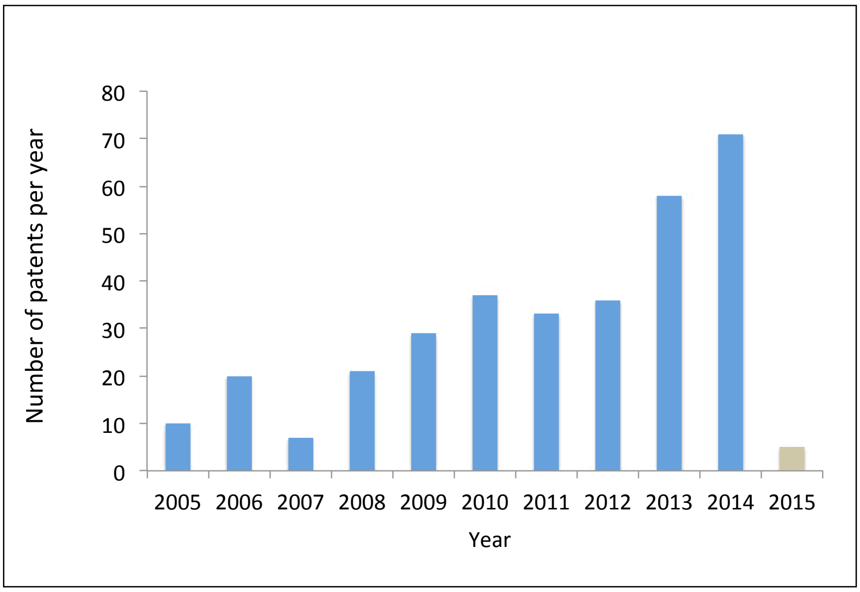
Credit: Roberto Danovaro.

5.2 Deep-sea innovation and patenting

The number of international deep-sea patents has increased exponentially during the last ten years, from approximately 10 in 2005 to more the 70 in 2015 (Fig 5.6). These results provide evidence of the increasing interest in the exploitation of deep-sea resources and on the relevance of the expected economic return from this kind of investment. Of the genes associated with WIPO patents, 17% are of unknown taxonomic origin, and almost none of the patent claims examined disclosed the geographic origin of material.

In terms of numbers of patents, China has led deep-sea patenting over the last years reaching almost 60% of the total number of international patents surveyed. The second most important deep-sea patent holder is the US, with approximately 22% while the rest of the world shares approximately 20% of the remaining patents (Fig. 5.7). The present analysis, however, did not investigate the number of patents actually commercialized and the current revenue of the patent exploitation. A more detailed analysis of each country's contribution to the production of deep-sea patents shows that France, Germany, and Japan are among countries producing more than 2% of the patents followed by Italy, Spain, Iceland, South Africa, Mexico and Singapore with 1%. (Fig. 5.7)

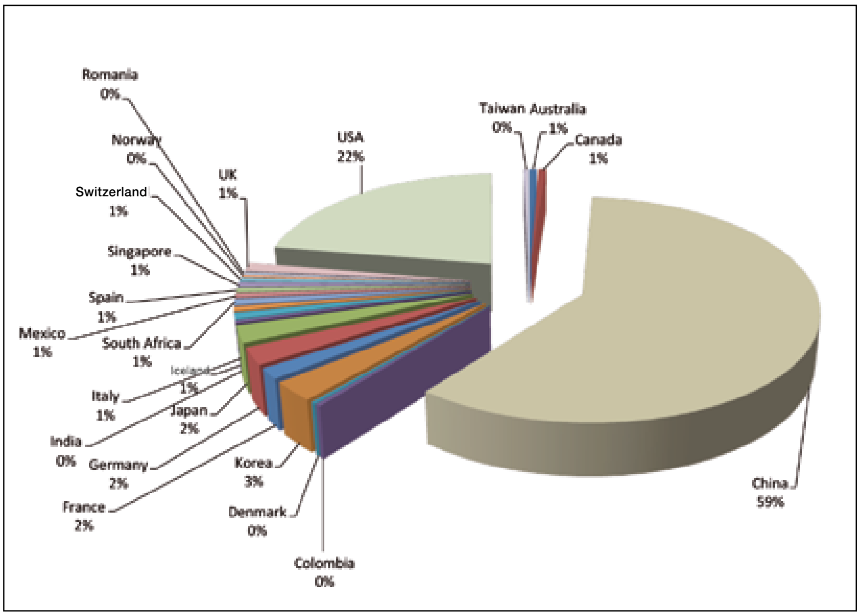
The main fields of interest are engineering-oceanography primarily devoted to the development of new technologies for a more efficient exploitation and exploration of the deep-sea resources (primarily oil and minerals) from one side and the sectors Biology/Medicine primarily for the identification of new molecules of industrial interest (pharmaceutical and processing) (Fig.5.8).



Credit: Roberto Danovaro.

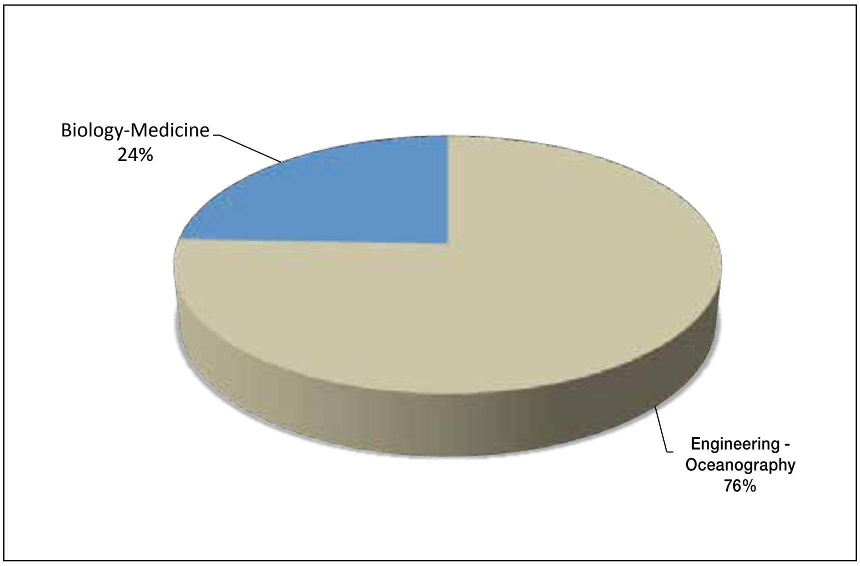
Fig. 5.6 Temporal trends (2005-2015) of the number of international deep-sea patents. 2015 is inclusive until May 2015. Data sourced from google patents (https://patents.google.com/).

Fig. 5.7 Percentage share of numbers of deep-sea international patents worldwide, data from 2005-2015. Data sourced from google patents (https://patents.google.com/).



Credit: Roberto Danovaro.

Fig. 5.8 Main sectors of deep-sea patents worldwide, data from 2005-2015. Data sourced from google patents (https://patents.google.com/).



Credit: Roberto Danovaro.

5.3 Stakeholder consultation on current and future deep-sea research investment

5.3.1 Rationale

The most recent foresight reports on the deep sea include Navigating the Future IV (EMB, 2013; chapter 8 therein), the Deep Sea Frontier (Cochonat *et al.*, 2007) and the Deep sea and Sub-Seafloor Frontier (DS3F) (Kopf *et al.* 2009), the latter two being primarily focused on the seabed and sub-seafloor. Though many of the emerging commercial activities in our deep ocean will happen on or close to the seafloor (e.g. seabed mining, oil and gas exploitation), it is important to note that those activities will directly and indirectly affect the entire water column, and therefore the system must be treated as a whole in studies on current and future knowledge needs and gaps.

"Without detailed knowledge of activities in the deep-sea, there is an overall lack of understanding of the marine environment, therefore further research, as a general rule, is always a priority".
Deep-sea fisheries stakeholder, UK

In addition, although all sectors of the Blue Growth strategy have opportunities in the deep-sea, there has been no recent European study focusing on the role of deep-sea research in this context. In addition, despite previous mapping of European marine investments (e.g. JPI-Oceans, 2015a), a need was identified to specifically consult deep-sea stakeholders and assess the current deep-sea investment landscape in Europe. As a related activity to the working group (WG), in 2014 the EMB launched a deep-sea investment study to gain stakeholder perspectives on deep-sea research investment, capabilities and research drivers and priorities in Europe. There are a diverse range of existing and emerging stakeholders in the deep sea and the investment required for both the research and technology development spans the public and private sectors, as industry requires strong knowledge to underpin development as well as advanced technology to exploit new or advanced deep-sea resources such as offshore wind using floating platforms or ultra-deep oil and gas reserves.

5.3.2 Stakeholder consultation design and targeted dissemination

A key objective of the EMB expert working group was to assess recent achievements in deep-sea research, current infrastructure and research capabilities and to identify gaps and priorities for future European research efforts (in the context of international efforts). To inform this review, the working group launched a consultation with the European deep-sea research community and wider stakeholders (including funding organizations and industry) to gather perspectives and trends in deep-sea research investments across Europe.

Three targeted versions of the consultation were created for the three main stakeholder groups , research producing organizations (RPOs), research funding organizations (RFOs), and industry. Each survey was split into the following 3 sections (see Annex III for an example).

1. **Baseline research:** Temporal, spatial and thematic perspectives and trends;
2. **Research Funding:** Sources (e.g. competitive vs. national capability, National vs. European, public vs. private), relevant policies, proportion of deep-sea investment, largest projects;
3. **Future investment:** Perceived major limitations and actions needed for sustainable blue growth.

EuropeanMarineBoard

Have your say in shaping Europe's #deepsea research agenda. EMB WG consultation on deep-sea research investment

bit.ly/1DMVskP

Fig. 5.9 Example of one of the tweets sent from the EMB twitter account disseminating the consultation. It was retweeted 17 times, with 22 link clicks and 2621 views.

The Consultation was initially launched in summer 2014 with a second consultation period from 28 January to 20 March 2015. The first consultation results were analyzed and published as a Masters thesis project[55] in September 2014. In addition, the WG invited a number of external deep-sea stakeholders spanning different stakeholder communities including industry, policy and conservation, to attend WG meetings in Oxford (24-25 April 2014) and Lisbon (13-14 November 2014) (see Annex II). Information gathered from the full consultation included perspectives on research priorities, relevant policies, and future requirements to ensure sustainable development of the deep sea. Three key stakeholder groups were identified for the consultation, namely Research Performing Organizations (RPOs), Research Funding Organizations (RFOs) and Industry. The surveys were created as a word document and also made available online (see also Annexes). The surveys were posted on the EMB website (WG Deep Seas webpage) and communicated through the EMB Twitter account; see Fig. 5.9).

The consultation was also announced and disseminated to the 35 EMB member organizations from 18 countries (2014 membership), EMB WG members and through WG member scientific expert channels. The EMB Secretariat and WG members were also active in sending targeted invitations to scientific projects (see Annex III for list of respondents). Invited industry stakeholders included participants of the WG stakeholder meetings (spanning deep-sea mining, blue biotechnology, aquaculture), targeted companies identified by EMB Secretariat and WG members, and an announcement to the World Ocean Council. Individual countries and networks were targeted after the survey had been disseminated to the networks and on Twitter, to try and ensure a wide geographical representation of responses for all stakeholders.

In total, 103 responses were received from 16 countries (14 European, 2 International). These included 83 from the marine research community and 20 from industry representing sectors including seabed mining, fisheries, and oil and gas (see Annex III for summary).

Fig. 5.10 WG Deep Sea members and invited industry stakeholders at EMB WG meeting, 13-14 November 2014, University of Lisbon, Portugal.. See Annex I and II for participants.

Credit: EMB

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[55] Donaldson, K. M. (2014) Investments in deep-sea research and commercial activities. University of Southampton

5.3.3 Perspectives on deep-sea research priorities

Stakeholders were asked to rank the areas of deep-sea research they were currently involved in, ranging from 1 as the least active up to 5 for areas of highest activity. The areas surveyed spanned scientific domains such as marine microbiology to societal, policy and legal areas of deep-sea research. Based on the survey responses (Fig. 5.11) there was a mismatch in levels of activity for certain areas of deep-sea research undertaken by research organizations compared to industry. For example, 70% of industry stakeholders noted medium-high to activity in policy and legal issues . This is perhaps expected since the EC (2012) reports that governance and legal issues will require attention if the full potential of Blue Growth was to be attained. In contrast academic researchers reported policy and legal issues as one of the smallest research areas with only 21.3% of respondents selecting medium to high activity in this area.

Other high priority areas of deep-sea research for industry were technology development and long-term monitoring, the former in marked contrast to scientists and science funders (Fig 5.11).

> *"Trying to obtain funding for deep-water ecological research is becoming ever more difficult, especially at national level. If fewer grants are successful in attracting funding, the UK will soon start to lose its prominence as one of the countries at the forefront of deep-water ecological research. In addition we may well lose our highly skilled researchers to other areas of research resulting in a lack of experienced people to train the next generation of scientists. This lack of knowledge will also result in an inability to use the equipment properly and safely."*
> Deep-sea researcher, UK

There was a similar trend for activity in seafloor mapping and seafloor surveying with 50% of industry respondents and approximately 30% of researcher respondents active in these areas. This disparity is initially surprising given the EC's goal of having the European seafloor mapped 2020. However, it is consistent with the EMB marine scientific stakeholder response to the Marine Knowledge 2020 Consultation[56] which proposed different roles for industry and academia in achieving this common goal, notably that industry should conduct the operational seabed mapping and surveying, surveying, whilst the academic research community could add value through scientific analysis of the raw data, conducted in an interdisciplinary, e.g. with regards to habitat mapping. This highlights the importance of shared access to data so that researchers can use the knowledge gathered by industry and *vice versa*. In addition, prioritization of seafloor mapping activities by academic researchers varied at national level with respondents from Portugal giving a high priority to seafloor mapping than other countries (Donaldson, 2014). This may reflect national legislation and policy since Portugal was the only country surveyed with a national level marine spatial planning (MSP) policy at the time of the survey (Donaldson, 2014).

For the academic research community, research areas with the most activity were predominantly related to an ecosystem approach of the entire deep sea (e.g. marine ecology, increasing general knowledge and anthropogenic and environmental impacts). In all of these areas, respondents from academia noted a higher activity than industry.

> *"It is unclear whether my research, which is all focused on the earth beneath the deep-sea, is considered part of deep-sea research or not. We normally fall in between marine science and earth science and suffer for it."*
> Deep-sea researcher, UK

In addition, respondents were also asked to compare how their level of activity across deep-sea research areas had changed between 2010 and 2015. In summary, understanding anthropogenic and environmental impacts and long-term monitoring showed the highest increase in priority from 2010-2015. According to the survey, environmental impacts increased from 16% of researchers ranking it a 4 out of 5 activity for the academic research community in 2010 to 41% in 2015 and anthropogenic influences increased from 26% in 2010 to 43% in 2015. Long-term monitoring and technology development also had large increases in priority, the former a 12% increase in respondents ranking it 4 out of 5, and the latter a 10% increase. Some areas of research showed a relatively dichotomous response

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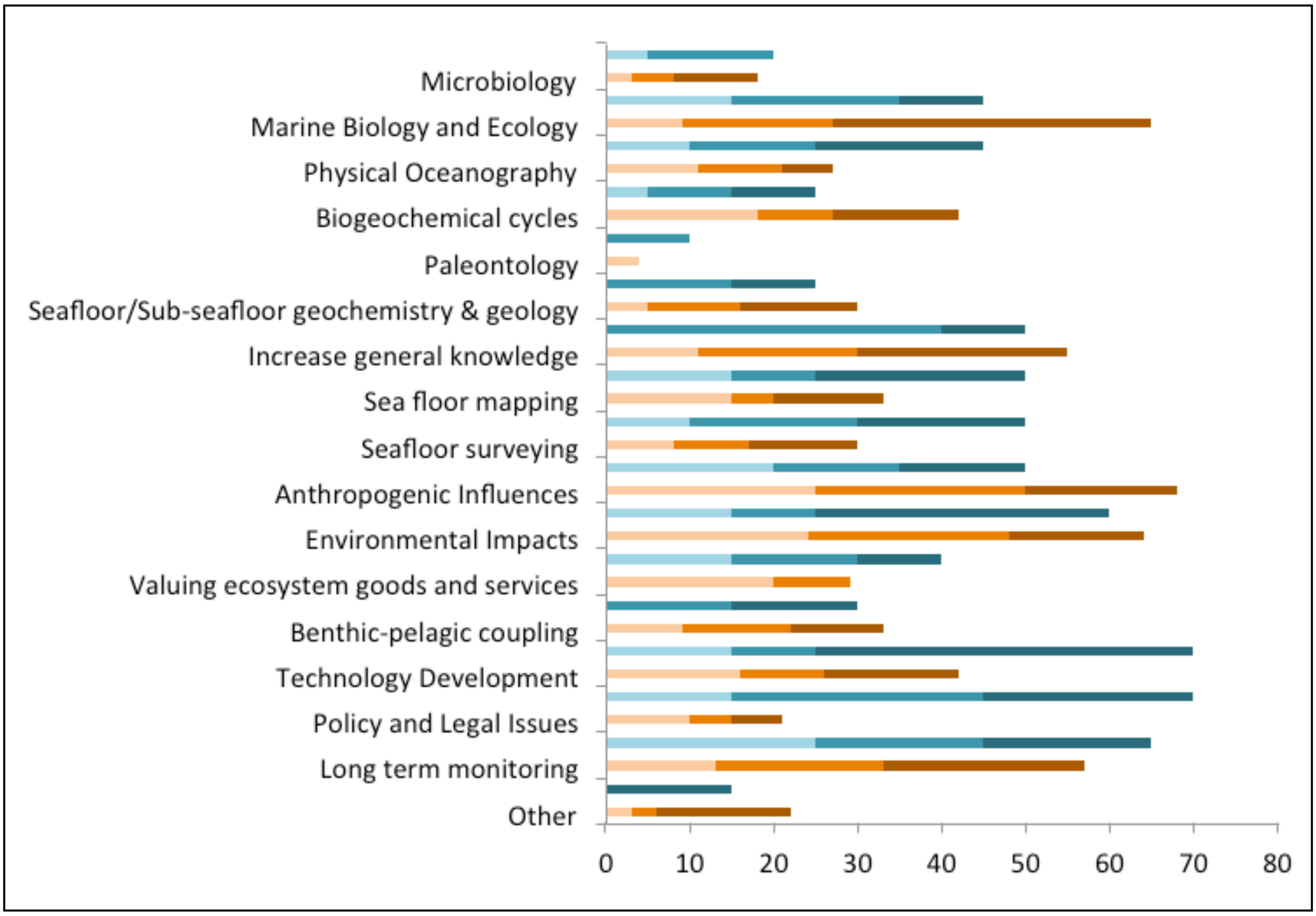
[56] European Commission Marine Knowledge 2020: from seabed mapping to ocean forecasting http://ec.europa.eu/maritimeaffairs/policy/marine_knowledge_2020/index_en.htm

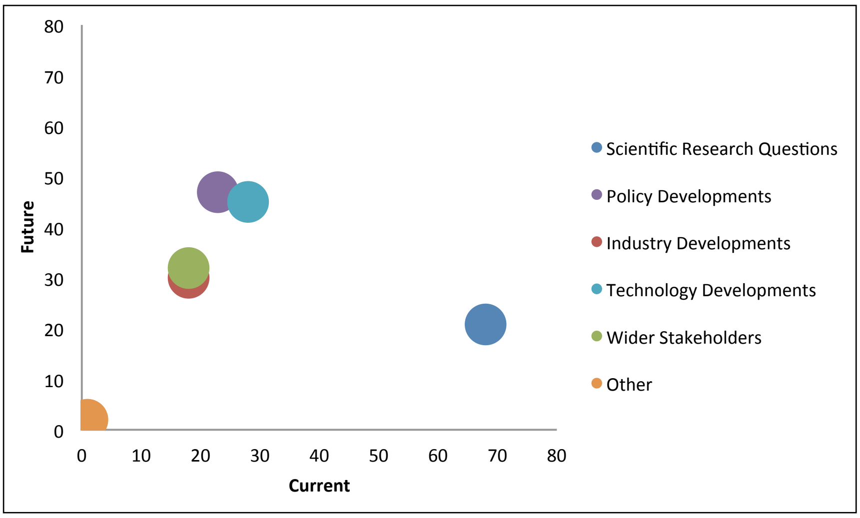


Credit: Karen Donaldson (EMB)

Fig. 5.11 Stakeholder perspectives on current (2015) deep-sea research areas individual researchers (orange) and industry (blue) are involved in, by percentage of respondents. These areas span thematic disciplines and overarching societal needs. Respondents were asked to rank their involvement for each discipline out of 5 (highest score). The lightest shade is the percentage respondents who ranked the research area 3; the darkest shade is the percentage respondents who ranked the research area 5. The lowest rankings 1-2 are not shown. The category of "other" included biotechnology, marine geophysics, tectonic or earthquake-related research, marine geology, paleoclimatology, paleoceanography, taxonomy and deep-water geoarchaeology. EMB consultation 2014-2015.

between the research and industry stakeholder communities (e.g. biogeochemistry). There was a large increase in 'other' category research priorities (examples include biotechnology, marine geophysics and deep-water geoarchaeology) between 2010 and 2015, demonstrating the increasing range of deep-sea research areas. It was noted that new areas of research and multidisciplinary science faced issues with obtaining funding (e.g. sub-seafloor research on the interface of marine biology and geology).

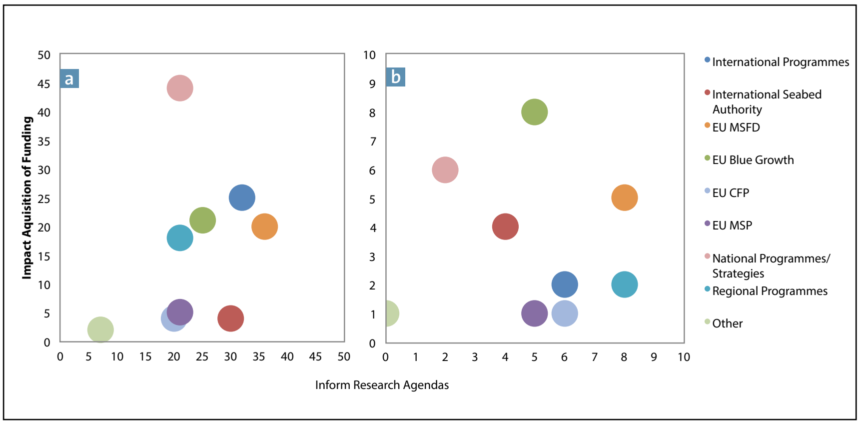
The academic community also provided their perspectives on the current and future factors that influence deep-sea research priorities (Fig. 5.12). Currently, the academic community perceive that scientific research questions have the largest influence on driving deep-sea research priorities. However, researchers also felt policy developments and technology developments, and to a lesser extent wider stakeholders and industry developments would have a larger influence in the future. Other factors researchers felt would influence their deep-sea research priorities include research community strategic planning, national and international initiatives and funding agencies agenda, and industry, referring especially to the development of the deep-sea mining industry.



Credit: Karen Donaldson (EMB)

Fig. 5.12 The current and/or future factors RPO respondents felt influence their research priorities. EMB consultation 2014-2015.

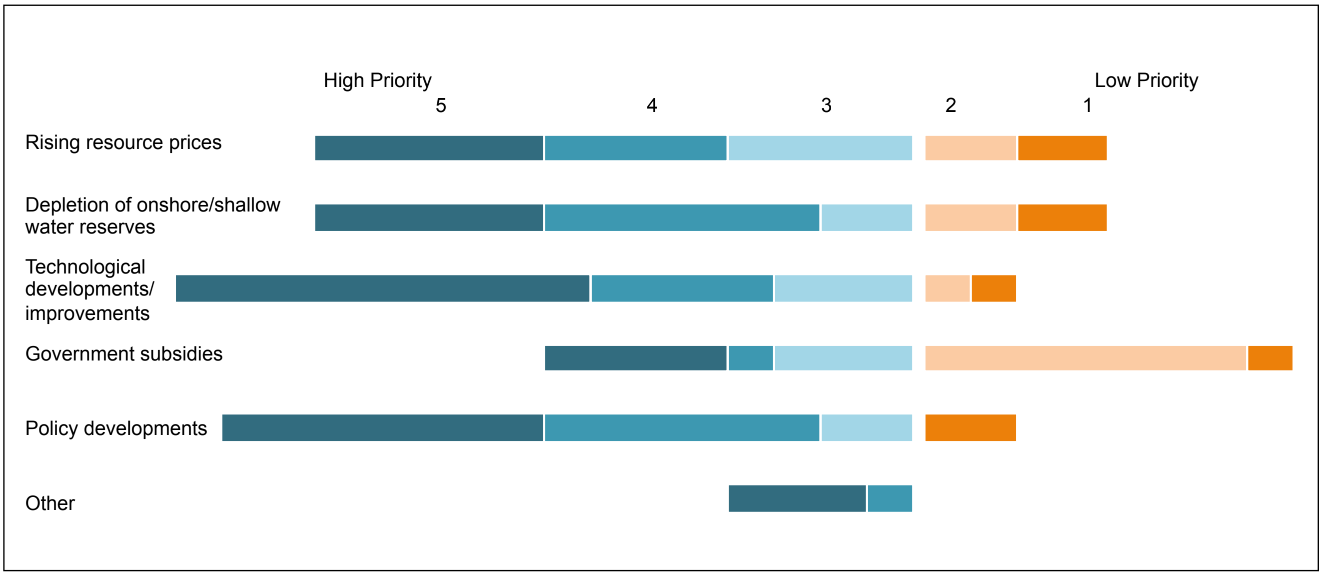
Stakeholders were also asked to reflect on the policies and programmes that inform deep-sea research or research agendas (Figure 5.13a individual researchers; 5.13b industry). National-level programmes were perceived to have the largest impact on the acquisition of funding whilst international organizations, such as the International Seabed (ISA) and European policies and Directives, such as the Marine Strategy Framework Directive and the Blue Growth strategy had the largest perceived impact on informing deep-sea research agendas. A number of individuals noted that the ISA should have more of an impact but currently does not have the resources required to keep up with the demand. Other international and European initiatives noted by respondents to inform research included the EU ESFRI, EuroGOOS, CBD, IMBER, ICES and GEOTRACES. Regional programmes included CIESM and OSPAR.



Credit: Karen Donaldson (EMB)

Fig. 5.13 The policies and programmes that RPO and industry respondents felt informed their research agendas (x axis) and/or impacted acquisition of funding (y axis) EMB consultation 2014-2015. **a**: Responses from academic researchers. National programmes had the largest impact on acquisition of funding, while international programmes and EU MSFD have the largest impact on research agendas. A number of individuals noted that the ISA should have more of an impact but currently does not have the resources required to keep up with the demand.
b: Responses from industry. EU Blue Growth has the largest impact on funding followed by national programmes, while EU MSFD and regional programmes have the largest impact on research agendas.

Industry stakeholders responded the main factors for involvement in deep-sea activities were technology development or improvement and policy developments (Figure 5.14). Other factors included requirements for additional power offshore, global awareness, development of rules and regulations, environmental protection, stakeholders co-operation, and strategic aspects of national and European resources access.



Credit: Karen Donaldson (EMB)

Fig. 5.14 Factors which contribute to industry's interest in different deep-sea related sectors. EMB consultation 2014-2015.

5.3.4 Perceived knowledge gaps and limitations

Stakeholder responses on perceived knowledge gaps and limitations indicated a mismatch between geographical areas which are the focus of current deep-sea research, and emerging areas of commercial interest, especially those related to seabed mining. The leading area for the development of seabed mining is the Pacific Ocean, with 16 exploratory contracts awarded by the International Seabed Authority[57] for seabed minerals, followed by the Indian Ocean with 3. For both these regions, there was a higher percentage of industry involved in deep-sea activity than researchers: Pacific Ocean (60% vs. 40%), Indian Ocean (45% compared to 20%). It was noted there is increasing cross-fertilization as industry is now hiring quite a few scientists to do their research for them for seabed mining in the Area. However, respondents noted this only applied to certain research areas and did not replace the need for non-commercial research. Approximately 20% of both academic and industry respondents noted activity in tyhe Artic region, although this is expected to increase as the Arcticwas noted as an environment rapidly changing as a result of climate change and a growing area for industry activity, with new technology and decreasing sea ice opening up new areas for exploration and exploitation.

European academic researchers noted their scientific activities were predominantly focused in the Atlantic Ocean (69%) and the Mediterranean Sea (61%). European industry respondents were also predominantly focused in the Atlantic Ocean (80%), followed by the Pacific Ocean (53%), but maintained relatively high activity in their respective EEZ (47%).

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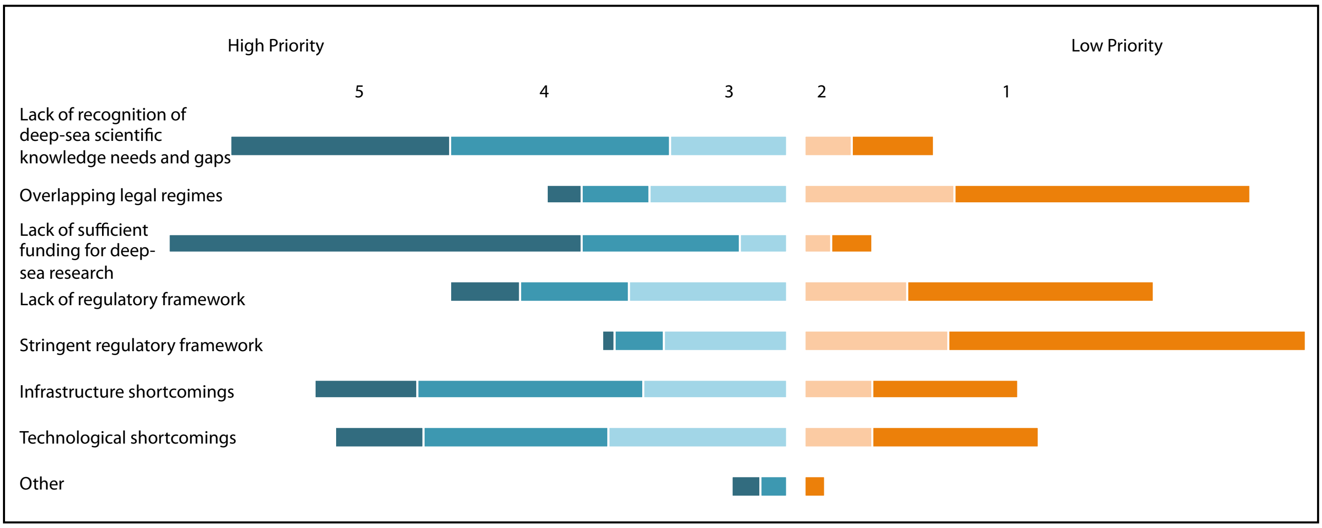
[57] http://www.isa.org.jm/deep-seabed-minerals-contractors

The stakeholder consultation also questioned researchers and industry on what they perceived as the major barriers to deep-sea research at the present time (Fig. 5.15). Lack of funding was identified as by far the most limiting factor on deep-sea research with lack of identification of research gaps and needs and lack of infrastructure also identified as significant issues (Donaldson, 2014). Legal and regulatory issues were identified as all presenting relatively little hindrance on deep-sea research. Issues raised on the "other" category included lack of human resources and management capacity, limited dedicated national support for research in the field, maintaining instrumental observatories in the deep sea for enough time with only 3-year research projects being the norm, lack of public perception on the importance of the deep-sea. Both accessing finance for research and focusing existing funding on marine / maritime areas are also identified as significant issues by the EC (2012). Lack of human capacity was also identified as one of three major issues by the EC (2014).

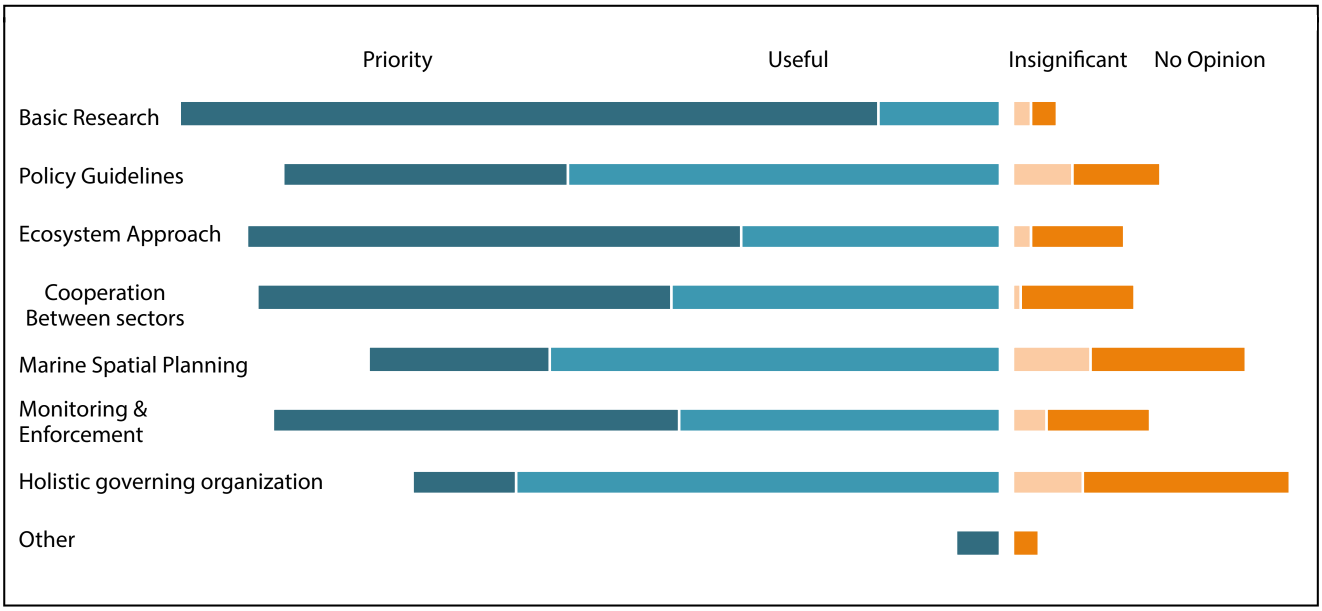


Credit: Karen Donaldson (EMB)

Fig. 5.15 Major limitations in investments in deep-sea research based on all responses. EMB consultation 2014-2015.

Stakeholders were also asked which actions were still needed to ensure sustainable development of the deep sea (Fig. 5.16). Basic research was considered priorities or useful to 95% of respondents surveyed, including both industry and RPOs (Fig 5.16). An ecosystem approach and monitoring and enforcement were also considered a priority, while policy guidelines and marine spatial planning (MSP) were considered useful.

Stakeholders from across different sectors, and particularly from industry, noted the need for pilot projects or demonstration sites for seabed mining.



Credit: Karen Donaldson (EMB)

Fig. 5.16 Actions still needed to ensure sustainable development of the deep-sea, based on all respondents. EMB consultation, 2014-2015.

> *"Environmental impact monitoring, risk analysis and education are needed to support commercial activities in the deep sea."*
> Deep-sea researcher, UK

> *"Due to a lack of research and long-term monitoring, many deep-sea habitats are under sampled, an accurate ecological baseline is unknown, and consequently, it is unknown how much the deep-sea contributes to Earth's biodiversity and the full extent of the ecosystem services it provides."*
> Deep-sea researcher, Germany

During further industry consultation, oil industry representatives also emphasized the need for basic knowledge. Long-term monitoring and sampling of fauna, water and sediment quality and hydrography were highlighted as being required to understand the spatial and temporal variation in deep-sea ecosystems. Likewise a representative from a fisheries management organization pointed to the need for basic data on the tolerance of deep-sea species to trawling impacts. Mapping the seabed was also identified by industry representatives as an important activity and connected with this the pooling of bathymetry and related data into publically-available data centres. The industry consultation also identified a range of problematic legal issues. These included systemic problems related to a division between international governmental organizations responsible for biodiversity and its conservation (e.g. Convention on Biological Diversity and UNEP) and those responsible for regulating exploitation (e.g. FAO, RFMOs) as well as sectoralization of agreements / conventions and their implementation. There were also more localized legal and technical issues such as the establishment of donation contracts between collaborating scientists and industry, rather than service provider contracts and the associated implications of liability for personnel and equipment.

5.3.5 An assessment of deep-sea funding

When asked which sources of funding were used, the majority of individual deep-sea researchers access public funding (85%) including national core funding (e.g. national capability), competitive funding and other contracts with 19% also sourcing funds from private foundations (Donaldson, 2014). This breakdown varied depending on the country, for example, 82% of 11 respondents from Germany receive all of their deep-sea research funding from public sources. Respondents from most other countries, including France, Norway, and the noted the use of more diverse sources of funding for their deep-sea research.

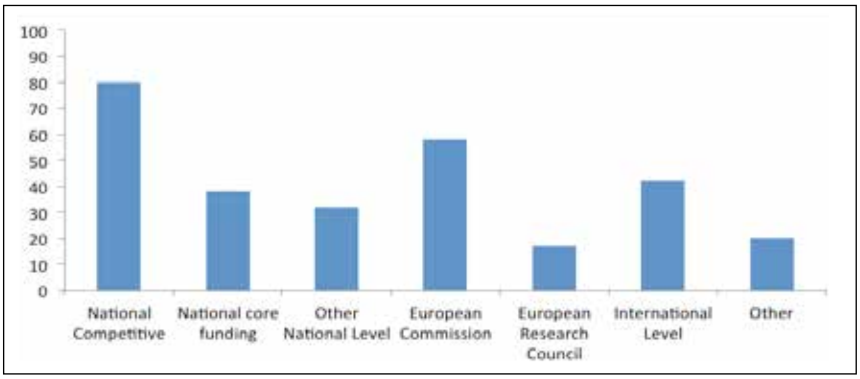
For funding programmes, the majority (80%) of RPO respondents stated involvement in national competitive programmes, followed by European funding such as the European Framework programmes (58%) and international level programmes (42%; Figure 5.17). Some respondents also commented that they are relying more heavily on European-level funding as national funding for marine and deep-sea research decreases. Respondents also noted an increasing trend in applications to private trusts/foundations (currently 19% of researchers receive some funding from that source), particularly as public funding for deep-sea research decreases, and national and European public funding calls are increasingly oriented towards applied science and technology thematic areas.

"Current calls are too focused to dissemination and [not enough on] basic science, this is especially dramatic in the study of deep-sea environments because we still ignore for example temporal dynamics for environments below commercial depths, regularly below 1,000m."

Deep-sea researcher, Spain

"European funding now largely targets networking... Networks are well established, and do not really need to be pushed any more. Funding of research should be the priority."

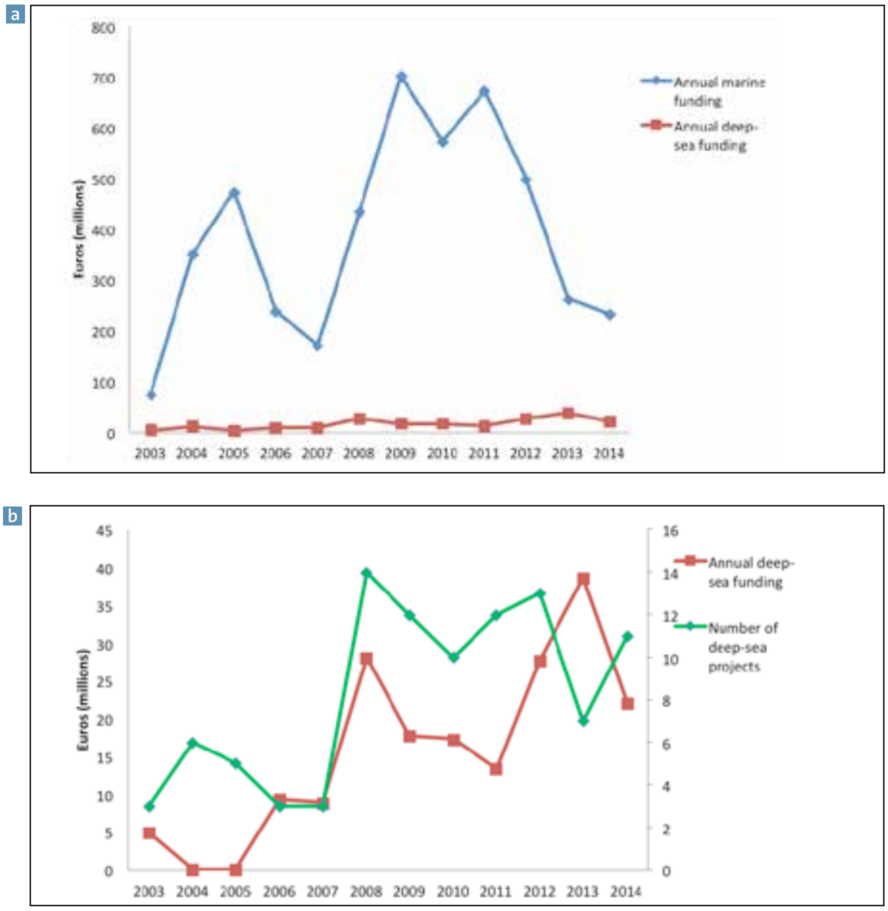
Deep-sea researcher, France



Credit: Karen Donaldson (EMB)

Fig. 5.17 Funding programme individual researchers are involved in, by percentage of respondents. EMB consultation, 2014-15.

In addition to stakeholder responses to the survey, further data on marine and deep-sea investment was obtained through keyword searches of open access online marine research project databases. At a level, data were obtained from the EurOcean Knowledge Gate 2.0 database using keywords deep sea, deep ocean, deep water, and hydrothermal vents. Results are presented in Figure 5.18a and 5.18b and Figure 5.19 and include data from the European Framework Programmes 6 and 7, Eurocores, LIFE and Interreg. Annual funding for European publicly funded marine related projects (blue line, Fig. 5.18) ranged from €74,861,135 in 2003 to €701,610,347 in 2009, while annual funding for deep-sea related projects (red lines, Fig. 5.18 and Fig. 5.19) was in most years much lower ranging from €3,686,338 in 2005 to €82,719,217 in 2013. Looking at the total marine and deep-sea funding over the 10 year period analyzed, marine funding was 25 times higher than deep-sea research. Looking at individual years, the proportion of deep-sea project funding was in general between 4-9% of the total marine funding committed, with the exception of 2013.



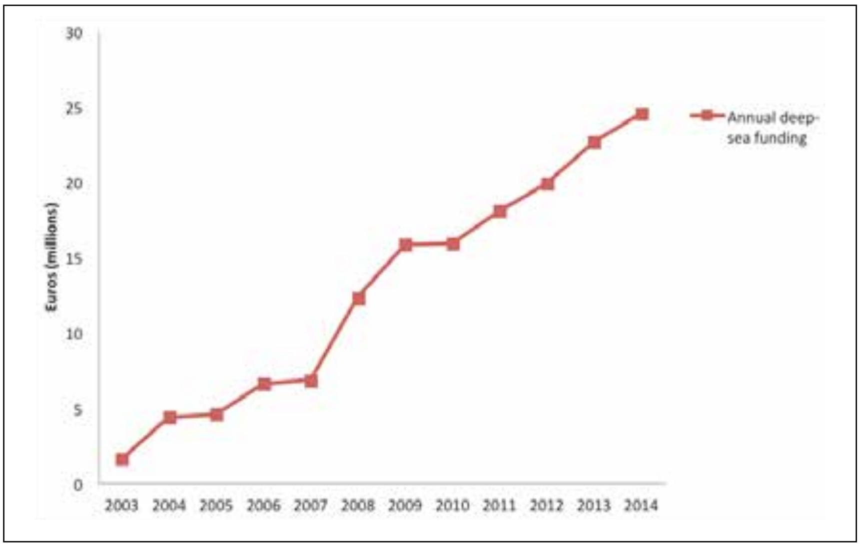
Credit: Karen Donaldson (EMB)

Credit: Karen Donaldson (EMB)

Fig. 5.18 Annual investment in marine and deep-sea related projects from public European funding programmes between 2003 and 2014. Information sourced from the EurOcean Knowledge Gate 2.0 online database (available until the end of 2014), using a keyword search for marine and deep-sea related projects. Available data are from the European Commission Framework Programmes (FP6 and FP7), Eurocores, LIFE and Interreg.

a: Total annual funding for marine related projects (blue line) and deep-sea related projects (red) in Euros, with total funding for each project based on the start year of the project.

b: Total annual funding and number of deep-sea projects funded at EU level per year (based on keyword search). The left axis (red line) represents total funding (Euros) for deep-sea projects started that year, and the right axis (green line) represents number of projects started each year. Note these graphs have not been adjusted for inflation.



Credit: Karen Donaldson (EMB)

Fig. 5.19 Annual investment in deep-sea related projects from public European funding programmes between 2003 and 2015. Based on keyword search from EurOcean Knowledge Gate 2.0 database. The original data are the same as deep-sea funding data presented in Fig. 5.17 (red lines). However, in Fig. 5.18 funding for each project was divided over the number of calendar years per project. In addition, Fig. 5.18 includes data until the end of FP7 (EurOcean, personal communication). Note, this graph has not been adjusted for inflation.

During the period covered by the study there was a shift from sector-oriented approaches to a broader challenge-based approach to research funding (EC, 2007). In the European Commission's seventh Framework Programme (FP7), for example, there was no dedicated thematic area for marine-related research; instead, it was recognized among the priority scientific areas which cut across themes (European Commission, 2007). This meant that although marine research was integrated into all themes, there was more competition with other scientific areas. From the aforementioned report, between 2007-2010, 644 marine-related proposals were approved for funding, worth an estimated €1.4 billion accounting for 6.4% of the financial contribution awarded by the EU across the FP7 programme and 5% in terms of number of proposals. (European Commission, 2007). Of the 644 approved marine-related projects, 25 (3.8 %) were deep-sea related worth €56.1m and accounting for 0.4% of financial contribution awarded by the EU to all marine related proposals or 0.04% in terms of number of proposals.

The latest EU framework program, Horizon 2020 (H2020), runs from 2014 to 2020 with nearly €80 billion of funding available over 7 years. All five Blue Growth focus areas are addressed by the first calls and there are also sub-calls, 'Blue Growth: Unlocking the Potential of Seas and Oceans' and 'Growing a Low Carbon, Resource Efficient Economy with a Sustainable Supply of Raw Materials' (European Commission, 2014). Though these calls do increase the amount of focus and funding for marine and maritime research, and potentially for deep-sea research, the vast majority of Blue Growth topics under the sub-calls are focused on innovation and providing support to the expansion of the maritime economy across Blue Growth priority areas.

Another issue identified for European funding was that there appears to be evidence for a bias towards larger RPOs obtaining more funding. This seems particularly the case when applying for large consortia grants e.g. H2020 Collaborative Projects. Potential reasons provided by stakeholders are that large research organizations generally have higher levels of core funding and are often able to direct more resources in terms of time and money to the preparation and writing of grant proposals. It may also reflect the fact that for European consortia, the competition for National institute involvement is high and large RPOs often benefit from high-level contacts between large RPOs and government research agencies and institutes as well as with their equivalents in other European States. Such an issue may impact on scientists within an entire country if it lacks large RPOs. It is noted that other competitive European funding streams such as European Research Council grants (funded through Horizon 2020) may not see the same levels of bias as these focus on fundamental research grants for individual researchers. However, whilst these are more bottom-up rather than thematic calls, the success rates can be as low as 9-15% (ERC, 2015) further adding pressure on the deep-sea research community who noted parallel trends in national competitive grant success rates.

> *"A significant problem is that the world of deep-sea research is very small and dominated (in terms of political influence) by a few key persons. This means that the limited resources are always delivered into the hands of the same people."*
> Deep-sea researcher, UK

This trend towards funding larger projects and networks can also be seen in Canada, where funding for individual research projects is decreasing while funding for research networks is increasing. This could indicate a transition towards a greater proportion of ocean science funding going towards networks. The networks support multiple researchers and their related projects, for up to seven years in some cases. For example, the increase in funding for networks in 2011/12 corresponds to the launch of the MEOPAR NCE and three SSHRC Partnership Grants[58].

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[58] Ocean Science in Canada: Meeting the Challenges, Seizing the Opportunity. MEOPAR: Marine Environmental Observation Prediction and Response Network, team of natural and social scientists; NCE: Networks of Centres of Excellence Partnership Grants provide support for formal partnerships over four to seven years.

An assessment of national deep-sea funding

The EMB study also included an assessment of national investment in deep-sea research across European states. It is not the purpose of this section to provide a comprehensive overview of national investment, but rather to note some general trends in national marine and deep-sea funding over the past decade based on stakeholder responses and further analysis of open access research funding data.

Across Europe, deep-sea research and related infrastructure is funded at national level through competitive grant schemes and core agency funding. Stakeholder respondents noted that national competitive funding increasingly includes thematic calls for strategic deep-sea research that are driven by policy or industry relevance. In contrast, they noted a decline in the funding for fundamental deep-sea research (also referred to as basic, blue skies, curiosity-driven and discovery research) through competitive grant schemes. Germany was the main exception to this rule where approximately 70% of scientific research is funded through open calls, reflecting a priority for a bottom-up approach based on scientific excellence.

Stakeholders from national funding agencies and RPOs across Europe also reported a trend for an overall reduction in funding for deep-sea research over the past 5 years (2010-2015). Undoubtedly, the Global Financial Crisis of 2007-2008 and the resulting austerity is at least partially responsible for the fall in national research funding across Europe. This trend was further investigated through national case studies, sourcing openly accessible data from online marine and wider environmental research funding databases, using keyword searches for deep-sea projects (see Donaldson, 2014).

From the stakeholder responses, there is evidence that at a national level, marine science and, in particular, deep-sea research in Europe has, in many cases, suffered from a progressive decline in funding since 2008 which has affected both core funding and competitive funding streams. Smaller deep-sea research departments that receive little core national funding have been hit hard by the dramatic decline in competitive funding which has also reduced the success rate of such grant programmes. In turn, larger RPOs have also suffered from cuts, particularly to core funding which has put pressure on budgets for vital research infrastructure including scientific equipment, ship costs and maintenance.

Europe is currently at the forefront of global deep-sea research. However, the implications of declines in deep-sea funding, particularly reported for some competitive funding programmes, could have a serious impact on national deep-sea research capability and delivery across Europe. This will inevitably affect the opportunities and training available for undergraduate, graduate and postgraduate students in deep-sea and wider marine science areas which may drive students to study elsewhere, resulting in a loss of expertise in deep-sea research across Europe. Another effect has been to force current professional deep-sea scientists to diversify into other areas of science that are less expensive (e.g. to work in shallow water ecosystems) resulting in a further drain in expertise.

This is coupled to the general trend for national and European funding programmes to focus increasingly on strategic marine science with an emphasis on applied science, technology and innovation. This is resulting in a further decline in the funding available for bottom-up, curiosity-driven deep-sea research, despite the need and demand from deep-sea stakeholders for fundamental deep-sea knowledge. Such trends can also be seen internationally. In the US, infrastructure expenses have risen over the past decade by approximately 18% even as the total National Science Foundation (NSF) Division of Ocean Sciences (OCE) budget fell by more than 10%. This has decreased the amount of funding available to support core research programmes, from 62% of the budget in 2000 to 46% of the budget in 2014 (National Academies, 2015).

5.3.6 Infrastructure

> *"Deep-sea technology and its use are very expensive (e.g. ROVs). International institutes should join their resources in providing a common pool for the use of special deep-sea equipment."*
> Deep-sea researcher, UK

The majority of survey respondents (69%) felt that infrastructure shortcomings were a major limitation regarding investment in deep-sea research, in particular the cost of ship time and the lack of permanent deep-ocean observation structures. A brief survey of infrastructure available for deep-sea research in Europe was also undertaken. Data were extracted from the EurOcean database for AUVs, ROVs, submersibles and research vessels. Annex V shows the size of the European research fleet, together with that of Russia and some other states peripheral to the EU. Oceanic and global-class research vessels are generally suitable for deep-sea work but the exact nature of what vessels can support depends on their design and available equipment. What is immediately obvious is that there are a large number of research vessels capable of deep-sea work in Europe. The UK, France, Germany and Norway and Spain are, in particular, well equipped with deep-sea capable research vessels. It should be pointed out that, in the case of the UK, not all of these are available for competitively-funded deep-sea work. Out of the global-class research vessels four belong to industry and five are military, leaving six vessels for what is usually understood as research science. Although this appears to be a substantial capability capacity, is barely sufficient to meet the current requirements of the science community (MSCC, 2014). As related in a meeting of the Marine Science Coordination Committee in the UK March, 2014: This indicates clearly that new requirements, including those for monitoring and maintaining Good Environmental Status under the MSFD, will lead to further pressure on seagoing research infrastructure, yet at the same time research infrastructure is under considerable financial pressure. In the UK, the MSCC states that a real prospect in the face of continuing cuts will be a reduction in the research fleet size, something that will *"result in a significant reduction in the marine science conducted by the UK"* (MSCC, 2013).

> *"Demand for vessel time continues to exceed capacity and could fully utilize the same number of ships as at present. One recent example of increased demand is the ambitious objectives for offshore and benthic habitat site monitoring, reports on priority marine feature condition and Good Environmental Status likely to be required under the UK marine biodiversity and monitoring programme. The affordability of vessels remains a concern as all members of the group are experiencing real-terms decreases in budget."*
> (MSCC, 2014).

A similar trend has been reported in the USA where, the UNOLS fleet has been reduced from 27 vessels in 2005 to 20 vessels in 2014, and is expected to shrink to 14 or fewer vessels by 2025 (National Academies, 2015; see also Annex V in this publication).

In addition to stakeholder responses, a review was made of available European databases on infrastructures, namely the EurOcean European Large Exchangeable Equipments[59] database, for large infrastructure that was capable of reaching depths greater or equal to 200m. Figure 5.20 shows the number of infrastructures available for deep-sea research per country. The number of large infrastructures available decreases as you increase the depth capability required. The deepest European capability is the ROV *Isis* from the UK, capable of 6,500m (Fig. 21). Results also highlight that capability is not equally spread across European countries. In addition, stakeholders noted that access to research vessels and large equipment is often prioritized for large oceanographic institutes and there is a need to provide more access to the full scientific community.

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[59] EurOcean – Centre for Marine Science and Technology maintains an on-line searchable info-base on the Large Exchangeable Instruments used in Europe for Scientific research: http://www.lexiinfobase.eurocean.org/search.jsp

As with research vessels, Germany, France, the UK and Norway have the largest number of deep-submergence vehicles (autonomous underwater vehicles, remotely operated vehicles, manned submersibles). Significant capability also exists in Spain (AUVs), Portugal and Greece (ROVs) and, outside the EU, in Russia (manned submersibles; Fig. 5.20). However, capabilities for use of such vehicles at depths greater than 3,000m is still relatively low (see Fig 5.21). Class 3 ROVs (>3000m depth capable) are expensive items to purchase and to run. These vehicles can typically be expected to undergo a maximum of 3 expeditions per year, amounting to perhaps 100 days at sea (Ratmeyer and Rigaud, 2009). The development of lighter hybrid ROV systems (systems that can operate in tethered or non-tethered mode) may provide a future alternative to current Class 3 ROVs which are both cheaper to run and also less demanding with regards to vessel capabilities.

Internationally in the US, the use of HOV *Alvin* declined by approximately 20% between 1990-1999 and 2000-2009, averaging about 200 dives per year in the last decade. In contrast, *Jason* (ROV) dives increased threefold in the same period. Since 2011, there has been a consistently high demand and use of *Jason* (approximately 170 days per year).

The results in Fig. 5.20 and 5.21 stress the need for new initiatives to help support and improve access to nationally and EU-funded infrastructure, e.g. building on the Eurofleets[60] initiative for coordinated access to European Research Fleet infrastructure and equipment. A response of the scientific community to these pressures has been to rely more heavily on privately-funded foundations such as the Schmidt Ocean Institute infrastructure for deep-sea work. This comes with its own risks as research objectives and aspirations of deep-sea scientists are increasingly subject to the interests of wealthy individuals or Foundations. This may lead to uneven funding of different research areas with a tendency to move towards "expedition" style research rather than sustained strategic and long-term research programmes. There are also opportunity costs as researchers spend increasing amounts of time in the search for funding. However, there are emerging public-private partnerships developing e.g. Global Ocean (see box 6.3, section 7.4.5).

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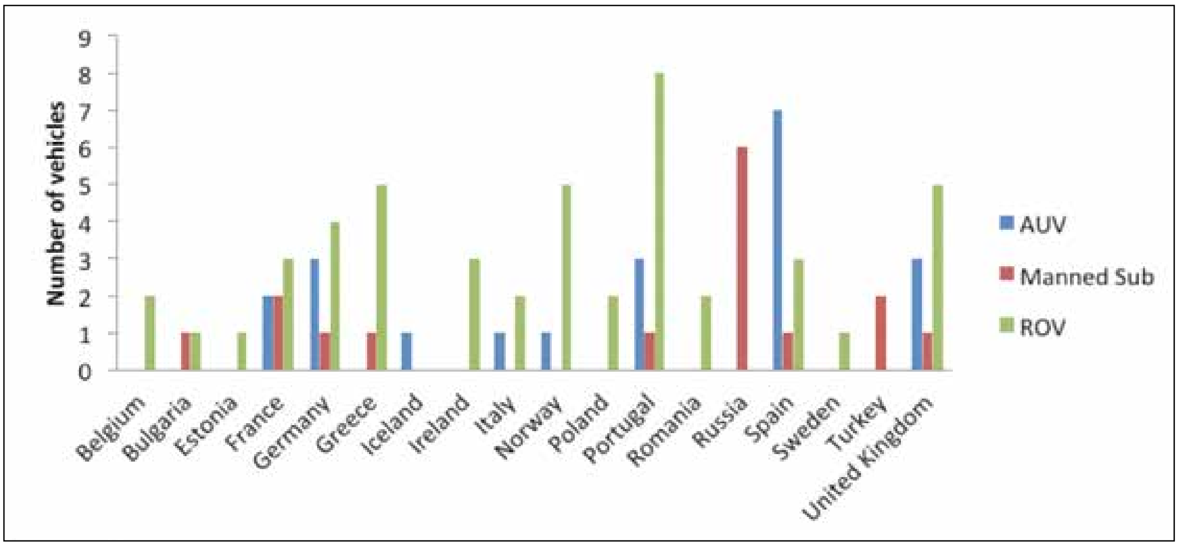
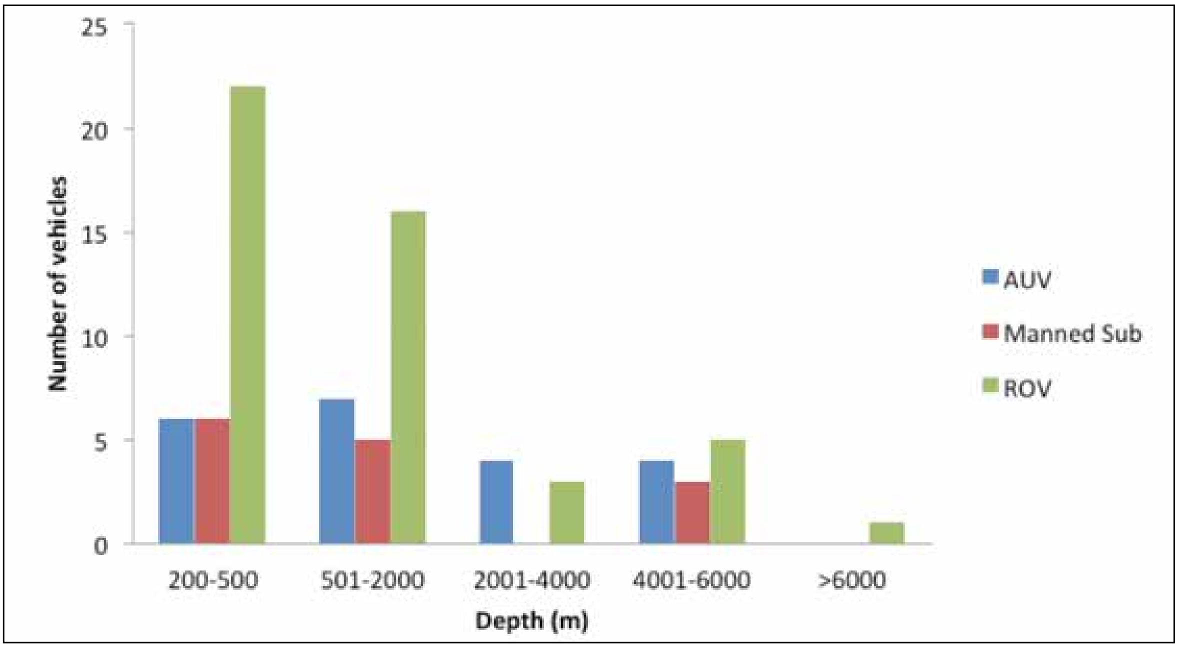
[60] http://www.eurofleets.eu/np4/home.html



Credit: Karen Donaldson (EMB)

Fig. 5.20 National capability for autonomous, manned, and remotely operated vehicles capable of depths ≥200m. Data were sourced from the EurOcean database, a comprehensive inventory of all European marine dedicated research facilities and regularly updated by EurOcean staff and interested parties who can submit records directly (EurOcean, personal communication). Data plotted are correct up to September 2015. These data do not include additional vehicles belonging to industry, government and military sources and scientific access is possible on a negotiated basis.



Credit: Karen Donaldson (EMB)

Fig. 5.21 Number and depth capabilities of deep-sea infrastructure in Europe, including only infrastructure capable of ≥200m water depth. Data were sourced from the EurOcean database, a comprehensive inventory of all European marine dedicated research facilities (see Fig. 5.21 for further information). Data plotted are correct up to September 2015. These data do not include additional vehicles belonging to industry, government and military sources and scientific access is possible on a negotiated basis. In addition, it is recognized that the European scientific community is currently developing further vehicles with a capacity >6000m.

Credit: HCMR

Credit: R. Mulligan

Credit: H. Robert RBINS

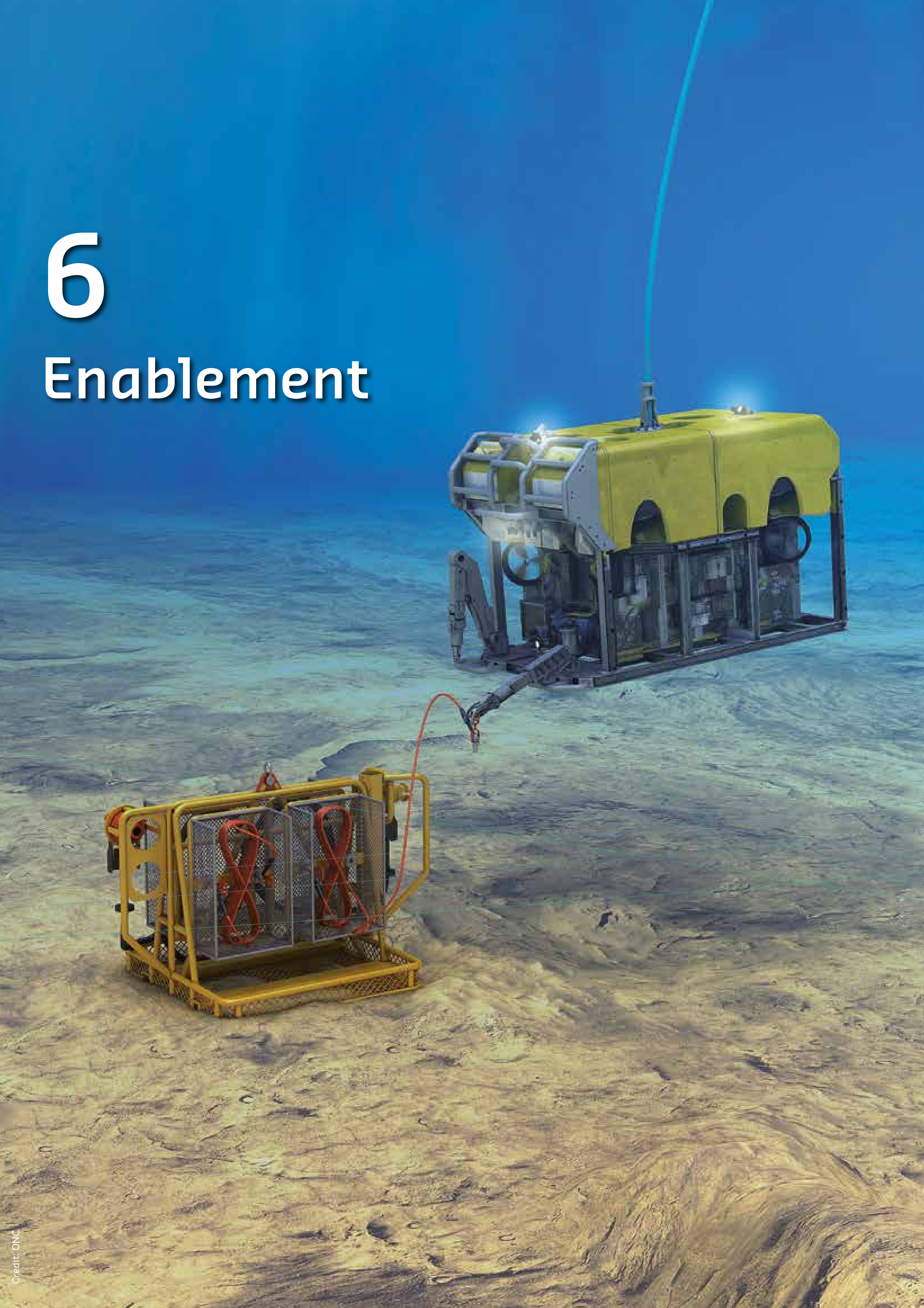
Fig. 5.22 Examples of European large infrastructure for marine scientific research.
Top row (left to right): Manned submersible *Thetis* (HCMR); Autonomous underwater vehicle (AUV) *Autosub6000* (NOC). Bottom: Recuperating the remotely operated vehicle (ROV) *Kiel 6000* (GEOMAR) on board of the RV *SONNE* during the mission SO-239 (CCFZ, Pacific Ocean).

5.3.7 Conclusion

- Both the science community and industry identified a strong need for an increase in basic research on deep-sea ecosystems including environmental baselines, biodiversity and ecosystem services;
- A need for seafloor mapping and surveying as well as a greater understanding of anthropogenic impacts and environmental impact assessment were also identified;
- Industry identified legal and policy issues as a barrier to achieving sustainable growth in the deep sea;
- There is evidence that the Global Financial Crisis of 2007-2008 continues to impact on funding for deep-sea research, both directly through competitive research grants and indirectly through impacts on availability of infrastructure;
- Small RPOs (e.g. universities and museums) are particularly vulnerable to funding constraints. There is a need for active engagement within the research community to involve such RPOs in large deep-sea research projects. The development of research clusters is one very good way of achieving such integration (e.g. clusters involving industry, government research institutes and universities);
- Availability of large infrastructure (ocean-going ships) and state-of-the-art technical equipment (e.g. deep submergence vehicles) is not matching the growing requirements of the deep-sea scientific and wider stakeholder community, e.g. with respect to marine monitoring (MSFD) and blue growth. Continued pressure on vessels and other infrastructure could make this situation worse, with the problem being especially acute for working at depths greater than 3,000m. It is critical that the current infrastructure for deep-sea research is maintained and, where possible, increased. The development of cutting edge technology such as hybrid ROVs may help to alleviate such issues if the production costs, running costs and operational constraints compared to ROVs can be decreased. The market for ROVs and AUVs and other marine autonomous systems is expected to increase significantly so a technological lead in this area is of economic interest to the EU in itself;
- Europe is currently a leader in marine research, with 13 of the top 25 leading countries in Ocean Science Output (2003-2011) being European. Norway leads in specialization, Switzerland is highest in impact, and the UK has the largest number of publications globally (after the US and China) (Council of Canadian Academies, 2013). If the EU wants to maintain leadership, there is a need for continued or increased funding to ensure high quality research and innovation and to continue to attract top researchers;
  - On average the G8 nations spend 0.8% of GDP on research and development. However, new analysis released in 2015 showed UK investment in publicly funded research dropped to less than 0.5% of GDP in 2012, which puts the UK at the bottom of G8 groups of countries;
- There is a need for long-term strategic planning to upderpin funding investements which can predict infrastructure needs, take account of economic cycles and changes is funding levels, and be adaptable to changing context and priorities, research needs and societal challenges.

6

Enablement



Credit: ONC

6.1 Research drivers

Credit: NOAA

Fig. 6.1 A deep sea red crab clings to a bubblegum coral. If you look carefully you can see a skate egg case on the same branch as the crab and a colony of the white morph of bubblegum coral in the background.

Despite recent major advances in ecological research, the knowledge to effectively manage human use of deep-sea ecosystems is still lacking. The main consequence of this are that we have to apply the precautionary principle until the actual impacts and resilience of different marine habitats and ecosystems have been assessed. At the same time, the advent of new technological developments offer unprecedented opportunities, which open the possibility to investigate priority research topics that were inaccessible until a few years ago. To do this we need to expand our capacity to conduct deep-sea research and identify the priorities for future investigations. Below we attempt to summarize the knowledge gaps for deep-sea science and governance, the questions they raise and approaches to tackle them.

> *"I think really strong science is required to underpin sustainable development, and you can have all the mapping, planning and monitoring you like, but if we don't understand how the ecosystems function (and we'll gain this through interdisciplinary research) we don't have a hope."*
>
> Deep-sea researcher, Ireland

6.1.1 Biological sciences

What are the patterns of biodiversity in the deep sea?

Although knowledge about deep-sea biodiversity has increased significantly, especially in the last 20 years it is still very scant and fragmentary. Most work has been done on slopes and basins close to the continents of Europe and North America but data on areas such as the Indian Ocean and regions distant from the continents are almost non-existent. Coverage is very unbalanced between the northern and southern hemisphere. Knowledge also decreases with increasing depth, for example, knowledge on deep-sea trenches is scattered and mostly focused on microbes. The level of knowledge on different components of benthic communities from viruses to megafauna, including understanding of abundance, biomass and diversity is highly variable: some components are more extensively and historically investigated than others. Knowledge on deep-sea pelagic communities is even scarcer making them probably one of the least-known parts of the Earth's biosphere.

Chapter 6 cover image: Siemens is developing power technology for deep sea factories. These self-sufficient oil and gas extraction facilities should one day exploit raw material deposits on the seafloor. Located thousands of metres under water, the factories must operate reliably for several decades. However, there is still no empirical data about the high water pressure's long-term effects on transformers and other network components. Siemens is therefore testing components for deep sea facilities in a special pressure chamber in Trondheim, Norway. Beginning in 2020, the Norwegian energy company Statoil plans to build oil and gas extraction facilities deep under water.

Specific questions:

- How many species are there in the deep sea?
- What is the biogeography of the deep sea and how have biogeographic patterns evolved?
- What are the representative vs distinctive habitats in the deep sea; where are the ecologically and biologically significant areas (EBSAs) and hotspots?
- What is the diversity, abundance and biomass of mesopelagic and bathypelagic organisms and how are they distributed?
- What factors drive the spatial distribution and biodiversity of different benthic components?
- What is the temporal variability of deep-sea benthic and pelagic ecosystems and what drives it?.

What are the patterns of connectivity between deep-sea ecosystems and between the deep and shallow water?

Many research questions on connectivity are global and can be more readily answered by studying the more approachable coastal systems. Although comparative approaches must also be valued it is important to identify key deep-sea specific processes to which research efforts should be directed. Connectivity covers a wide area of ecology including consideration of intraspecific population connectivity, source-sink population dynamics, trophic links, species interdependencies and pelagic-benthic coupling.

Credit: MARUM

Fig. 6.2 Cold-water corals off Ireland at 750m depth.

Specific questions include:

- What patterns of evolution, gene flow and genetic structure are exhibited in the deepsea (cryptic diversity vs low rates of evolution and genetic slow-down (Pawlowski *et al.* 2007)?
- What role does the allee effect play in deep-sea populations?
- Are source-sink dynamics a significant driver of patterns of community structure in the deep sea?
- What are the implications of population connectivity in the deep sea for conservation and the design of efficient networks of MPAs?
- What are the patterns of connectivity between shallow and deep populations of species and how important is this in the future management of habitats and species, including commercially important species such as the red coral (*Corallium spp.*)?
- What are the trophic links in deep-sea ecosystems and between deep-sea and shallow-water ecosystems? This includes consideration of food limitation, alternative food sources in the deep sea (chemosynthesis-based communities) and the relevance of pelagic-benthic coupling?
- What is the connection between surface productivity, particle fluxes (biological vs. physical pumps), energy and carbon at the seafloor, effect on biomass and diversity?
- What are the links / interactions between the geo- and bioprocesses (geomicrobiology) in the deep sea?

- What are the predictions of climate change effects on food supply to the deep sea?
- How do patterns of ocean circulation and mixing affect the distribution and connectivity of populations of deep-sea species over short to long timescales?
- What is the impact of expanding oxygen minimum zones (OMZs) on zooplankton distribution (habitat compression) in the deep sea and what are the resultant potential changes to the remineralization length scale for different nutrients? Does this lead to changes in particle flux to the deep sea? Are there feedbacks on fluxes from the sediment?
- What is the role of the deep-sea biota in biogeochemical cycles and how does the biogeochemistry of the ocean influence deep-sea ecosystems?
- What role do deep-sea pelagic ecosystems play in deep-sea foodwebs, carbon, vital rates, benthic-pelagic coupling?
- What is the spatial and temporal variability in deep-sea connectivity (e.g. short term and wide scale of pelagic processes/responses vs long term localised benthic processes/responses)?

How do deep-sea ecosystems function and what ecosystem services do they provide?
Given the lack of knowledge about fundamental aspects of the distribution of life in the deep ocean it is not surprising that the functional ecology of deep-sea ecosystems is not understood. These include understanding of the fundamental connections between species within ecosystems and how this links to basic processes such as biogeochemical cycling, the interplay and feedbacks between biological and physical environment and the links between deep-sea ecosystems and the rest of the Earth system. Ecosystem services provided by the deep sea have been listed (Armstrong *et al*, 2012) but there is little understanding of these both in a qualitative and quantitative sense.

Specific questions include:

- What ecosystem services are provided by the deep sea and how important are they to the Earth system and to humankind?
- What is the relationship between biodiversity and ecosystem function in the deep sea?
- What are the elemental fluxes from benthic sediments to the deep sea (reservoirs)?
- How is the biological carbon pump influenced by processes in the deep ocean and what are the feedbacks (if any) to the climate system?
- What do deep-sea biological palaeoarchives tell us about the effects of climate change on the ocean in the past?
- What is the influence of pressure on organisms (piezoeffects Tamburini *et al.* 2009) and particle degradation?

How do human activities impact on the deep ocean and how can we monitor such impacts?

Human activities are now evident throughout the deep sea in terms of the presence of litter, debris, plastics, chemical contamination and the destructive effects of deep-sea fishing and other activities. However, there is little understanding of the mode of action of many human impacts on the deep sea and the significance of impacts at a variety of spatial and temporal scales.

- What is the footprint of human activities and impacts on the deep-sea?
- How significant are human impacts on deep-sea ecosystems?
- How resilient are deep-sea species, communities and ecosystems to human impacts?
- What are the physiological effects of pollutants on deep-sea species (ecotoxicology) and how does this impact on the function of deep-sea ecosystems?
- What are the routes of pollutants into and through the deep sea and what is their residence time?
- What are the impacts of sediment release or resuspension on the deep water column and benthos from activities such as deep-sea trawling, deep-sea oil and gas drilling, release of mine tailings and deep-sea mining?
- What are the impacts of cold nutrient rich waters on surface productivity resulting from OTEC?
- How do we differentiate ‘natural’ variation in deep-sea ecosystems from changes resulting from human activities?
- What are good indicators to measure deep ocean change?
- Can we restore deep-sea ecosystems and can this be done economically?

6.1.2 Physical sciences

What is the role of deep-ocean circulation in transporting material in the ocean?

Whilst the general ocean circulation is quite well understood, ocean circulation in the deep-sea at regional and local scales including its temporal variation is not well understood. Understanding the role of the ocean in global biogeochemical cycling, at the large scale, transport of pollutants at a regional scale and in the dispersal of sediment plumes at a local scale all require detailed understanding of ocean circulation. Some aspects of circulation are key to ocean ecology such as current-topography interactions on seamounts and the dispersal of larvae of deep-sea organisms between suitable habitats.

Specific questions:

- How does seabed bathymetry interact with deep-sea currents?
- What is the role of deep-ocean physics and chemistry in carbon sequestration and how will this change in future as CO_2 emissions accumulate in the Earth system (i.e. what are the negative and positive feedbacks to atmospheric CO_2 concentrations)?
- What is the role of ocean currents in transporting material from hydrothermal vents (e.g. mesoscale eddies, Adams *et al.* 2011)?
- What are the links between the deep sea and the upper water column (sub mesoscale circulation)?
- How can the dispersal of sediment plumes and other materials (e.g. oil release) be more accurately modelled and predicted in the deep sea?

What biogeochemical processes are critical controls on elemental cycles in the deep-sea?

The overall distribution of the elements in the ocean is now reasonably well established but the mechanisms controlling this are still poorly understood. Critically at the present time we are still lack basic information on the biogeochemical processes, and their rates, that alter the in-situ chemical speciation of elements in the deep ocean. Recent findings that there are large scale (1000's of km long) hydrothermal plumes for Fe in some locations in the deep sea has overturned previous paradigms regarding deep-sea biogeochemistry and indicates that hydrothermal vents may have more than a local impact on earth systems. The development of new techniques (e.g. isotopic composition of chemical species, metabolomics, proteomics, transcriptomics) coupled with advanced sampling systems that are equipped with new physical and chemical sensors able to withstand the rigors of the deep ocean is key to improving our knowledge of the biogeochemistry of the deep sea.

Credit: Sandra Brooke, Oregon Institue of Marine Biology

Fig. 6.3 Squat lobster (*Eumunida picta*) in thickets of the deep-sea coral species *Lophelia pertusa.*

Specific questions:

- Does iron (Fe) released from deep-sea hydrothermal vents make its way to the euphotic zone?;
- What is the influence of particle remineralization and scavenging on elemental distributions in the deep ocean?;
- What are typical respiration rates in the deep ocean?;
- Is deep ocean bacterial production in the water column limited by the concentration of specific organic molecules?;
- What chemical tracers are available to detect transport of materials through the deep oceans (e.g. from sediment plumes from deep-sea mining)?;
- Which deep-water processes are critical to improving the description of deep-sea biogeochemical cycles in global climate models?

How are deep-sea mineral resources formed and what is their distribution?

There is still a lack of understanding as to how many deep-sea mineral resources are formed and what their distribution is on the seabed and buried beneath the seabed. Even where deposits are known there is often little information on the grade of mineral ores and their variability over an area. Optimal methods for mineral mining, transport to the ocean surface and processing are still in their infancy.

Specific questions:

- What are the ore formation processes involved in the various deep-sea mineral deposits?
- How do these processes vary spatially and what can this tell us about the variation in metal content of ores?
- What is the distribution of deep-seabed mineral deposits?
- What are the economics of deep-sea mineral exploitation?
- What are the potential impacts on ecosystems of deep-sea mining?

What is the threat posed by deep-sea marine geohazards to industry and humankind?

Major disasters incurred by marine geohazards such as tsunamis pose a significant threat to human population and also to deep-ocean industry. The oil and gas industry, for example operate on the continental slope where the presence of methane hydrates can cause instability of deep-sea sediments. SMS deposits located on mid-ocean ridges or in back-arc basins can be located in areas of intensive seismic activity and they can be a risk of volcanic eruption.

Specific questions:

- What geological risks are present in areas where new types of human activity are taking place in the deep sea?
- Do new industrial activities in the deep ocean increase the risk posed by geohazards (e.g. extraction of methane hydrates)?
- What is the risk of a tsunami caused by deep-sea geohazards in the waters of Europe and elsewhere?

6.2 Infrastructure and technology approaches

Fig. 6.4
a: Lander
b: ROV *Victor* in the Atlantic Ocean
c: Oil and gas seafloor platform
d: BoBo benthic lander
e: Submersible vehicle *MARUM-QUEST* deployed from the research ship *METEOR* during an expedition in the Arabian Sea
f: Marsite recovery of the SN4 seafloor observatory in the Gulf of Izmit (Marmara Sea)
g: Deploying an AUV
h: Megacorer used to take sediment cores of the seabed

> *"A lot of sophisticated and high tech equipment is available to explore deep sea environments, but [much more] needs to be developed to study accurately deep-sea ecosystems (in situ monitoring, material fixation in situ, sampling and transfer under in situ conditions, etc). European, international and private funding are needed to ensure sustainable deep sea basic and applied research."*
> Deep-sea researcher, France

6.2.1 An opportunity for Europe

The vast breadth and depth of the deep sea means that this can only be explored, monitored or managed with the use of relatively sophisticated technologies. This is a huge opportunity for Europe, whose existing and advancing research, development and manufacturing capabilities for deep-sea infrastructure and technology give it a natural advantage. Europe's fleet of ocean-going research vessels (those of most relevance for deep-sea studies) is large and thanks to regular replacement of vessels the average age of the fleet is low. Both factors are important as the exploration and sampling of the deep sea is heavily dependent on the use of latest-generation acoustic and sampling devices. Europe is a leader in both multi-beam echo sounding and acoustic underwater positioning systems - necessary both for environmental impact studies of any exploitation as well as deep-water mapping and construction work. Companies in several countries are making important advances in pressure-tolerant deep-sea technologies which hold enormous promise, both in terms of price and weight advantages, for the future. The enormous volume represented by the deep sea make the use of autonomous systems and fleets of such systems unavoidable for its exploration, mapping and conservation. Several European research centres are making major progress in adding intelligence and swarm behaviour to such systems, further work on improving operational reliability to make year-long autonomous deployments a reality is however necessary, although it is noted this requires more complex, energy-hungry systems.

The sections below summarize the current and emerging drivers for deep-sea technology development and present examples of research applications and future needs.

6.2.2 Infrastructure and technology drivers

The drivers for deep-sea infrastructure and technology development can be summarized as:

- **Accurate and repeatable underwater positioning:** No environmental monitoring or management system can hope to succeed unless repeated ("time-series" or "before and after") measurements of the same parameters are made at the same place. Such technology is available and utilized by the offshore oil and gas industry but is hugely expensive and often tailor-made for particular applications or installations;
- **Sampling capabilities adapted to the object to be sampled:** Rocks, sediments, water, micro- and macro-biology need to be sampled at representative densities and with sufficient metadata (e.g. the temperature, turbidity, O_2-content etc. of the water at a sampling site for fauna) to be both useful and representative. In many cases this requires visual control of the sampling and precise localization and navigation;
- **Sensor technology:** The development of sensors is an area of high interest for a number of active groups, both in Europe, the US and Canada. There is a reasonable level of investment in the area, with funds from national organisations (NERC-UK, DFG-Germany, DoE-USA), being combined with international initiatives such as funds from the EC (e.g. FP7 programs such as the Oceans of Tomorrow initiative mentioned earlier). There is increasing interest from commercial organisations such as those in the oil and shipping industries to have better sensors for analytes they are interested in, in some

cases they are working with research partners, funding the development of these sensors. The goals of these programs are to create small, cheap, mass produced highly robust sensors for a wide range of EOV's that determine the concentrations or values of a number of variables to fill our knowledge gaps. Ideally the sensors produced will be deployable on a number of platforms including, buoys, AUV's, ROV's and cabled networks;

- **Autonomous systems:** Making a significant impact on deep-sea research will require a commitment to robotic technology above and beyond that committed so far to space exploration. Questions of vehicle reliability, power sources, communication and navigation are similar in both deep-sea and space exploration. Europe is a crucible of the development of autonomous vehicles (AUVs, ASVs, drones) and further development is required in terms of operational depth (where applicable), range, endurance and sampling capability. It is important that such development is accompanied by increased capability in terms of vehicle control (including machine intelligence and coordinated behavior), navigation, communication and networking;
- **Instrumented cables** (links to Int. Telecomms Union itu.net and their "green repeaters"), deep-water technologies (oil installations, environmental surveys), new resource exploitation technologies (e.g. mining equipment), education ("internet on the seafloor");
- **High-bandwidth connections** to land for large volumes of data; integrated trans-disciplinary four-dimensional data bases; modelling capacity for high resolution models of huge volumes of the ocean; deep-water hazard monitoring;
- **Monitoring:** The development of monitoring technologies, including infrastructures and sensors, will benefit to the understanding of the temporal variability of ocean systems on time scales ranging from seconds to decades, but also to spatial variability and the assessment and survey of the potential impacts of exploitation of deep-sea resources. Technologies range from completely autonomous stations easy to deploy and recover for short time periods and monitoring stations with communication capabilities (EMSO-Açores), to completely cabled infrastructure (e.g. NEPTUNE Canada) laid to function for 25 years. Figure 6.5 presents a summary of depth and spatial capabilities of ocean observing platforms.

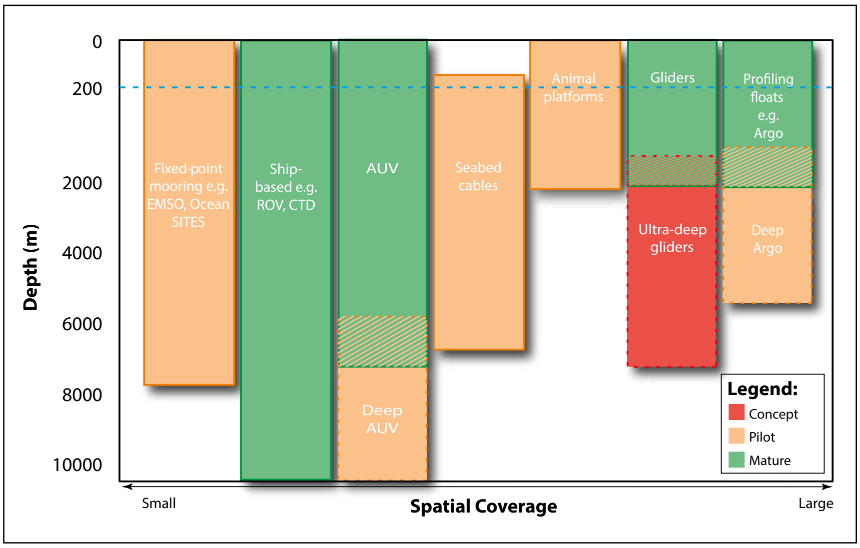


Fig. 6.5 Depth and spatial capabilities of ocean observing platforms showing three levels of development, namely concept (red), pilot (orange) and mature (green). Maturity levels based on information provided by stakeholders in 2014-2015.

Credit: Karen Donaldson (EMB)

- **Engineering:** The exploration, monitoring and management of the deep sea are, by their very nature, activities occurring in remote and generally harsh environments. As such, they pose enormous engineering challenges, many of which have not yet been fully met. Presently, the main factors hindering efficient work there are (a) energy limitations, (b) limited long-term reliability of sensors and platforms over seasonal to multi-year time scales and (c) difficulties in transmitting high volumes of data from remote locations. Key challenges will be to find ways of reliably accessing environmental energy in the deep sea and on the high seas to power vehicles and sensors deployed there, to make vast improvements in the reliability and redundancy of equipment used and to establish a high-bandwidth communication network in regions where even satellite coverage can be poor. It is important that engineering best practice is used where possible to reduce or mitigate environmental impacts of industrial activities affecting the deep sea;
- **Predictive and extrapolative modelling:** The very size of the deep ocean makes it important that observational technology is used to maximum efficiency. This requires modelling both (a) a priori to determine the key regions of the deep ocean whose monitoring will yield the most widely applicable results and (b) following data acquisition to extrapolate the results to wider areas of the ocean basin (c) for modelling potential environmental impacts (e.g. plume dispersal);
- **Assessment of representative regions and the variables to be measured and monitored:** In many cases, the characteristic scales of features in the deep ocean (e.g. microbial or meiofauna geographic range, spacing of food sources or required habitats) are only poorly known, making the definition of representative areas for exploration, monitoring and management difficult. Work is required on defining the relevant length scales, the essential variables which must be measured and the spatial and temporal density of measurements required.

"It's difficult to maintain instrumented observatories in the deep-sea for enough time with only three year research projects."
Deep-sea researcher, Spain

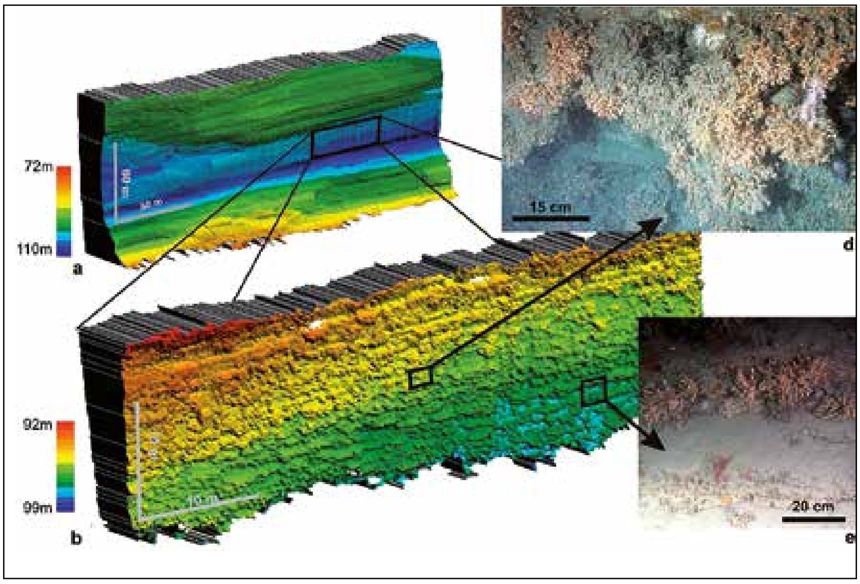
"Infrastructure shortcomings are a major limitation to deep-sea research especially given the scarcity of permanent deep ocean observation infrastructure."
Deep-sea researcher, The Netherlands

Emerging areas of technology development driving ocean exploration

- **Coordinated Behaviour:** Using multiple autonomous vehicles to repeatedly survey an area is already a reality in land-based regions such as those hit by natural disasters. This technology is ripe for transition to the deep sea;
- **Underwater optical communication:** Although proven in several test regions, this technology is not yet established as standard. But the enormous advances in LED-technology presently occurring will open the way for long-distance (several 100m), high bandwidth (several Mbits/sec.) underwater communication. The clarity of many deep-sea water bodies is particularly conducive to the use of this technology;
- **Multifunctional sensor packages** that can capture the essential ocean variables (EOV's) to address key questions, for instance a package measuring pH, dissolved inorganic carbon and alkalinity, to give a synoptic view of these climate system variables. Such packages must be small, to allow deployment on a number of platforms, energy efficient and robust. Aspects of this particular technology theme is being specifically addressed by projects funded under the EC FP7 Oceans of Tomorrow call.
- **Deep ocean observatories:** The Global Ocean Observing System (GOOS) are developing a Deep Ocean Observing Strategy assessing the latest technology and infrastructure available to monitor and understand the deep ocean and proposing an initial list of Essential Ocean Variables (EOVs) for a deep ocean observing system (GOOS, 2014).

6.2.3 Deep-sea habitat mapping

Fig. 6.6 Morphology and photographs of the main cold-water coral community in Whittard Canyon.



Credit: Huvenne *et al.* 2011

Sampling tools are required to allow high-resolution, large-scale, and long-term data collection in deep-sea ecosystems. This will enable habitat mapping for extending macroecological approaches in deep-sea ecosystems. AUVs fitted with high definition cameras and water samplers can map extensive seafloor habitats and define megafaunal species distributions in great detail. There is also a move towards 3D habitat heterogeneity mapping and visualization (Fig. 6.6, Huvenne *et al*. 2011). Sampling of macrofauna and meiofauna pose more of a challenge but here alternative approaches may become (increasingly) valuable (e.g. e-DNA). Such approaches also require advances in long-term observation of deep-sea physical and chemical dynamics. Large-scale observations must, at the same time, be coupled with collection of the organisms to ensure accurate identification, characterization and the definition of distributions. Deep- sea observatories with the ability to sample physical and biological components represent the future for long-term monitoring needed to evaluate the impact of climate change on deep-sea ecosystems in terms of their function. Pelagic ecosystems require special consideration in terms of mapping biological diversity and understanding spatial and temporal variation. Multi-frequency acoustics are a key technology but at present their deployment is generally restricted to the surface where the vertical range of survey is approximately 1000m depth. Submerged systems, either towed, lowered or deployed on AUVs, gliders or neutrally buoyant drifters are required. Sampling of the deep pelagic fauna also requires new approaches either depending on optical survey (e.g. AUV or drifter-mounted cameras) or trapping of organisms in pressure-tight vessels for study in situ or in high pressure aquaria.

6.2.4 Molecular tools to investigate unknown biodiversity and functions

In situ molecular tools offer great promise for high-resolution observation from microbes to larger invertebrates, including cryptic species. Currently available molecular tools and new chips allow sequencing of DNA *in situ*, offering new opportunities to investigate biodiversity, symbiotic interactions, connectivity, and functions of deep-sea species as well as spatial and temporal variability in deep-sea communities. Some of these approaches still need evaluation as to their resolution and reliability (e.g. eDNA) whilst others, aimed at detection of specific organisms are more reliable.

6.2.5 Next generation deep-sea ecological experiments

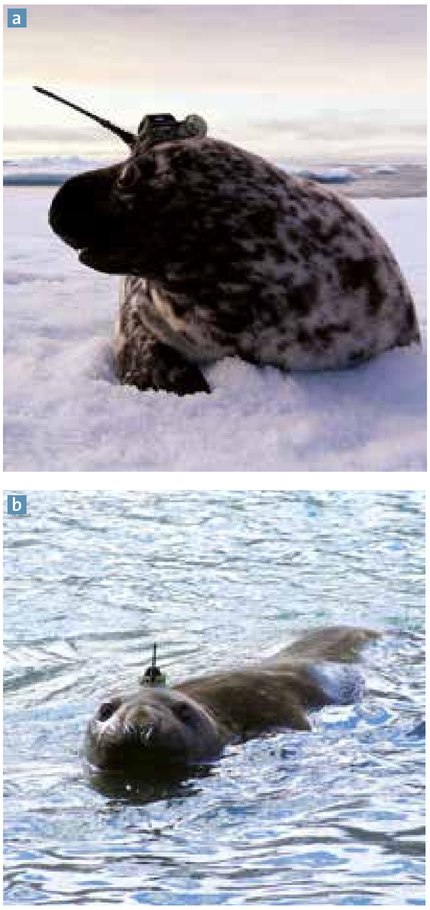
In situ deep-sea experiments, now made possible by the availability of sophisticated technologies, will allow increasingly complex ecological manipulations, launching a new era of better understanding of deep-sea ecosystem functioning and restoration strategies for deep-sea habitats degraded by mining, oil spills, or bottom trawling. Pressure vessels can transport organisms from the seafloor to the surface for manipulative experiments, or to evaluate larval dispersal potential and other ecological characteristics at a time when molecular tools offer novel insights into connectivity questions. ROVs and programmed landers can now deploy respiration chambers, release isotopically labeled food resources onto the seafloor at preprogrammed intervals (Danovaro *et al.,* 2014), and inject carbon dioxide into deep-sea ecosystems at different concentrations to study faunal response to acidification. A similar strategy might be used to deploy other substances (e.g., antibiotics) to evaluate microbial–macrobial interactions or ecotoxicological properties of pollutants.

6.2.6 Deep-sea habitat restoration

Restoration of degraded deep-sea habitats must be a research priority. Deep-water corals survive and grow in laboratory conditions and experimental reintroduction to the seafloor has proved successful; plans are underway to initiate experiments for restoration of hydrothermal vents, cold seeps (with mineral crusts), and manganese nodules after mining. Efforts are also ongoing to develop swarms of autonomous undersea vehicles to transplant and monitor deep-sea restoration over relatively broad areas.

6.2.7 The use of animal platforms as novel deep-sea observatories

The development of deep-sea observatories is expanding our ability to understand processes occurring in these remote regions through direct and continuous observations. Yet we are limited by the local dimension of these observatories, their preferential or exclusive setting for abiotic variables and the highly scattered localization. Novel tagging of deep-sea organisms can study their interactions, foraging and dispersal, as well as changes to oceanographic conditions as most platforms include CTDs. Despite this there are still some limitations with the current technologies , especially with regards to being able to easily capture and tag animals in a way that lets you release them in good shape back to the environment. Current methods include gluing a pad to the fur of the seal, to which a satellite tag is attached, attaching acoustic tags externally on a stalk which is anchored to the



Credit: K.M. Kovacs & C. Lydersen, NPI

Credit: L. Boehme

Fig. 6.8 One project using marine mammals as animal platforms is Maine Mammals Exploring the Oceans Pole to Pole (MOEP) which uses CTDs that can relay data via satellite to study marine mammals and the remote polar regions. The species commonly used are southern and northern elephant seals, Weddell seals ringed seals, hooded seals. Most seal species can dive deeper than 200-400m, with the record holders being the southern elephant seals which have been recorded diving to over 2100m. a: A young male hooded seal wearing a CTD-SRDL from the North Atlantic.

b: Southern elephant seal tagged with a CTD-SRDL on South Georgia animal with a barb, and implanting a tag whilst the animal is under anesthetics. It is time to push for the development of a novel approach of tagging of deep-sea organisms such as deep-sea sharks, some of which have an ubiquitous distribution, which would allow us to gather crucial information from wide deep-sea regions, providing also novel insights on the biology of these creatures. Projects using marine mammals have become essential for gathering data in polar oceans, see Fig. 6.8 for more details.

6.2.8 Deep Sea multidisciplinary technology

Research technology has developed rapidly over the last few decades bringing internet and continuous data flow to and from the deep sea, mostly with increasing use of Remotely Operated Vehicles (ROVs) and, more recently, Autonomous Underwater Vehicles (AUVs), cabled underwater observatories and the recent funding for the development of Europe's first ultra-deep glider to 5000m (Box 6.1; Fig. 6.9)[45]. There is, nonetheless, still a trade-off between area covered and resolution with detailed studies covering extremely small areas of seabed. Consequently, although we are beginning to understand small areas of seabed quite well, we still need to extrapolate to the vast areas in between. One potential way of improving this process is to work with offshore industries and to capitalise on their infrastructure to carry out environmental monitoring, while sustaining previously made EU investments (e.g. European Multidisciplinary Seafloor Observation (EMSO) initiative). This also applies to research infrastructures initially built for other purposes such as seafloor neutrino telescopes.

BOX 6.1 GLIDERS GO ULTRA DEEP

BRIDGES (Bringing together Research and Industry for the Development of Glider Environmental Services) will develop two deep-sea gliders: one glider will be technologically and economically optimized for services down to 2400m (the Deep Explorer), the other one for 2400m down to 5000m (the Ultra-Deep Explorer), allowing exploration of the whole water column and bottom in 75% of the world oceans. These multi-mission vehicles will be capable of performing operations for fundamental research, for long-term environmental monitoring (Copernicus, MSFD, and for offshore industry (oil and gas, sea-mining).

The modular design will allow interchangeable payloads tailored to the application, including (ecosystem) Essential Ocean Variables (temperature, salinity, oxygen, nutrients, chlorophyll, CDOM, ...), hydrocarbons/crude oil, and acoustic sensing, as well as novel sensors developed by BRIDGES for glider in-situ chemical sampling, micro-organism imaging, and water sampling allowing to tackle novel research for marine biology. The BRIDGES vehicles will also include hybrid propulsion to allow fixed depth surveys, such as investigating along a pipeline or monitoring benthic habitats.

More on www.bridges-h2020.eu

Fig. 6.9 Conceptual hydrodynamic design of the D and UD Explorers to be developed as ultra deep gliders by the European H2020 BRIDGES project Courtesy of ALSEAMAR-ALCEN.

One common denominator in all approaches must be the multidisciplinarity of the teams and projects and the cross-sector funding (from robotics to blue biotech and mineral mining industries and scientists).

6.2.9 Data visualization, storage, analysis and sharing

One of the major barriers to successful advancement of deep-sea science is the lack of an ability to share data in a timely and efficient manner. Within the scientific community, substantial progress has been made in the coordination of such data through international projects such as the Census of Marine Life, the Ocean Biogeographic Information System (OBIS)[61], in which millions of geo-referenced species records have been assembled, and the World Register of Marine Species (WORMS)[62].

Careful consideration must now be given to how to best observe the deep ocean in an integrated, shared and internationally coordinated way. This will require significant coordination across the scientific, industry and policy communities to ensure that issues of data priority for scientific publication, confidentiality in the case of industry, and security in the case of States, are maintained whilst maximizing opportunity to share information. Such an effort will require significant dedicated funding probably mainly from public finances. Europe is already investing in initiatives such as the European Marine Data and Observation Network (EMODnet)[63] and the European Earth Observation Programme Copernicus[64] - both long-term marine data initiatives of the European Commission – which offer users unrestricted access to standardized, harmonized and interoperable marine data, products and metadata. The further support and development of such initiatives is vital to foster a cross-sector approach to data sharing and to achieve large-scale goals such as the target to provide a seamless multi-resolution digital map of the entire seabed of European waters by 2020.

The potential dramatic increase in the gathering of image data (video and stills), 2D and 3D seismic data and molecular data all generate significant challenges in terms of data storage and analyses requiring new approaches to information architecture. Machine-learning approaches will likely be critical in extraction of data from video or stills images whilst much faster computing, data storage and transfer capabilities are likely to be required for seismics. High throughput molecular approaches to studies of diversity, connectivity and physiology are also computationally demanding and the field is currently undergoing significant advances in data analyses approaches.

[61] http://www.iobis.org/

[62] http://www.marinespecies.org/

[63] http://www.emodnet.eu/

[64] http://www.copernicus.eu/

6.3 Overcoming a fragmented regime of governance

From the overview in Chapter 3 of maritime activities and related regulatory frameworks, it appears that ocean governance is highly fragmented pursuant to a sectoral and geographical approach. But, as the Preamble of UNCLOS reminds us, “the problems of ocean space are closely interrelated and need to be considered as a whole” (para. 3). This is particularly true for the deep ocean, including ABNJ. According to De Marffy (2004) four pillars of ocean governance can be identified as:

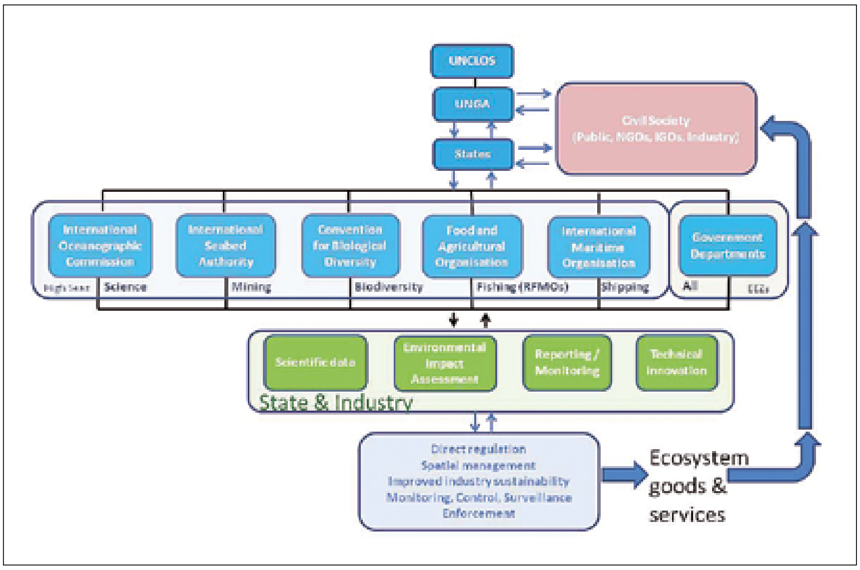
1. The legal pillar, which sets up the legal framework under which all activities in the oceans must be carried out;
2. The political pillar, which deals with actions taken by intergovernmental bodies;
3. The institutional pillar, which represents the administrative mechanism needed to ensure the integrated approach, in particular in enhancing coordination and cooperation between all international actors having a role to play in the management of the oceans; and finally,
4. The capacity-building pillar, including the financial component, which constitutes the necessary tool to achieve effective ocean governance.

The legal pillar is primarily embodied in the UNCLOS which creates the jurisdictional framework within which all maritime activities take place. This framework aimed to be all-encompassing but, 30 years after its adoption, gaps have emerged for sustainable management of activities in the deep sea. The regime for the deep seabed Area is insufficient in order to deal with the exploration and exploitation of marine genetic resources located there (see section 3. on biotech) or other activities impacting deep ocean biodiversity, such as potential renewable energy installations or geoengineering schemes. Global problems, such as climate change and transnational organised crime, and the search of solutions to tackle them have highlighted the limits of this system. Zonal fragmentation can be an obstacle to the implementation of concerted actions such as marine spatial planning, in particular on the high seas or the seabed Area. Moreover, the plethora of specialised instruments, with a sector specific and/or a geographical focus, add to this obstacle. Fig. 6.10 highlights this issue by showing the institutional framework which regulates human activity in the ocean, with divisions by industrial sector or management focus (e.g. conservation).

There has then been a call for “an integrated, interdisciplinary and inter-sectoral approach” (UNGA resolution 60/30, 8 March 2006) to both the political and institutional pillar. This approach does not concern only the law-making processes but, especially, the implementation and enforcement mechanisms. The fact that States play a key role in implementation and enforcement of regulations implemented by IGOs means that there is a strong potential for vested interests to influence the operation of such bodies or for non-compliant actors to operate through States that do not have the infrastructure to enforce (e.g. flags of convenience). Implementation is often also through voluntary agreements or through consensus decision making driving down regulatory standards or allowing opt-outs. There are also high levels of non-compliance with regulations, agreements and voluntary codes amongst States as well. This has led to a more general reflection on the institutional machinery created by LOSC and institutional stratification which nowadays characterizes ocean governance.

> *“Stakeholders need help for coordinating overlapping legal regimes to ensure the access to the sea (e.g. Arctic Ocean).”*
> Deep-sea researcher, Germany

> *“There is next to nothing in place in terms of coordinated effective action to ensure sustainable development of the deep-sea.”*
> Deep-sea fisheries stakeholder, UK



Credit: Alex Rogers

Fig. 6.10 A schematic of the institutional framework of ocean governance and management within the high seas and Area and within EEZs. The diagram illustrates the legal and implementation framework used to actively manage the ocean. UNCLOS, the UNGA and States direct policy and legislation regarding the use of the oceans which is then implemented via sectorial institutions. Within the EEZ of a State these are largely Government Departments. On the high seas a variety of UN Agencies and regional management organization implement policy and regulate activities. In order for these activities to be carried out in a sustainable manner States and industry finance scientific research, EIAs, reporting and monitoring and technical innovation. These activities also feed into the direct regulation and monitoring of human activities on the ocean. Effects on the goods and services provided by marine ecosystems feedback to civil society who then potentially influence policy makers connected with UNCLOS / UNGA and State Governments to implement changes in policy and implementation of that policy. Major issues in the current system include the compartmentalization of different sectors, the balance of State and industry funding of ocean management, implementation of regulatory activities and public awareness of ocean health (without which the feedback to policy does not work).

6.4 Overcoming disciplinary and sectorial barriers

6.4.1 The link between science and society

Obtaining the knowledge needed to better understand the deep sea, and to address the challenges and seize the opportunities identified above requires strengthening our capacities to produce the systemic science that is called for. The deep oceans are inextricably linked to human societies through our numerous dependencies, interactions and connections with the oceans: together they constitute a complex social-ecological system. Understanding such systems, and designing appropriate governance, management, exploitation and action options in order to address the grand challenges we are confronted with and make the long-term transition to sustainability requires a paradigmatic shift towards more holistic and systemic science. By its very nature, and the complexity of both the natural processes and the human-nature interactions involved, the deep sea is an archetypical domain for which such paradigmatic shift is needed.

Capacities to support such shift include in particular:

- Developing social science, legal and economic research capacity;
- Increasing inter- and transdisciplinary capacity;
- Increasing capacity to produce knowledge for assessments, including indicators and baselines;
- Developing more effective interfaces between science, policy, and society;
- Bridging the gap between academia and industry;
- Training the future generation of scientists and practitioners and retraining the current one, to be able to stand up to the knowledge and management challenges they are facing.

> *"Human resources and management capacity are major limitations regarding deep-sea research activities."*
> Deep-sea research, Portugal

> *"A sustainable approach always needs a holistic consideration of the system or the topic or problem to be successful. Science alone is not enough - governance and legal aspects, e.g., are important as well."*
> Deep-sea researcher, Germany

BOX 6.2 DOSI THE DEEP-OCEAN STEWARDSHIP INITIATIVE

DOSI was initiated in part by INDEEP, the international network for scientific investigation of deep-sea ecosystems. The mission of DOSI is to integrate science, technology, policy, law, economics and industry to advise on ecosystem-based management of resource use in the deep ocean and strategies to maintain the integrity of deep-ocean ecosystems within and beyond national jurisdiction.

DOSI is a partnership of scientific organizations and individual experts collaborating through seven working groups to address priority deep-ocean issues including:

1. ecosystem-based management in the deep sea,
2. knowledge gaps and ocean assessments,
3. transparency, compliance and industry engagement,
4. awareness raising and capacity building in developing nations,
5. conservation and sustainable use of marine genetic resources beyond national jurisdiction,
6. communication and networking; and
7. deep-sea fisheries management

http://www.indeep-project.org/deep-ocean-stewardship-initiative

6.4.2 Developing the social science and economic research capacity

Beyond natural science research, a broad array of social, legal and economic science research is important to support sustainability in the deep sea. Today, there is still limited social and economic science expertise on the deep sea. This can be addressed by raising interest in students and young researchers in the human science disciplines for studying and researching deep-sea related issues and offering specifically targeted training and M.Sc. or Ph.D. programmes. But it also requires that funding agencies integrate the need for such research in their programming and funding efforts.

6.4.3 Increasing inter- and transdisciplinary capacity

Social-ecological systems are characterised by complexity, they involve many interacting elements (natural and human), at multiple spatial, temporal and administrative scales. Studying them requires a systems approach requiring interdisciplinary and often transdisciplinary approaches. By transdisciplinary approaches we understand work that moves beyond the domain of disciplinarity, generating new approaches to scientific knowledge production that either transcend the formalism of a single discipline altogether and/or operationalize integrative collaborations between academics and non-academics, such as local communities, industry and/or policy-makers, as a core part of the scientific work. (Farrell *et al.* 2013). These will require not only the development of the human science capacity to participate in such transdisciplinary endeavour, but also the training of scientists from different backgrounds in transdisciplinary practices. Interdisciplinarity is still quite difficult to achieve in practice, and we too often fall back into typical multi-disciplinary approaches which merely collate input from various disciplines, without really fostering integration. Transdisciplinarity is even further down the road and still in its infancy and will require a learning process on the part of both the research and research-funding communities. In Europe, an example of development of interdisciplinary research on the deep seas is provided by HERMES (FP6), HERMIONE (FP7)[65] and MIDAS, deep-sea ecosystems projects which evolved from initially very multidisciplinary projects to more integrated interdisciplinary efforts, allowing the participating scientists to learn along the way.

6.4.4 Increasing capacity to produce knowledge for assessments, including indicators and baselines

To be able to produce assessments of the deep sea, from integrated assessments of e.g. drivers, pressures, state, impacts and trends, to strategic impact assessment offering an integrated view of planned activities in an area, to more specific environmental impact assessments of the sort required by e.g. the mining industry to develop an operation programme, there is a need to develop specific knowledge, in particular in terms of monitoring and indicators. Because we are dealing with a complex social-ecological system, existing monitoring, data and indicators are not sufficient to support policy and investment decisions: there is a need for better understanding of systems science, forward-looking information, systemic risks and the relationships between environmental change and human well-being. (EEA, 2015)

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[65] http://www.eu-hermione.net/

Sustainable Development Goals

The environmental sustainability for the ocean is of universal concern and thus calls for a global forum for the formulation of sustainable development targets, supported by indices, ocean policies and monitoring mechanisms to measure their success.
The idea to shape the post-2015 development agenda using a set of sustainable development goals (SDGs) emerged from the recent UN Conference on Sustainable Development (known as the "Rio+20 Conference"), where member states agreed to launch a process to define such goals. This led to a call for an *SDG Ocean and Coasts* that would encourage the development of new instruments that are binding under international law, the modification or extension of existing instruments and the monitoring of the implementation of, and compliance with, current and future international targets for all maritime zones, explicitly including areas beyond national jurisdiction (Visbeck *et al.*, 2014).

With input from the international scientific community (see Fig. 6.11) the Proposal of the Open Working Group on Sustainable Development Goals submitted to the United Nations General Assembly in August 2014 contained SDG 14 which aims to *"Conserve and Sustainably Use the Oceans, Seas and Marine Resources for Sustainable Development"*. In August 2015 UN Member States reached agreement by consensus on the draft outcome document of the new sustainable development agenda, confirming the inclusion of SDG Goal 14[66]. This contains ten targets, ranging from reducing marine pollution of all kinds and minimizing the impacts of acidification to increase the scientific knowledge, develop research capacity and transfer marine technology. All 10 targets are relevant to the deep seas and require increased levels of understanding of deep sea systems in able to reach them. At the time of publication the marine SDG is termed an orphan SDG as no UN organization has been specifically tasked with promoting the achievement of its targets.

Credit: Matt Greenslade

Fig. 6.11 The 5th Meeting of the Global Ocean Commission (GOC 5), took place in New York, US, on 17 May 2015. (From left to right) Obiageli 'Oby ' Ezekwesili, David Miliband, Trevor Manuel. The GOC were a crucial contributor to SDG international negotiations (http://www.globaloceancommission.org/wp-content/uploads/GOC_Post2015_Ocean-indicators_final.pdf)

[66] https://sustainabledevelopment.un.org/sdgsproposal.html and: https://sustainabledevelopment.un.org/topics/oceanandseas

6.4.5 Bridging the gap between academia and industry

To ensure sustainable use of deep-sea resources and maintain the integrity of our deep ocean ecosystems there is a need to better connect the world of academic research with industry research. Research in industry is driven by company objectives, which can include the delivery of a service to society, market goals and/or expectations on increasing revenues for continuous growth of the business. Academic research can be driven by curiosity, knowledge production, problem solving, innovation and/or individual or university competitiveness and ranking considerations.

"Industry needs knowledge gathered by researchers, deep-sea research is expensive and mostly depends on public funds. If industry needs researchers, at least a fund should be created to fund basic research."

Deep-sea researcher, Portugal

There is still often a great disconnect between these two worlds. Academia often lacks the right mechanisms and funding to ensure efficient communication of its results to industry and, in turn, industry often lacks the incentive to engage with academia to explore the bigger picture of their activities or to make data accessible for academic use (e.g. monitoring data around industrial infrastructure). So, how can these two worlds be better bridged? How can we increase the quality and quantity of industry and academia dialogues and collaborations? The research interests of academics and industry are often quite different, however, there are opportunities to produce good academic research that can assist industry. Similarly, industry collects a lot of data and produces a lot of analyses that can be extremely useful to academia, e.g. to study status and trends of ecosystems. To improve collaboration, it is imperative that both sides understand each other's specific needs. This is mostly achieved by incentivizing a greater mix between academics and business/industry players, allowing the flow of ideas and exchange of experiences to increase the levels of mutual knowledge.

Promoting exchange of staff, post graduate studies in industry setups and incorporating more industry-related subjects in academic training can contribute to more effective industry-relevant applied research and better data exchange.

Diversifying the current undergraduate and post-graduate education plans, where future researchers are made more aware of current societal, academic, and industrial needs and bottlenecks and are trained to use their technical skills in various public and private research settings can also support better academia/industry interfaces. Incorporating business, innovation, entrepreneurship and technology transfer education in science courses can also contribute to decrease the size of this industry/academia gap. SERPENT, DELOS, ABYSSLINE, and MIDAS are all examples of projects aimed at bridging the gap.

BOX 6.3 THE GLOBAL OCEANS MODEL

Credit: Global Oceans

Fig. 6.12 Global Oceans science-configured OSV with modular laboratories, workshop, dry and cold storage, independent power supply, on-deck personnel housing, and operational support.

Global Oceans is a globally-focused, US-based non-profit organization (www.global-oceans.org). It is working with the international ocean science community as a strategic, operational and transactional bridge between scientific institutions and the private-sector to enable greater use of existing private-sector infrastructure for oceanographic research. This model will fill infrastructure gaps within existing research initiatives; enable a range of adapted platforms dedicated to supporting new research programmes; and increase the geographic scope and frequency of access to open ocean and deep-sea environments. Global Oceans enables more seamless resource sharing and research collaboration across institutions, government agencies and national boundaries.

The differentiating operational strategy is the selective mobilization by Global Oceans of regionally-deployed, time-chartered offshore service vessels (OSVs), normally operating as part of the support network for the offshore energy industry; together with modular containerized lab systems shipped to a project office at each departure port. Project offices, local logistics and asset security are facilitated through a port services provider with over 300 global port locations. Compared with dedicated research vessels, regional deployment eliminates the time and cost associated with long transits to the study region. This approach also alleviates large capital-intensive investments associated with owning and maintaining a dedicated fleet. The ability to bring vessels into service as needed and configure them for research results in a demand-based, mission-adaptive and readily scalable operational capacity that can be priority-driven rather than resource constrained.

Over 3,000 OSVs ranging from 50 to 100m in length are distributed globally, with 10% to 20% of the global fleet generally available for independent charter. These can be adapted for deep-sea research, including a wide range of research assets from private-sector partners that are available for integration including ROVs, AUVs, UAVs, HOVs, CTDs, surface vehicles, modular seafloor drilling systems, GIS mapping and computer labs, analytical and genomics instrumentation, and other equipment.

An example of this application is a Global Oceans' proposal to support a new global study of the physical dynamics of seamounts and the structure and function of seamount ecosystems, called the Global Seamount Assessment Programme (GSAP). A series of dedicated, multi-year seamount expeditions, all regionally deployed from adapted platforms, will utilize deep ROVs and a standardized sampling protocol; with a coupled broad-survey "whole-organism" analysis (taxonomy, visual documentation, physiology, proteomics) and genomics (on-site DNA and RNA separation and storage for post-expedition sequencing and analysis). GSAP study data can also support the recently developed Seamount Ecosystem Evaluation Framework (SEEF) (http://www.seamounteef.org/) and will include under-studied regions such as the Indian Ocean. This systematic global seamount study will contribute to a more definitive understanding of the functioning, biodiversity, endemism and ecological role of oceanic seamounts – and to improved policies for their conservation and management.

Furthermore, promoting the identification of research gaps that are relevant to both academia and industry can strengthen the design and implementation of successful novel scientific programs with adequate funding and impact. Multi-stakeholder fora bringing together industry, academia, policy-makers, research funders and civil society can be extremely useful to foster dialogue and cooperation and explore ways to continuously improve the interaction. One example of a new funding model for a scientific community-industry partnership is INSITE (Box 6.4) which focuses on building the knowledge base needed to better understand the influence of man-made structures on the ecosystem of the North Sea for a range of stakeholders. Another initiative is the Global Oceans Model (Box 6.3) set up to make greater use of existing private-sector infrastructure for oceanographic research.

In the case of blue biotechnology, the best solution to develop successful marine bioactives is to design, from the beginning, joint academic-industry discovery and development programs (Martins *et al.*, 2014). Indeed, some of the recent successes in marine natural product developments have only been made possible due to close collaborations between academic and industrial partners. Results of this strategy are now coming to market (e.g., Yondelis® and RefirMAR®) (see Box 3.2 above).

In Europe, public funds such as the European Commission's Seventh Framework Programme have greatly contributed to wider collaborative research. The latest European Commission research and innovation programme, Horizon 2020, takes a step further offering several incentives to promote SME involvement[67] and partnership between academia and industry[68]. This approach combines the expertise of excellent academic groups with deep knowledge of marine life, analytical and synthetic techniques, etc., with the industry and SME's fast development needs, market awareness and business expertise. It should be noted that industry can also play a role in matching funding for such initiatives and there should not only be incentives for collaboration but also improving access to data and knowledge produced by industry. In addition, where co-funding or joint partnerships between academia and industry is not possible, initiatives such as the European Blue Economy Business and Science Forum and a marine Knowledge and Innovation Community (KIC) could be used to support dialogue and cooperative ventures between academia and business to improve the sustainability of deep-sea economic activities.

With an integrated approach, such science clusters can be pushed forward and contribute to building innovative solutions for today's societal needs, using the ocean as the next frontier of development.

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[67] E.g. SME instrument: https://ec.europa.eu/programmes/horizon2020/en/h2020-section/sme-instrument

[68] E.g. Research and Innovation actions

BOX 6.4 INSITE: INFLUENCE OF MAN-MADE STRUCTURES IN THE ECOSYSTEM

One example of a new funding model for a scientific community-industry partnership is INSITE, a scientifically-led, long-term environmental joint industry project (JIP) with the aim 'to provide stakeholders with the independent scientific evidence-base needed to better understand the influence of man-made structures on the ecosystem of the North Sea.' The programme started in April 2014 when eight energy company sponsors signed the JIP Agreement.

INSITE was developed in response to an Oil and Gas UK led JIP 'Decommissioning Baseline Study'. The two year study gathered knowledge and experience in the decommissioning of offshore structures and pipelines, and identified that gaps exist in the data set used to describe the influence of man-made structures on the North Sea ecosystem.

The independence of the Programme is ensured by the establishment of the Independent Scientific Advisory Board (ISAB), chaired by Dr. Graham Shimmield, by which proposals are requested from the research community and funding awards made. To demonstrate independence and transparency, the programme sponsors are committed to engage proactively with the broader stakeholder community of the North Sea and to make the findings available in the public domain. Requirements of the programme include papers and articles published in the scientific media and Stakeholder workshops at the end of years 1 and 2. The first Request for Proposals to solicit Pre-proposals for research in support of delivering the INSITE objectives was published on 9 July 2014. The estimated fund for the first or Foundation Phase of the INSITE Programme is a net of £1.8 Million over three years, which could increase as new sponsors join.

http://www.insitenorthsea.org/

6.5 Ocean literacy

6.5.1 Public outreach and education projects

> *"We need to change public perceptions of the importance of the deep sea and the difficulty of studying it."*
> Deep-sea researcher, UK

What should people know, want to know or really do know about the oceans? The under-representation of ocean-related content in the school curricula of most European countries and the general limited public knowledge on the ocean is in contrast with its vastness and prominent role in Earth´s life-support system. Ocean literacy is the people's knowledge and understanding needed to realize how the oceans affect their daily lives and the potential impact of humankind on the ocean's future health. A more educated community will experience a closer, respectful connection with the oceans and will better understand the need of a science-based policy for their sustainable management and therefore will also be willing to support further investment in marine research and technology. Not surprisingly the promotion of ocean education and literacy is a priority of the recently issued Rome Declaration which specifically called for "sustained support for ocean literacy, best practice in science communication, citizen science initiatives and knowledge transfer to be embedded in marine research projects and programmes".

In the USA, the joint effort of dozens of agencies and hundreds of individuals resulted in an Ocean Literacy Framework (Strang and Tran, 2010) comprising a *"Guide"* describing 7 essential principles, supported and explained by 45 fundamental concepts[69] and a detailed *"Scope and Sequence for Grades K1–12"* represented in a series of conceptual flow diagrams and cross-references, providing educators with

[69] Available at www.oceanliteracy.net

guidance as to what students at different levels need to comprehend in order to achieve full understanding of the essential principles[70]. However in Europe, and despite serious concerns about the protection and the health of the oceans, the implementation of a coherent Ocean Literacy plan has yet to be provided (and a consensus on "what people should know about the oceans" is perhaps complicated by the large cultural diversity across Europe).

"The deep sea is a bit removed, it's hard to find a link to everyday life. There's huge potential [for teaching opportunities] but we need resources."

Ocean Education Officer, Ireland

The apparent lack of general public knowledge on the oceans and particularly on the deep sea does not diminish, on the contrary it may even increase, the fascination of the unknown. For centuries, the mystery of the deep has inspired arts and literature, entertainment and more recently other media. The novel by Jules Verne *20,000 Leagues Under The Sea*, published in the 19th century, is probably the most iconic fiction work featuring the deep sea, with numerous editions, adaptations and variations in stage plays, movies (from a short film by Méliès in 1907 to the most recent version to be released in 2016), animation, comic books and graphic novels, besides multiple references in popular culture worldwide.

With less than two centuries of history, deep-sea research has only recently overcome many of the initial limitations. Scientific advances and technological development allowed easier access to the deep sea considerably raising the scientific level and accuracy of documentaries (e.g *"Blue Planet Episode 2 – The Deep"* with David Attenborough narrating journeys into the abyss showing colossal seascapes and strange creatures never filmed before or *"Deepsea Challenge"* chronicling filmmaker James Cameron's diving expeditions in the *Deepsea Challenger* submersible) and other information vehicled by the media. New ways to explore and even to interact with deep-sea organisms and the environments they inhabit are being offered to the general public and increasing their willingness to discover the so-called last frontier on Earth. In this respect, outreach projects and informal education efforts (e.g. public aquaria, science centres, museums, NGOs, media) are essential tools for more involvement and active participation of the general public.

For instance, in the Te Papa New Zealand's national museum the Marsden Fund Project is a pioneer sampling programme with Baited fish traps and Baited Remote Stereo Underwater Video Systems focused on the knowledge of the deep-sea fish fauna which provides public access (through YouTube) to video footages of extraordinary and rarely seen deep-sea life forms.

Two excellent examples of outreach projects are the Nautilus Live[71] and Science Communication Fellowship of The Ocean Exploration Trust and the Learning Resources and Events at Ocean Networks Canada[72]. In addition to conducting scientific research, the Ocean Exploration Trust offers E/V*Nautilus* expeditions to explorers on shore via live video, audio, and data feeds from the field and bring educators and students of all ages aboard, offering them hands-on experience in ocean exploration, research, and communications. Science Communication Fellows share accounts of ocean science, expedition operations and daily life with student groups and audiences engage people of all ages in real-time exploration through live audio commentary and question-and-answer sessions from aboard the ship. Fellows then bring their expedition experience back to their own classrooms, organizations and communities in the form of engaging lesson plans and activities around their time at sea aboard *Nautilus* and other vessels. Ocean Networks Canada operates the world-leading NEPTUNE and VENUS cabled ocean observatories and offer

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[70] http://oceanservice.noaa.gov/education/literacy/ocean_literacy.pdf

[71] www.nautiluslive.org

[72] http://www.oceannetworks.ca/learning

BOX 6.5 DEEP OCEAN LITERACY: THE ABYSSBOX

In France, the Abyssbox project (Shillito *et al.* 2015) was initiated by a collaboration between two French research teams (Ifremer and Université Pierre et Marie Curie) and the Aquarium Oceanopolis in Brest. The objective of this permanent exhibition was to present live hydrothermal organisms at their ambient pressure to the general public, taking benefit of the technological progress of the scientists to study such organisms at their living pressure (Shillito *et al.* 2008) and of the yearly maintenance cruise of the EMSO-Açores deep-sea observatory to have access to fresh specimens. This project is not limited to a live exhibition but allows the running of science experiments at the yearly scale on the behaviour or the life cycle of these organisms.

Fig. 6.13 AbyssBox. Live *Segonzacia mesatlantica* in the Abyss box maintanined at 170bars.

through its website a comprehensive package of learning resources and events for students and educators and three citizen science projects: through "Digital Fishers" citizen scientists are invited to collaborate on the investigation of trawling impacts on deep-sea ecosystems, mapping of seafloor geology or planning a future seafloor installation; "Coastbuster" is a project for mobile reporting of marine debris; and through "Camera Watching" people around the world have been watching live underwater video cameras, and reporting unusual creatures and events.

Sharing the excitement of a live dive with an ROV was also the objective of a project proposed by Ifremer and called "the abyss night". This event proposed in 2006 and 2014 a live transmission of images acquired by the ROV Victor on hydrothermal vents to a 250 to 500 persons audience on land at Brest and Paris, followed by a session of questions to the scientists on board the vessel.

6.5.2 Citizen Science

Citizen science, a manner of collecting data and observations in which collaborators who may lack credentials and formal institutional affiliation can contribute to the work, and crowdsourcing, a more general process of obtaining needed services, ideas or other resources including funding, from the contributions of a large group of people especially through the internet – are non-traditional ways to overcome research limitations (e.g. spatial and temporal distribution of collections and data, funding) which empower civilian scientists with the pride of data contribution to science, providing an incredible opportunity for outreach as well as improving science education and increasing public awareness (Lauro *et al.*, 2014)[73] [74]. The development of research infrastructures such as ONC or EMSO, and the ability to monitor in real time animal communities using imagery is a good opportunity to collaborate with citizen scientists for the treatment of the thousand' of hours of video acquired. For example, Digital Fishers from NEPTUNE Canada where the public can watch 15 sec video clips and describe what they see selecting from the fields below the screen (Fig. 6.14).

The processing of this video archive could be performed using specifically web-based software gathering essential information for scientists (e.g. H2020 project Environmental Research Infrastructures providing shared solutions for science and society ENVRI^{PLUS}).

As the global ocean is changing rapidly and over a range that can have a profound influence on human societies, public engagement in understanding the vital connections between people and the ocean becomes important because sooner or later informed and responsible decisions will need to be taken regarding the oceans and the exploitation of their resources. Ocean Literacy is therefore an imperative to face the societal challenges of a more ocean-oriented economy.

Fig. 6.14
a: ROV *Hercules* encounters a sperm whale at 598m below the Gulf of Mexico on the live streaming programme Nautilus Live.
b: Digital Fishers, a crowd-sourced ocean science observation game.
c: Example of people on a ship. Outreach initiatives include Classroom@Sea, an initiative to bring real marine science into the classroom by recruiting teachers to work alongside a scientific team on a UK research ship and report back.
d: An event to show support for deep-sea conservation at Warsaw Zoo.

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[71] https://www.zooniverse.org/

[72] http://www.seafloorexplorer.org/

7

Recommendations

Credit: MARUM

In this chapter, eight high-level goals for deep-sea research are presented in the context of expanding commercial activities, increasing human and natural pressures and the need for effective and practicable governance frameworks to underpin the management of deep-sea activities and resources. These goals are based on the knowledge gaps and research questions already presented in Chapter 3 and the research needs, further summarized into cross-cutting thematic areas, in section 6.1. For each goal, specific action areas are identified. Some issues, such as data and observations, are cross-cutting which results in a small degree of overlap between the different goals and action areas. It is proposed that these goals and action areas, taken as a coherent whole, can form the basis for a European integrated framework to underpin sustainable development of deep-sea activities and support Blue Growth.

1. Increasing our fundamental knowledge of the deep sea

Key action areas:

- Support fundamental research on deep-sea ecosystems;
- Develop innovative, science-based governance models for deep sea resources;
- Promote long-term monitoring and observing programmes and systems targeting deep-sea locations of recognized importance.

As part of the process of developing this position paper, the expert working group met with deep-sea stakeholders from the range of industrial sectors, management agencies and civil society. A clear and consistent message from these stakeholders was the need for fundamental scientific knowledge of the deep sea. There is a critical lack of knowledge on biodiversity, ecosystem functioning, resilience and connectivity for the whole deep sea. Identifying key indicator species and suitable proxies for different deep-sea ecosystems and better understanding the links and interactions between surface waters, mesopelagic and deep waters, and between the water column and seabed, all require significantly greater research effort.

Enhanced knowledge of deep-sea ecosystems is necessary to establish baselines, inform environmental impact assessments and strategic environmental management plans and to monitor the long-term impact of human activity on the seafloor, sub-seafloor and pelagic components of the deep sea system. Improved baseline knowledge is also critically important to inform effective decision making, environmental regulation and ocean governance in the deep sea.

Commercial operators can also benefit from an effective regulatory system that ensures compliance with the principles of sustainability and environmental protection. Hence, research is needed on effective science-based policy and governance models, to support progress in area-based management, and the identification and possible protection of areas of ecological importance in the deep sea (for example, based on the criteria and process for describing ecologically or biologically significant marine areas (EBSA) under the Convention for Biological Diversity).

Chapter 7 cover image: Deep-sea medusa jelly-fish
in the South Atlantic at a depth of 2,900m.

The EU Marine Knowledge 2020 Strategy promotes a more coherent approach to ocean observation whereby data is collected once but can be used many times by multiple users across different sectors including science, industry and management. Observing the more remote and inaccessible deep sea presents particular challenges which make it even more costly and technologically difficult than for coastal and shelf seas. However, both research and management will depend on the provision of access to quality-controlled physical (including geological), chemical and biological data from the deep sea to support improved knowledge of the system and more effective regulation and management. Public-private partnerships could play a key role in mapping the deep sea and in putting in place sustainable observing infrastructures that can deliver long-term time series data.

2. Assessing drivers, pressures and impacts in the deep sea

Key action areas:

- Develop improved knowledge of natural and human drivers, pressures and impacts;
- Understand stressor interactions and cumulative impacts;
- Establish "Good Environmental Status" for deep-sea ecosystems;
- Investigate alternative supply strategies for targeted resources;
- Reduce impacts and develop area-based strategic environmental management plans.

As with coastal seas, the deep sea is subject to drivers, pressures and impacts derived both from human activities and from natural phenomena. The impacts of climate change on the surface ocean as well as in coastal and shelf seas will influence patterns of change in deeper waters, affecting, for example, biodiversity and food webs, ocean chemistry (including ocean acidification), and heat storage and transfer. In addition to the impacts of climate change driven by anthropogenic CO_2, human activities such as bottom trawling, drilling for oil and gas and the laying of seabed pipelines and cables can cause direct and serious damage to deep-sea ecosystems. The impacts of these activities on ecologically important, reef-forming deep-water corals, for example, have already been documented in many regions, globally. Deep-sea mining will add to these existing impacts in multiple ways.

Understanding and quantifying drivers, pressures and impacts in the deep sea is, therefore, a crucial step towards developing a comprehensive set of environmental targets and associated indicators that can be used to determine and monitor environmental health status in the deep sea. This goal is further complicated by the need to examine the interactions between different stressors and the role of cumulative impacts. Applying and extending the concept of Good Environmental Status, a key tenet of the EU Marine Strategy Framework Directive, could form the basis for an environmental governance regime which can underpin the protection of deep-sea environments while promoting Blue Growth.

Research to provide alternative supply strategies for high-value deep-sea resources (minerals and rare earth elements) which are currently being targeted is also necessary. Recycling of used material and in some cases the potential for artificial laboratory-based synthesis may serve to reduce future impacts on vulnerable deep-sea environments. At the same time, more research is needed to inform ways to minimize the impacts of any mining that does occur and to help design representative no-mining areas that would be part of strategic environmental management plans.

3. Promoting cross-disciplinary research to address complex deep-sea challenges

Key action areas:

- Promote cross-sector research collaboration (e.g. industry-academia; academia-NGO);
- Develop a marine Knowledge and Innovation Community (KIC);
- Embed cross-disciplinary, problem-oriented approaches in the training of early career researchers.

Expanding commercial interest in the deep sea and related societal, environmental and governance challenges mean that a more holistic approach to deep-sea research is needed, combining expertise from natural sciences, social sciences and humanities. A strong tradition of such cross-disciplinary research is a strength of European science, distinguishing it from other international competitors, and should continue to be nurtured. Addressing these complex challenges will also require a multi-stakeholder approach, employing cross-sector partnerships to tackle societal questions in a way that is solutions-oriented.

Existing initiatives at European level could be used to foster cross-sector stakeholder interaction for deep-sea research and technology development, e.g. through the recently launched EU Science and Business Forum, a possible Sector Skills Alliance, and a potential future marine Knowledge and Innovation Community (KIC) under the auspices of the European Institute of Innovation and Technology (EIT).

The ability to address complex cross-disciplinary research challenges can also be fostered as part of the training of early stage researchers in deep-sea sciences. University students, particularly those at postgraduate level (M.Sc. or Ph.D.), should be supported to find work placements in industry and management organizations as part of their training. Courses should also include basic elements of economics, law and social sciences training. Such experience can play a vital role in ensuring that early-stage researchers understand the societal importance of their research and become familiar with working with scientists from other disciplines and with non-scientists from other sectors. It can also prepare them for tackling complex systems-based problems which require solutions involving multiple disciplines.

4. Innovative funding mechanisms to address knowledge gaps

Key action areas:

- Target public funding (EU and national programmes) at fundamental research in support of sustainability and protection of natural capital;
- Investigate innovative funding mechanisms and sustained funding streams for research and observation (e.g. long-term time series);
- Advance progress towards internationally coordinated mapping of the deep sea floor.

Whether for the purposes of research or for industrial activity, the deep sea is difficult and costly to access. To date, only 0.0001% of the deep sea has been sampled biologically (EMB, 2013). Although recent technological advances made access to this vast and remote environment considerably easier, exploratory activity still requires ocean-going vessels, platforms and heavy equipment. In considering future support for deep-sea research, key questions include:

Who should fund what?

Continued industrial development in the deep sea (e.g. deep-sea mining, oil and gas production and deep-sea fisheries) will require advanced technologies and significant investment, the vast majority of which will come from private sources (marine biodiscovery in the deep sea is currently an exception as it is primarily supported by public funding sources). For these reasons, the most effective way that European public research funding investments can support Blue Growth in deep-sea activities is to fund fundamental scientific research and the establishment of environmental baselines, as described in Goal 1 above. Where possible, this should be done in a timeframe that will complement and keep track with industrial expansion in the deep sea. Key areas for public research investment include, *inter alia*, mapping deep-sea terrain and habitats, studying deep-sea biodiversity, understanding deep-sea ecosystem functioning, connectivity and resilience, developing sustained deep-sea observing systems, identifying appropriate baselines and targets for environmental health, and developing innovative governance frameworks to ensure the most efficient and equitable utilization of deep-sea resources and allocation of subsequent benefits.

Is there scope to develop innovative, funding mechanisms and what would these look like?

The increasing costs associated with deep-sea research and the growing stakeholder and user community working in the deep sea offers opportunities for new funding mechanisms such as public-private partnerships (PPPs) to support, for example, the cost of ship-time, platform maintenance and seabed mapping. The above-mentioned KIC scheme coordinated by the European Institute of Innovation and Technology (EIT) is one initiative that could be used to develop PPPs addressing deep-ocean challenges. Internationally, the concept of an ocean bank for sustainability and development is also gaining traction as a vehicle to bring together deep-sea stakeholders to distribute knowledge and funding and deliver solutions to these challenges[75]. In addition, in response to the International Seabed Authority's recent stakeholder consultations, several respondents proposed a Seabed Sustainability Fund paid for by revenues from mining in The Area to support seafloor research. Another example of an innovative funding mechanism is provided by the INSITE programme (see section 6.4.5.) which addresses the research needs to support management of decommissioned man-made structures (oil and gas platforms, pipelines and cables) in the North Sea.

How can we deliver sustained funding sources for longer-term needs such as ocean observation and training?

There is a need to extend the horizon of deep-sea science programmes to be more in line with large-scale space projects both in terms of economic scale and duration. JPI Oceans could be a useful vehicle for deep-sea research funding in the future. JPI Oceans brings together 20 European member countries (in 2015) to align national funding streams and address common research challenges. As a coordination mechanism, it has the capacity to deliver long-term funding solutions in line with the needs of its member countries. JPI Oceans launched its Strategic Research and Innovation Agenda (SRIA) in May 2015 (JPI Oceans, 2015b). The SRIA identifies ten strategic areas that will be the focus for JPI Ocean activities in the future, the first of which is "Exploring Deep-Sea Resources". In 2015, JPI Oceans is already facilitating a multinational pilot action, led by German institutions, to survey and study the DISCOL site in the southeastern Pacific[76]. Scientists are examining longer-term environmental impacts of physical disturbance to the deep seabed (which can, in turn, provide insights on potential impacts of deep-sea mining). Through this pilot action, JPI Oceans has demonstrated that it can be a key platform to coordinate member state investments in deep-sea research and observation in the future. It also has the capacity to engage with industry to promote public-private research funding.

Ensuring a broad participation in deep-sea science

An outcome of the expert working group stakeholder consultation was that there should be a more inclusive approach to the participation of small as well as larger research performing organizations in national and international funding programmes. Deep-sea research requires input from a range of scientific disciplines and a foundation of students being trained by universities in marine science and other relevant disciplines. It is important that EU funding calls ensure broad participation in deep-sea research projects not just across states but also across the range of academic and non-academic institutions that can contribute to advancing deep-sea science. This should also be a priority at national level.

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[75] http://wwf.panda.org/what_we_do/how_we_work/conservation/marine/news/?247910/Funds-are-needed-for-marine-protected-areas

[76] https://jpio-miningimpact.geomar.de/home

5. Advanced technology and infrastructure for deep-sea research and observation

Key action areas:

- Promote and fast-track new technologies for platforms, sensors and experimental research;
- Develop and utilize multi-purpose deep-sea platforms;
- Improve current computational capacity and approaches for physical and biological modelling for deep ocean science;
- Develop sensors for biological and biogeochemical parameters;
- Support industry-academia collaboration in technology development.

Because the deep sea is extremely difficult for humans to access, technology is key to expanding our exploration of this vast and remote planetary environment. For many years there has been a reliance on deployment on cables of specialized equipment from ocean-class research vessels such as bottom trawls, landers, water sampling and coring arrays. More recently, the development of ROVs and untethered AUVs, gliders and Argo Floats has opened up new possibilities for observing and sampling deep-sea environments. The development of new sensors is also a key area to allow observation of deep-ocean variables across a range of physical, chemical and biological parameters. In general, improving functionality, durability, reliability, longevity and accessibility of observing platforms, sensors and sampling tools, and making communication and data transfer more rapid and efficient are key priorities for underpinning deep-sea research and observation.

Some specific actions which also deserve attention include the use of multi-purpose deep-sea platforms which can support novel research, the testing of new equipment and ideas, and international collaboration. Multi-purpose platforms provide a useful opportunity for cost-effective knowledge generation of interest to both funders and researchers.

Rapid advances in temporal observation potential with cabled observatories could fundamentally change our view of deep-sea dynamics. A current limitation of these observatories is that they monitor almost exclusively abiotic variables. Sensors for biological and biogeochemical measurements are still in their infancy. There is an urgent need to expand the potential of these technological platforms to investigate key biological parameters enabling the possibility to monitor changes in the population dynamics, assemblage structure and biological functions over time. In particular, *in situ* molecular tools can offer potential for high-resolution observation from microbes to larger invertebrates, including cryptic species. Currently available molecular tools and new chips allow the sequencing of DNA *in situ*, offering new opportunities to investigate biodiversity, symbiotic interactions, connectivity, and ecological function in deep-sea species.

There is significant scope for the deep-sea research community to work with offshore industries and capitalize on their infrastructure to collect environmental data in support of research goals, while at the same time sustaining existing EU investments (e.g. the EMSO initiative). This also applies to research infrastructures initially built for other purposes such as seafloor neutrino telescopes.

6. Fostering human capacities in deep-sea research

Key action areas:

- Promote and expand training and career opportunities for research, policy and industry;
- Take account of needs for both scientific and technical/ICT expertise.

The EC has identified a shortage of scientists, engineers and skilled workers able to apply new technologies in the marine environment as a barrier to achieving the full potential of Blue Growth in Europe (EC, 2014). This was also evident specifically for the deep-sea environment from the stakeholder consultation that supported the production of this position paper. The generation of knowledge and useful services from deep-sea data requires expert interpretation and specialized skills. There is also a growing need for scientific advice to inform the ongoing development of appropriate regulatory frameworks to govern access to and utilization of deep sea resources. This requires a combination of scientific expertise and skilled knowledge brokers able to communicate effectively between the scientific, legal and policy communities. Many scientific graduates will not end up in a research career but may use their scientific training to work within the science advisory process, supporting robust and evidence-based decision making. UNCLOS as it applies to Areas Beyond National Jurisdiction (ABNJ), for example, relies for implementation on key agencies and conventions (e.g. the International Seabed Authority and the International Maritime Organization). The new international instrument for biodiversity beyond national jurisdiction will require significant scientific input both in the development and implementation phases.

Finally, there is a clear lack of entrepreneurial and innovation skills in the current generation of marine scientists. There is not a natural tendency amongst them to recognize and transfer knowledge outputs into products and services with added commercial value that can improve consumers’ lives or alleviate some of today’s current societal challenges. Training the next generation with these skills is imperative if we wish to unlock the full potential of blue growth in the EU and maximize the impacts of research in meeting societal needs.

To support these goals it is best to start by providing the appropriate training at university level. This will not just support early stage researchers embarking on a research career, but also those with scientific training who may opt for a career in industry or policy. It can also foster the broad range of specialist technical and ICT skills needed to underpin modern marine science and promote cross-disciplinary training approaches as described in Goal 4 above.

7. Promoting transparency, open data access and appropriate governance of deep-sea resources

Key action areas:

- Ensure adequate representation of scientific expertise contributing to developing legal and policy frameworks addressing deep-sea resources (notably preparation of a new Implementing Agreement under UNCLOS) and development of an ISA regulatory framework for seabed mining;
- Promote transparency and open access to data as guiding principles for deep-sea governance;
- Improve technology transfer between publicly-funded research and the private sector;
- Develop deep-sea ecosystem restoration protocols.

Commercial activities in the deep sea are now a reality and are growing and diversifying. However, regulatory frameworks and transparency standards for deep-sea activities are under-developed and not yet adequate to deal with emerging activities of commercial interest. This is particularly true for ABNJ, where there is a particular need to develop realistic and science-based standards for seabed mining and innovative approaches to facilitating access and benefit sharing for biotic and abiotic resources. It will be important to ensure that any regime for marine genetic resources in ABNJ will serve to stimulate the growth of a nascent European marine biotechnology sector, targeted as one of five priority growth areas in the EU Blue Growth Strategy. At the time of publication, the UN has embarked on the preparation of a legally binding international instrument under UNCLOS. The envisaged scope, as agreed by the BBNJ working group[77], will include marine genetic resources (MGR), including questions on the sharing of benefits, measures such as area-based management tools, including marine protected areas, environmental impact assessments and capacity-building and the transfer of marine technology. Scientific advice will be critical to ensure that any new implementing agreement is practicable and fit-for-purpose.

Transparency, open participation and open data access should be guiding principles for the development of policy and legal frameworks governing access and utilization of deep-sea resources including fisheries, oil and gas, marine minerals and marine genetic resources. The EU now requires that knowledge outputs of EU-funded projects should be stored in an open access public data bases. The EMODnet initiative, promoted by the EU Marine Knowledge 2020 Strategy, provides a central portal for open access to marine data, products and metadata, relying on quality-assured, standardized and harmonized marine data which are interoperable and free of restrictions on use. EMODnet is currently underutilized as a resource for accessing deep-sea datasets.

There is also scope for much greater technology transfer between academia and industry and for sharing selected monitoring and surveillance information, including geo-mapping and vessel tracking to assist companies in their own vessel/pipeline management and ensure self-regulation and compliance.

[77] BBNJ Working Group refers to 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.

Industry-academia collaboration can also promote restoration strategies for deep-sea habitats degraded by future mining operations, oil spills, bottom trawling or other sources of impact. Deep-water corals, for example, have been shown to survive and grow in laboratory conditions and experimental reintroduction to the seafloor has proved successful. Plans are underway to initiate experiments for the restoration of hydrothermal vents, cold seeps (with mineral crusts), and manganese nodules after mining but the effectiveness of restoration is far from certain. Work is also in progress to develop swarms of autonomous undersea vehicles to support and monitor deep-sea restoration efforts over relatively broad geographical zones.

8. Deep ocean literacy to inspire and educate society to value deep-sea ecosystems, goods and services

Key action areas:

- Promote communication and education on the societal importance of the deep sea to students and the general public using the best principles of ocean literacy;
- Embed ocean literacy approaches in deep-sea research projects and programmes.

The deep sea is our hidden planet, a vast and under-explored realm that, despite its remoteness, has great societal value producing a wealth of ecosystem goods and services. With the expansion of commercial activities in the deep sea, it is more important than ever that society values this resource and takes account of the intrinsic value of the deep sea. The Ocean Literacy movement - first established in the USA but now growing in Europe - aims, through a range of communication and education actions, to create a more “ocean literate” society. An ocean literate person understands their influence and impact on the ocean and the ocean’s influence and impact on them.

Because of its capacity for wonder and fascination, there is scope to use the deep-sea realm as a topic that can inspire and educate society and in particular the younger generation on the intrinsic value of the ocean (monetary and non-monetary) and the goods and services it provides to society. It is crucial to use ocean literacy initiatives to raise awareness of the diversity of life in the deep sea and the need to identify, protect and sustainably manage vulnerable deep-sea habitats and their biodiversity. The technological challenges for deep sea exploration have in themselves the potential to generate the interest of young people to follow career paths in technology-oriented subjects such as engineering and ICT.

One way to support this process is to make the deep-sea more accessible through online and digital content, e.g. real-time connections to the deep-sea and interactive education programmes linked directly to deep-sea research programmes. Links should also be made with commercial activities in the deep sea to educate people on the economic value and the need for a balanced approach to sustainable management of the deep sea. National curricula should also include more content on the oceans and the deep sea in particular.

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List of acronyms

ABNJ	Areas Beyond National Jurisdiction, The Area
AC	Alternating Current
ARGO	Array for Real-Time Geostrophic Oceanography (International project)
AUV	Autonomous Underwater Vehicle
BECS	Biomass energy with carbon storage
BECCS	Biomass Energy with CO2 capture and storage
BIM	Bord Iascaigh Mhara The Irish Sea Fisheries Board
BWMC	International Convention for the Control and Management of ships' Ballast Water and Sediments
CBD	Convention on Biological Diversity
CCAMLR	Convention on the Conservation of Antarctic Marine Living Resources
CCFR	Code of Conduct for Responsible Fisheries
CCFZ/CCZ	Clarion-Clipperton Fracture Zone
CCS	Carbon Capture and Storage
CCSBD	Coastal Areas and Climate Change Biodiversity and Sustainability
CDR	Carbon Dioxide Removal
Cefas	Centre for Environment, Fisheries, and Aquaculture Science
CFP	Common Fisheries Policy
CIESM	The Mediterranean Science Commission
CITES	Convention on the Illegal Trade of Endangered Species
CoML	Census of Marine Life (international project)
Copernicus	The European Earth Observation Programme (formally GMES)
Defra	Department for Environment, Food and Rural Affairs
DELOS	Deep-ocean Environmental Long-term Observatory System
DG	Directorate General (European Commission) (DG MARE)
DONET	Dense Oceanfloor Network System for Earthquakes and Tsunamis
DOSI	Deep Ocean Stewardship Initiative

DS3F	Deep Sea and Sub-Seafloor Frontier (EU FP7 project)
EBSA	Ecologically and Biologically Significant Area
EC	European Commission
ECO2	Sub-seabed CO2 Storage: Impact on Marine Ecosystems
ECORD	European Consortium on Ocean Research Drilling
ECV	Essential Climate Variable
EEA	European Environment Agency
EEZ	Exclusive Economic Zone
EFZ	Exclusive Fisheries Zone
EIA	Environmental Impact Assessment
EIFeX	European Iron Fertilization Experiement
EPPR	Emergency Prevention, Preparedness and Response
EMB	European Marine Board
EMSO	European Multidisciplinary Seafloor Observation
EOR	Enhanced Oil Recovery
EOV	Essential Ocean Variable
ESFRI	European Strategy Forum for Research Infrastructures
ETI	Energy Technologies Institute
EU	European Union
EuroARGO	European contribution to the global ARGO ocean observation project
FAO	Food and Agriculture Organization
FCT	Portuguese national funding agency for science, research and technology
FP	Framework Programme (European Commission funding)
GDP	Gross Domestic Product
GEOTRACES	An international study of the marine biogeochemical cycles of trace elements and their isotopes
GEOSS	Global Earth Observation System of Systems

GES	Good Environmental Status
GFCM	General Fisheries Commission for the Mediterranean
GHSZ	Gas-Hydrate Stability Zone
GMES	Global Monitoring for Environment and Security (see Copernicus)
GOC	Global Ocean Commission
GVA	Gross Value Added
H2020	Horizon 2020 Programme
HNLC	High nutrient low chlorophyll
HOV	Human Occupied Vehicle
HVDC	High Voltage Direct Current
IASC	International Arctic Science Committee
ICES	International Council for the Exploration of the Seas
ICJ	International Court of Justice
ICPC	International Cable Protection Committee
IGO	Intergovernmental organization
IMBER	Integrated Marine Biogeochemistry and Ecosystem Research
IMO	International Maritime Organization
IMP	Integrated Maritime Policy
INDEEP	International Network for Scientific Investigations of Deep-Sea Ecosystems
IODP	Integrated Ocean Drilling Program
IPCC	Intergovernmental Panel on Climate Change
IPOA-IUU	International Plan of Action to Prevent, Deter and Eliminate IUU Fishing
ISA	International Seabed Authority
ISSRP	InterRidge Statement of Commitment to Responsible Research Practice at Deep-Sea Hydrothermal Vents
ITLOS	International Tribunal on the Law of the Sea
IUU	Illegal, unreported and unregulated fishing

IWC	International Whaling Convention
JPI-Oceans	Joint Programming Initiative for Healthy and Productive Seas and Oceans
LoVe	Marine Ecosystem Project
MAR	Mid-Atlantic Ridge
MARPOL	International Convention for the Prevention of Pollution from Ships
MARS	Monterey Accelerated Research System
MCS	Monitoring, control, surveillance
MDG	Millennium Development Goals
MoU	Memorandum of Understanding
MEOPAR NCE	Marine Environmental Observation Prediction and Response Network National Centre of Excellence
MGR	Marine Genetic Resources
MIDAS	Managing Impacts of Deep-Sea Resource Exploitation
MMO	Marine Management Organization
MMSG	Ministerial Marine Science Group
MNP	Marine Natural Products
MOR	Mid-ocean ridges
MPA	Marine Protected Area
MS	Member State
MSFD	Marine Strategy Framework Directive
MSP	Maritime Spatial Planning
NAFO	North Atlantic Fisheries Organization
NAMMCO	Agreement on Cooperation in Research, Conservation and Management of Marine Mammals in the North Atlantic
NASCO	North Atlantic Salmon Conservation Organization
NATO	North Atlantic Treaty Organization
NEA	Nuclear Energy Agency
NEAFC	North East Atlantic Fisheries Commission

NEMO	New Energy for Martinique and Overseas
NEPTUNE	North-East Pacific Time-Series Underwater Networked Experiments
NERC	Natural Environment Research Council
NGO	Non-Governmental Organization
NIS	NON-Indigenous Species
NPFC	National Pollution Funds Centre
NOC	National Oceanography Centre (United Kingdom)
NSF OCE	National Science Foundation Ocean Sciences
OCT	Overseas Countries and Territories
ODP	Ocean Drilling Program
OGC	Open Geospatial Consortium
OGUK	Oil and Gas United Kingdom
OMZ	Oxygen Minimum Zone
OOI	Ocean Observatories Initiative
OSPAR	Oslo-Paris Convention for the protection of the marine environment of the North-East Atlantic
OTEC	Ocean Thermal Energy Conversion
PADI	Professional Association of Diving Instructors
PAME	Protection of the Arctic Marine Environment
PCB	Polychlorinated Biphenyl
PETM	Palaeocene-Eocene thermal maximum
POP	Persistant Organic Pollutants
PSSA	Particularly Sensitive Sea Areas
RandD	Research and Development
REE	Rare Earth Elements
RFMA	Regional Fisheries Management Arrangement
RFMO	Regional Fisheries Management Organization

RFO	Research Funding Organization
RIDE	Roatan Institute of Deep-Sea Exploration
ROV	Remotely Operated Vehicle
RPO	Research Performing Organization
RTD	Research, Technology and Development
SACs	Special Areas of Conservation
SAI	Significant Adverse Impacts
SCI	Site of Community Importance
SDG	Sustainable Development Goal
SEA	Strategic Environmental Assessment
SEAFO	South East Atlantic Fisheries Organization
SERPENT	Scientific and Environmental ROV Partnership using Existing iNdustrial Technology
SIOFA	South Indian Ocean Fisheries Agreement
SME	Small and Medium Enterprise
SMS	Seafloor Massive Sulphides
SOO	Ships of Opportunity
SPI	Science–Policy Interface
SPRFMO	South Pacific Regional Fisheries Management Organization
SRM	Solar Radiation Management
SSHRC	Social Sciences and Humanities Research Council
STOA	Science and Technology Options Assessment
SWE	Sensor Web Enablement
TRIPS	Trade Related Intellectual Property Rights Agreement
UK	United Kingdom
UKCS	United Kingdom Continental Shelf
UNCLOS	United Nations Convention on the Law of the Sea

UN	United Nations
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNFCCC	United Nations Framework Convention on Climate Change
UNFSA	United Nations Fish Stocks Agreement
UNGA	United Nations General Assembly
UNOLS	University National Oceanographic Laboratory System
USA	United States of America
VENUS	Victoria Experimental Network Under the Sea
VME	Vulnerable Marine Ecosystem
VMS	Vessel Monitoring Systems
WGDEC	Working Group on Deep-Water Ecology (ICES/NAFO)
WGDEEP	Working Group on Biology and Assessment of Deep-Sea Fisheries Resources (ICES)
WTO	World Trade Organization

Annex I

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Annex II

Stakeholders attending EMB WG Deep Sea workshops

24-25 April 2014, Somerville College, University of Oxford, UK

Anne Walls, BP, UK

Jeff Ardron, Commonwealth Secretariat, London (at time of workshop, Institute for Advanced Sustainability Studies, Germany)

Andrew Kenny, CEFAS, UK

Larissa Schapkova, Shell, UK

Ernst Kloosterman, Industrial Biotech Network, Norway

6 November 2014, University of Lisbon, Portugal

Fernando Barriga, Director, Centre for Mineral Resources, Mineralogy and Crystallography, University of Lisbon, Portugal

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Bruno Sommer Ferreira, CEO Biotrend, Portugal

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Monica Verbeek, Seas at Risk

Annex III

Stakeholder consultation respondents

See acronym list for stakeholder organization type

INSTITUTE / ORGANIZATION	COUNTRY	STAKEHOLDER ORGANIZATION TYPE
University of Vienna	Austria	RPO
BELSPO	Belgium	RFO
DEME	Belgium	Industry
eCOAST	Belgium	Industry
Vrije Universiteit Brussel	Belgium	RPO
Cyprus Oceanogrpahy Centre	Cyprus	RPO
CNRS	France	RPO
Ifremer	France	RPO
Institute for Sustainable Development and International Relations (IDDRI)	France	RPO
IUEM-UBO	France	RPO
LEGOS/CNRS	France	RPO
Sorbonne Universités	France	RPO
Technip	France	Industry
UPMC	France	RPO
AWI	Germany	RPO
BHM PENLAW	Germany	Industry
DeepSea Mining Alliance	Germany	Industry
GEOMAR	Germany	RPO
Institute for Advanced Studies in Sustainability	Germany	Industry
Jacobs University Bremen	Germany	RPO
MARUM	Germany	RPO
Zoological Museum	Germany	RPO
Hellenic Centre for Marine Research	Greece	RPO
Marine Institute	Ireland	RFO

INSTITUTE / ORGANIZATION	COUNTRY	STAKEHOLDER ORGANIZATION TYPE
National University of Ireland	Ireland	RPO
NUI Galway	Ireland	RPO
Conisma and Polytechnic University of Marche and Stazione Zoologica Anton Dohrn	Italy	RPO
INFN	Italy	RPO
ISPRA	Italy	RPO
OGS	Italy	RPO
University of Bari Aldo Moro	Italy	RPO
OceanflORE	Netherlands	RPO
DNV GL	Norway	Industry
Insitute of Marine Research	Norway	RPO
NIVA	Norway	RPO
CESAM	Portugal	RPO
IPMA	Portugal	RPO
Marine and Environmental Sciences Centre	Portugal	RPO
Portuguese Task Group for the Extension of the Continental Shelf (EMEPC	Portugal	RPO
Universidade de Aveiro	Portugal	RPO
University of Algarve	Portugal	RPO
University of the Azores	Portugal	RPO
CSIC	Spain	RPO
Insitut de Ceències del Mar	Spain	RPO
Instituto Español de Oceanografía	Spain	RPO
Damen Dredging Equipment	The Netherlands	Industry
IHC Mining	The Netherlands	Industry

INSTITUTION	COUNTRY	STAKEHOLDER
Royal Netherlands Institute for Sea Research (NIOZ)	The Netherlands	RPO
Wageningen UR	The Netherlands	Industry
Black Sea Commission	Turkey	RPO
Albatern	UK	Industry
British Petroleum	UK	Industry
Cefas	UK	Industry
Deep Sea Forum of the Marine Alliance for Science and Technology for Scotland	UK	Industry
Marine Scotland	UK	RFO
National Federation of Fishermen's Organizations	UK	Industry
National Oceanography Centre	UK	RPO
Natural History Museum	UK	RPO
Newcastle University	UK	RPO
Scottish Association for Marine Science	UK	RPO
Scottish Renewables	UK	Industry
SWFPA	UK	Industry
University of Aberdeen	UK	RPO
University of Liverpool	UK	RPO
University of Plymouth	UK	RPO
University of Southampton	UK	RPO
VentSeaTech Pty Ltd	Australia	Industry
Nautilus Minerals	Canada	Industry

Annex IV

Deep-sea investment survey.

Survey template for RPOs. Further surveys were produced targeted at RFOs and Industry.

Consultation on Investment into Deep-Sea Research and Related Activities

For Research Performing Organizations / deep-sea researchers

This survey aims to determine what influences funding for deep sea research, as well as temporal, spatial, and thematic trends in research and funding. For the purpose of this study, **'Deep Sea' is defined as the open ocean region in waters > 200m water depth, including the water column, the seafloor and the sub seafloor.'**[78] Thank you for your participation and input.

Part 1: Introduction

Name (will not be published):

Organization Name (if applicable):

Organization location (country):

Contact email (will not be published):

Contact telephone number (will not be published):

Please tick if you are not willing to be contacted for follow up questions:

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[78] 'The deep sea is defined as the area of the ocean that is deeper than the continental shelf edge, which lies at variable depths. For simplicity, the upper boundary of the deep sea is often placed at 200m depth…' (European Marine Board, 2013. Navigating the Future IV. Ch. 8) http://www.marineboard.eu/images/publications/Navigating%20the%20Future%20IV-168.pdf

Part 2.1: Baseline Research

1. **What are the Deep Sea research areas that your organization is currently involved in today?**
(Please rank each area 1 to 5; 1 is least priority (not active area), 5 is highest (very active area)

	1	2	3	4	5
Microbiology					
Marine Biology and Ecology					
Physical Oceanography					
Biogeochemical cycles					
Paleontology					
Seafloor / Sub-seafloor geochemistry and geology					
Increase general knowledge					
Sea floor mapping					
Seafloor surveying					
Anthropogenic Influences					
Environmental Impacts					
Valuing ecosystem goods and services					
Benthic-pelagic coupling					
Technology Development					
Policy and Legal Issues					
Long term monitoring					
Other (please specify in box below)					

Please explain (optional):

2. **What Deep Sea research areas were your organization involved in 5 years ago (2010)?**
(Please rank each area 1 to 5; 1 is least priority (not active area), 5 is highest (very active area)

	1	2	3	4	5
Microbiology					
Marine Biology and Ecology					
Physical Oceanography					
Biogeochemical cycles					
Paleontology					
Seafloor / Sub-seafloor geochemistry and geology					
Increase general knowledge					
Sea floor mapping					
Seafloor surveying					
Anthropogenic Influences					
Environmental Impacts					
Valuing ecosystem goods and services					
Benthic-pelagic coupling					
Technology Development					
Policy and Legal Issues					
Long term monitoring					
Other (please specify in box below)					

Please explain (optional): e.g. if not possible to prioritize state any trends e.g. deep-sea marine biology and ecology research has increased since 2010.

3. **In which region(s) is your deep sea related research focused?**
   (Please tick all that apply)

Respective EEZ	
Overseas Territory	
North Sea	
Celtic Sea	
Baltic Sea	
Black Sea	
Mediterranean Sea	
Atlantic Ocean	
Pacific Ocean	
Indian Ocean	
Southern Ocean	
Arctic Ocean	
Other, please specify:	

Please explain (optional):

Part 2.2: Research Funding

Policy Context

4. **Geographically, what marine science funding is your organization involved in?**
   Please list the specific programmes

	PROGRAM(S) USED
National competitive funding	
National capability funding	
Other National Level:	
European Commission eg. FP7, H2020, ESFRI	
European Research Council	
International level	
Other, please specify:	

Please explain (optional):

5. **What are the relevant policies or programmes that inform your organizations marine research or research agendas?**
   Please check all that apply, and name if not already listed

	INFORM RESEARCH AGENDA	IMPACT ACQUISITION OF FUNDING	NOT RELEVANT
International Programmes eg. International Marine Minerals Society, please specify:			
International Seabed Authority			
EU Marine Strategy Framework Directive			
EU Blue Growth Strategy / Communication			
EU Common Fisheries Policy			
EU Maritime Spatial Planning			
National Programmes / Strategies please specify:			
Regional Programmes eg. OSPAR, RFMOs, please specify:			
Other, please specify:			

Please expand (optional):e.g. are there any specific policies related to deep-sea that are informing your organization / National research agenda?

6. **What current factors influence your research priorities, specifically for the seep sea, and what factors do you feel will play a role in the future?** Please tick all that apply

	CURRENT	FUTURE
Science excellence /scientific research question		
Policy developments		
Industry Developments		
Technology Improvements		
Wider stakeholders eg. NGOs		
Other, please specify:		

Please explain (optional):

Research Budgets

7. **What was your organizations approximate annual budget for funding marine/maritime RandD for the last 6 years?** Please give specific values. If not possible, explain why below:

	TOTAL BUDGET (please indicate Specific Currency)
2014	
2013	
2012	
2011	
2010	
2009	

Please explain:

We are interested to compare total marine investment with funding for deep-sea research

1. **If possible, please specify the proportion of your budget that was used for deep sea related activities for the last 6 years.** If not possible, explain why below:

	TOTAL BUDGET FOR DEEP-SEA RELATED ACTIVITIES (please indicate Specific Currency)	If an exact figure is not possible, please indicate an approximate % of deep-sea budget: total marine research budget
2014		
2013		
2012		
2011		
2010		
2009		

Please explain (optional):

2. Where does this funding for deep sea research come from?
Please tick all that apply, and if possible, include the percentage breakdown.

	WHICH APPLY	PERCENTAGE
Public		
Public Contract		
Private Contract		
Public-private		
Private Trusts / Foundation		
Other, please specify:		

Please explain (optional):

3. What is included in your cost analysis for your deep-sea research budget?
Please tick all that apply.

Ship time	
Research Infrastructure	
Equipment	
Field Work	
Personnel	
Other, please specify:	

Please explain (optional):

4. What was your approximate annual budget for deep sea related research for the last 6 years, and what percentage of the funding came from each level?
NB. On the online form this question is a text box, please complete specifying year and percentages.

	SPECIFIC CURRENCY	NATIONAL LEVEL	EU LEVEL	INTERNATIONAL LEVEL	OTHER:
2014					
2013					
2012					
2011					
2010					
2009					

If not possible to list, please explain why: (eg. lack of relevant funding category)

5. **Which infrastructure and heavy equipment (if any) does your organization use?**
   Please list specific numbers and values:

	OWN	VALUE	EXTERNALLY SUPPLIED	VALUE	OTHER:
Research Vessels					
AUVs					
ROVs					
Manned submersibles					
Permanent Seafloor Observatories					
Deep Sea Observatory					
eInfrastructure eg. Databases					
Other, please specify:					

Additional information (optional) eg. Location of equipment:

Deep Sea Research Projects

6. **Please list the 5 largest deep sea research projects you've been involved in during the past 5 years (approximately):**
   NB. This question is for individual researchers to provide examples of deep-sea research projects.

PROJECT TITLE	TOTAL FUNDING	TYPE OF FUNDING	INTERNATIONAL LEVEL	TIMING (start-finish dates)

Please use the box below to expand on (optional):
- the type of funding e.g. National, Regional, European, International, Public or Private (or both).
- project aims

7. **From a research perspective, are you involved in any private-public partnerships, and if so, what are they and what funding do you receive for your research?**[51]

[51] Eg. SERPENT Project, which aims to make industrial ROV technology and data more accessible to the world's scientific community; producing EIA's for industry or government organizations, providing technical advice etc. http://www.serpentproject.com/.

Commercial Activities

1. **Does your organization currently fund any deep sea research related to commercial activity?**
   If no, please go to section IV: Future
   If yes, what industry sectors are your organization involved in, either publically or through public-private partnerships?
   Please check all that apply and name program eg. SERPENT

	PUBLIC	PUBLIC-PRIVATE	PROGRAM NAME
Technology Development			
Hydrocarbon Exploitation			
Deep sea mining			
Bio prospecting			
Deep-sea Trawling			
Aquaculture			
Renewable Energy			
Other, please specify:			

Please expand (optional):

Part 3: Future

1. **In your opinion, what are the major limitations regarding investments in Deep Sea research activities?**
   (Please rank 1 to 5; 1 is least priority, 5 is highest)

	1	2	3	4	5
Lack of recognition of deep-sea scientific knowledge needs and gaps					
Overlapping legal regimes (EEZ, ABNJ)					
Lack of sufficient funding for deep-sea research					
Lack of regulatory framework					
Stringent regulatory framework					
infrastructure shortcomings					
Technological shortcomings					
Other, please specify:					

Please explain (optional):

2. What other actions are still needed to ensure sustainable development of the deep seas?

	PRIORITY	USEFUL	INSIGNIFICANT	NO OPINION
Basic Research				
Policy guidelines				
Ecosystem Approach				
Cooperation between sectors				
Marine Spatial Planning				
Monitoring and Enforcement				
Holistic governing organization				
Other, please specify				

Please expand (optional):

Any other comments?

Thank you for completing this stakeholder questionnaire. Please submit to kared@vliz.be

Annex V

Number of research vessels in Europe and some adjacent states

Data for European countries were sourced from the EurOcean European Research Vessels Infobase. Data for the US were sourced from the National Academies 2015 publication Sea Change: 2015-2025 Decadal Survey of Ocean Sciences and data for Canada from Canadian Coast Guard Fleet database.

STATE	REGIONAL	OCEANIC	GLOBAL
Belgium	3	0	0
Bulgaria	0	1	0
Croatia	2	0	0
Denmark	0	2	1
Faroes	2	0	0
Finland	0	1	0
France	1	1	6
Germany	9	4	6
Greece	1	3	0
Iceland	0	1	1
Ireland	0	0	1
Italy	4	1	3
Netherlands	1	1	3

STATE	REGIONAL	OCEANIC	GLOBAL
Norway	1	4	5
Poland	3	1	0
Portugal	1	0	2
Romania	0	0	1
Russia	4	3	19
Spain	6	0	4
Sweden	4	2	1
Turkey	5	1	1
Ukraine	0	0	1
United Kingdom	1	1	3
TOTALS	**50**	**28**	**71**
US (UNOLS)	2	5	7
CANADA (CCG)	4	3	3

Design: Zoeck nv

Cover image: The *"Candelabra"* black smoker at a water depth of 3,300m in the Logatchev Hydrothermal Field on the Mid-Atlantic Ridge.
(Credit: MARUM – Center for Marine Environmental Sciences, University of Bremen)

European
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