EMB POLICY BRIEF

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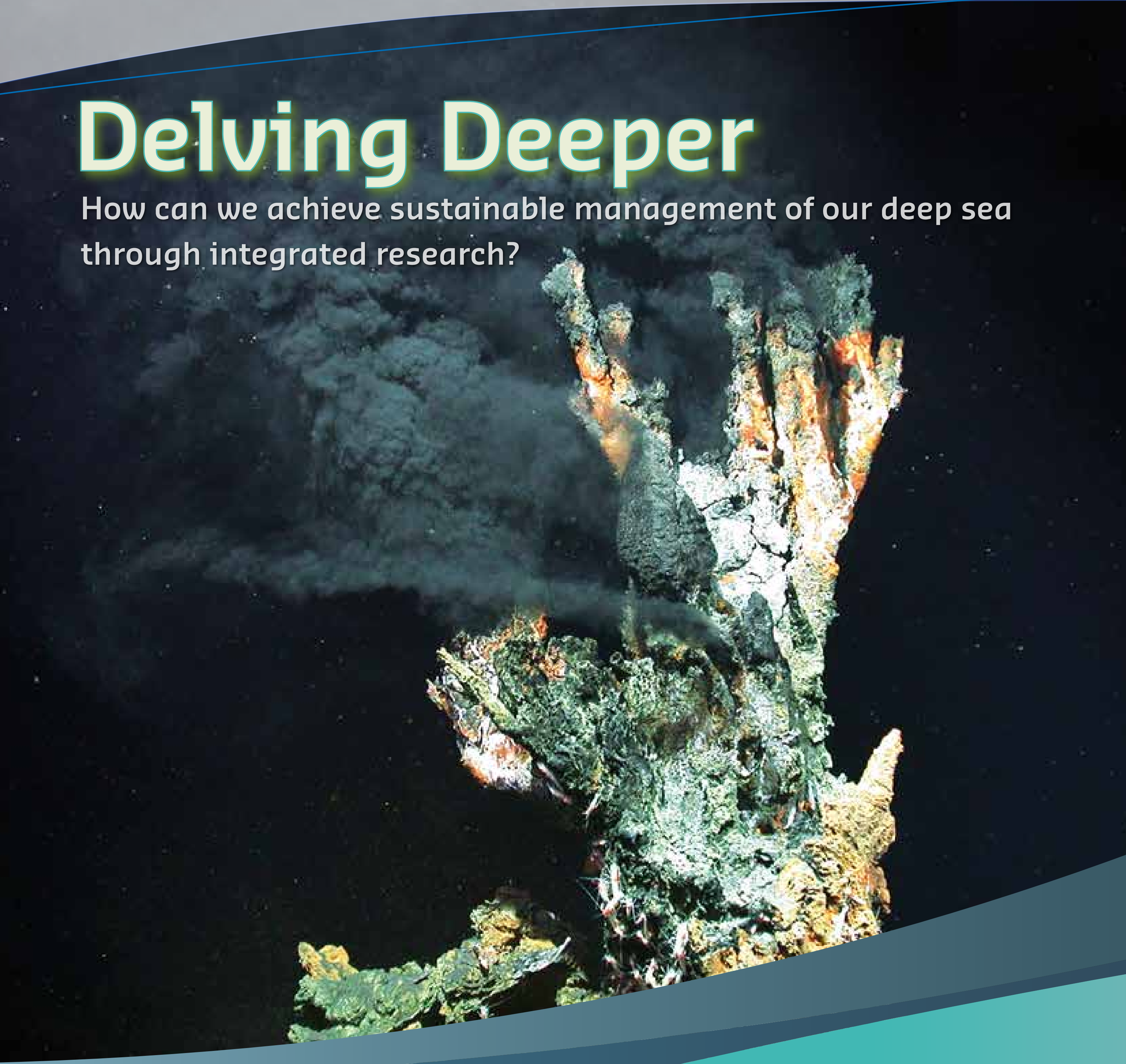
Delving Deeper

How can we achieve sustainable management of our deep sea through integrated research?



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European MARINE BOARD
Advancing Seas & Ocean Science

The European Marine Board provides a pan-European platform for its member organizations to develop common priorities, to advance marine research, and to bridge the gap between science and policy in order to meet future marine science challenges and opportunities.

Established in 1995, the European Marine Board provides the essential components for transferring knowledge for leadership in marine research in Europe, with the objective of promoting the establishment of the European *marine* Research Area. Its members are major national marine or oceanographic institutes, research funding agencies, and national networks of universities with a strong marine research focus. In 2015, European Marine Board represents 36 Member Organizations from 19 countries.

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This policy brief is based on Position Paper 22* of the European Marine Board, drafted by an interdisciplinary working group (WG Deep Seas, Jan. 2014-Sept. 2015) of 14 experts from 9 countries, nominated by the EMB. The working group, in consultation with wider stakeholders, conducted an extensive review of the deep-sea research landscape and set out key research needs 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.

* 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.

Exploring the deep sea

Sometimes referred to as the earth's "inner space", the deep sea covers 65% of the earth's surface and remains the last frontier on our planet. Over 200 years of deep ocean exploration has uncovered a rich diversity of life and habitats, from cold and dark abyssal plains, to hydrothermal vent ecosystems which may hold secrets to the origins of life. Yet this vast domain remains largely unexplored. Once considered remote and inaccessible, commercial activities combined with technological advancements are driving the blue economy deeper, resulting in more pressures and impacts on the deep sea than ever before. This is changing our interaction with the deep sea, resulting in a mismatch between the rising demand and capability to exploit deep-sea resources, and a lack of scientific knowledge and regulatory frameworks needed to effectively manage the deep sea. Major progress in integrated deep-sea research is urgently required to establish environmental baselines and underpin an effective ecosystem-based management plan for the deep sea.

Deep-sea facts

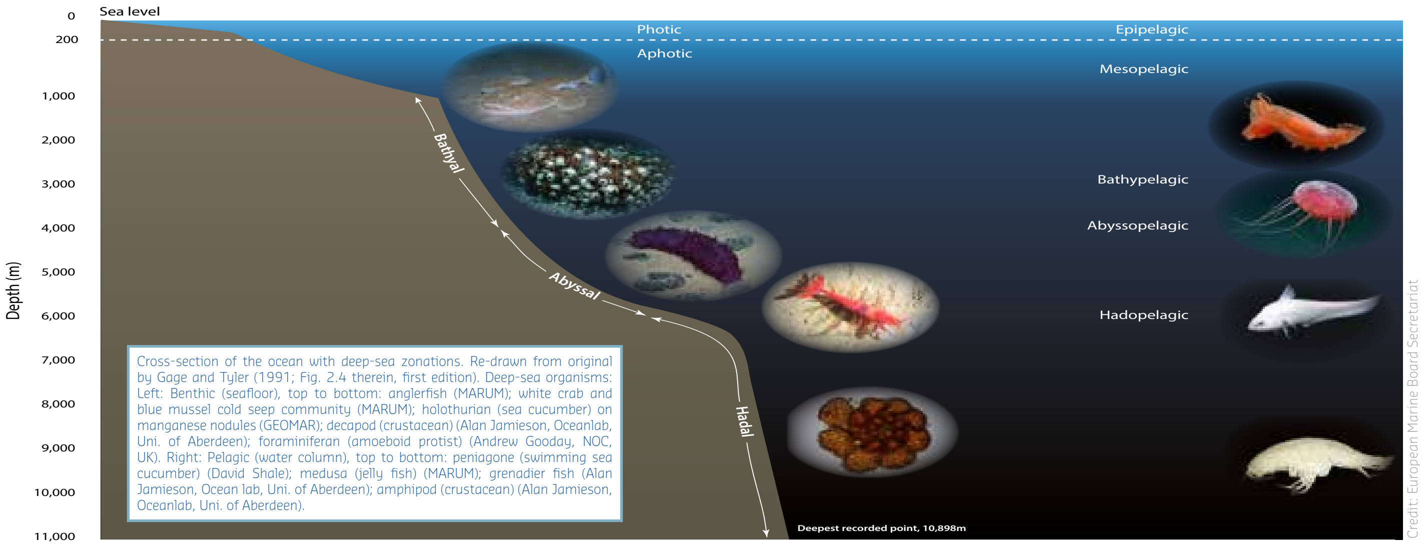
- The "deep sea" is defined here as that part of the seabed and water column that exists below 200m depth. It covers 65% of the earth's surface and provides over 95% of its habitable space or biosphere;
- 1 billion km^3 of our planet is deep water pelagic, yet less than 0.0001% has been investigated;
- Deep-sea life occurs at temperatures ranging from -2°C to more than 120°C;
- The average depth of the deep sea is 4.2km with the deepest point recorded as 10.89km at "Challenger Deep" in the Mariana trench, western Pacific Ocean;
- During the international Census of Marine Life programme (2000-2010), every second specimen collected from abyssal waters deeper than 3,000m was new to science and previously undescribed;
- Two thirds of all known coral species live in the deep sea and can reach ages of 5,000 to 8,500 years old.

Living life at the extremes

The deep sea is the world's largest biome, connecting 1 billion km^3 of deep water and a wealth of submerged landscapes including mountain ranges, volcanic chains, hydrothermal vents, canyons and trenches, seamounts, abyssal plains, cold seeps, carbonate mounds, deep-water coral reefs, and gas hydrates. Such environments host a rich and highly diversified microbial and animal life adapted to the dark and living under extreme pressures and temperatures. These include ancient taxa such as stalked crinoids more than 350 million years old. 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 making populations particularly vulnerable to change. Some communities, such as those found around hydrothermal vents, also display a high level of endemism, living in isolated "island-like" communities adapted to specific conditions with a low resilience to disturbance.

Deep-sea ecosystems and connectivity

Understanding how deep-sea ecosystems function is vital if we are to assess and monitor the cumulative effects of natural and anthropogenic pressures and impacts. We still do not understand the complete life cycle of any deep-sea species (either invertebrate or fish) and fundamental processes of reproduction and recruitment are virtually unknown. In addition, the deep sea does not exist in isolation but is intimately connected with surface waters and, in turn, with the earth and climate systems. Organic matter transported from the surface to the deep seafloor provides a vital food source for many deep-sea organisms and forms the basis for the carbon pump, transferring carbon to the deep sea. As a result, the deep sea is not immune to the impacts of climate change, with evidence for ocean acidification, changes to circulation, warming and expanding oxygen minimum zones already observed in the deep ocean.



Cross-section of the ocean with deep-sea zonations. Re-drawn from original by Gage and Tyler (1991; Fig. 2.4 therein, first edition). Deep-sea organisms: Left: Benthic (seafloor), top to bottom: anglerfish (MARUM); white crab and blue mussel cold seep community (MARUM); holothurian (sea cucumber) on manganese nodules (GEOMAR); decapod (crustacean) (Alan Jamieson, Oceanlab, Uni. of Aberdeen); foraminiferan (amoeboid protist) (Andrew Gooday, NOC, UK). Right: Pelagic (water column), top to bottom: peniagone (swimming sea cucumber) (David Shale); medusa (jelly fish) (MARUM); grenadier fish (Alan Jamieson, Ocean lab, Uni. of Aberdeen); amphipod (crustacean) (Alan Jamieson, Oceanlab, Uni. of Aberdeen).

What does the deep sea provide for us?

Deep-sea environments provide us with ecosystem goods and services that we are often unaware of. Some ecosystem services are quantifiable and have a direct market value. These include the provision of food through fisheries, marine-derived bioactive compounds, and oil, gas and mineral resources. However, the ocean also provides a broad range of ecosystem services that cannot be valued directly. Climate regulation, carbon sequestration, oxygen production and waste remediation are unseen services but essential for planetary health and human wellbeing.

Blue growth goes deep

There is currently a rapid development of interest to access ocean resources in deeper waters beyond the continental shelf. This includes established industries such as fisheries, and oil and gas production, which are moving operations deeper than ever before. In addition, emerging activities such as deep-sea mining, blue biotechnology and the development of renewable energy schemes, identified as priority areas by the EU Blue Growth Strategy, are the subject of major interest from both the private sector and some national governments. However, we 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). These economic opportunities also present specific challenges which will depend on the scale of the activities, the size and biological characteristics of the ecosystems impacted, and the trade-offs in terms of economic benefit compared to alternative strategies, e.g. recycling of rare earth elements.

PROVISIONING SERVICES
- Carbon capture and storage
- Finfish, shellfish, mammals
- Oil, gas, minerals
- Chemical compounds
- Waste disposal sites

SUPPORTING SERVICES
- Nutrient cycling
- Habitat
- Resilience
- Primary productivity
- Biodiversity
- Water circulation & exchange

REGULATING SERVICES
- Gas and climate regulation
- Waste remediation and detoxification zones
- Biological regulation

CULTURAL SERVICES
- Educational
- Scientific
- Aesthetic
- Existence / Bequest

Some key deep-sea ecosystem goods and services (summarized from Armstrong *et al.*, 2012)

A call from industry for fundamental deep-sea research

In a stakeholder consultation (103 responses from 16 countries), 95% of respondents, including industry, reported fundamental deep-sea research as the highest priority for informing future activities in the deep sea. A key knowledge gap identified by many stakeholders was the need for baseline knowledge on biodiversity and ecology, ecosystem functioning and connectivity, spatial and temporal variation in deep-sea ecosystems and resilience of deep-sea species to pressures. Long-term monitoring and sampling of fauna and the surrounding environment was seen as an integral part of impact monitoring. There was also a call for further mapping of the seabed, including habitat mapping, together with the pooling of bathymetry and related data into publicly-available data centres.

Credit: Alex Rogers

FISHERIES

40% of the world's fishing grounds are now deeper than 200m. Yet there is limited commercial value for most deep-sea fish and many are long-lived (some more than 100 years) with slow reproductive strategies, making them exceptionally vulnerable to overexploitation. There is growing scientific evidence to limit bottom trawling to the upper 600m of the ocean in order to conserve biodiversity whilst minimizing commercial impact.

Knowledge gaps include:

- Resilience and life cycles of targeted fish and non-target (bycatch) species and the ecosystems they live in;
- Strengthening of the use of social-ecological data and research to provide an effective evidence base to underpin an ecosystem approach to fisheries management.

Credit: MARUM

MARINE MINING

This sector is still in an exploration phase. However, the first industrial mining operation for seafloor massive sulphides within the EEZ of Papua New Guinea is planned for 2018. There is also considerable interest in the mining of manganese nodules in the Clarion Clipperton Fracture Zone of the Pacific Ocean and the exploitation of methane hydrates, although the technology for industrial scale exploitation is not yet available and major concerns exist about the potential environmental impact of such activities.

Knowledge gaps include:

- Resource evaluation, study of ore and gas hydrate formation processes, exploration and mapping of the deep seabed, as well as mining areas;
- Development of minimum impact extraction technologies;
- Baseline knowledge to support development of appropriate Environmental Impact Assessments and an effective regulatory framework.

Credit: Greenpeace / Gavin Newman

BLUE BIOTECHNOLOGY

There is growing interest in the use of organisms found in deep-sea environments as a source of bioactive compounds which could be used to generate new drugs, nutraceuticals and industrial products.

Knowledge gaps include:

- Which organisms from which deep-sea environments present the greatest potential for biotechnology research?
- Which methodologies and technology developments can maximize potential for biodiscovery and minimize possible impacts from biomass sampling (e.g. synthetic biology)?
- How can benefits derived from biodiscovery based on organisms collected in ABNJ be shared in an equitable manner without inhibiting biotechnology research?

Credit: FMC Konsberg

ENERGY: OIL AND GAS, RENEWABLES

Around a third of oil and gas extracted worldwide comes from offshore sources and experts predict that by 2015, as much as 12% of oil will be extracted at depths greater than 200m, compared to 2% in 2001. Industries are also investing in renewable energy opportunities including floating wind and deep-ocean turbines and Ocean Thermal Energy Conversion (OTEC). However, all are still in the concept or pilot stage.

Knowledge gaps include:

- Advanced technologies to support the development of renewable ocean energy opportunities and the safe extraction of oil and gas from deep-water wells;
- Assessing human impacts of both standard operations and the risk of oil spills, and safely and environmentally decommissioning deep-sea structures;
- Understanding the impacts of cold nutrient rich waters on surface productivity, e.g. to optimize OTEC.

Achieving Ecosystem-Based Management of the deep sea

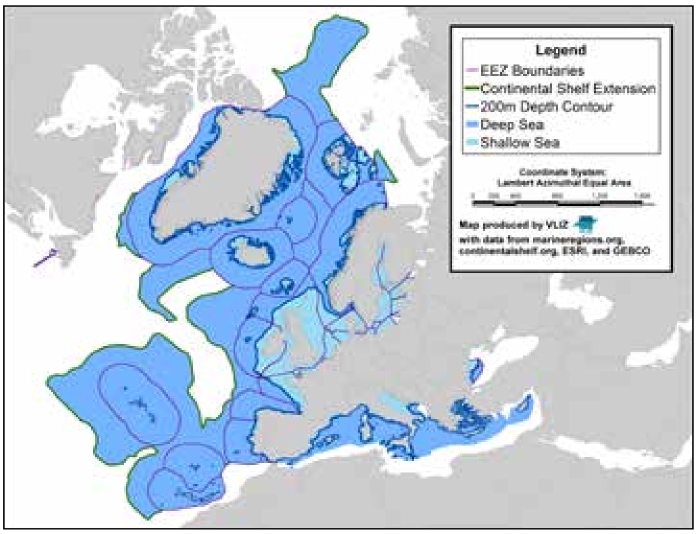
Out of sight, out of mind?

The industrialization of the deep sea and increased inputs of anthropogenic materials into marine ecosystems now mean that the footprint of impacts extends over most of the global ocean and is clearly evident in the deep sea. Commercial exploitation activities in the deep sea remain highly contentious, particularly regarding the potential risks and environmental impacts associated with such activities and the current lack of adequate regulation, risk assessment, and technologies for dealing with incidents such as oil spills. In addition, the deep sea has shown signs of long-term impact and slow recovery from disturbance, even after periods of more than 20 years.

Illegal, unreported and unregulated fishing (IUU fishing) remains an evident problem that continues to place both fish stocks and ecosystems at risk. This issue is particularly pertinent for deep-sea fisheries which target some of the most vulnerable and relatively small stocks that are often localized to specific features (e.g. seamounts) in remote areas. Aside from the obvious environmental impacts, the additional challenges for regulation and management of these deep-water fisheries, some of which benefit from government subsidies, rarely justify the commercial benefits.

Good Environmental Status in the deep sea

The European Union already has a progressive approach to ecosystem-based management through the Integrated Maritime Policy and, specifically, the Marine Strategy Framework Directive (MSFD). However, there is currently a lack of standards for offshore and deep waters and a harmonized methodology at EU level is needed. Understanding and quantifying drivers, pressures and impacts in the deep sea, together with cumulative impacts, is a crucial step towards developing a comprehensive set of environmental targets and associated indicators that can be used to extend the concept of Good Environmental Status (GES) to the deep sea and to inform conservation and management, including the identification of Special Areas of Conservation and the design of Marine Protected Area networks.



Credit: VLIZ

Map highlighting deep-sea waters within European national jurisdictions (not including outermost regions). Blue lines indicate the 200m depth contour. Purple lines represent the Exclusive Economic Zone (EEZ) boundaries. The outer delimitations (green lines) represent the claimed Extended Continental Shelves.

[1] Notably the preparation of a new Implementing Agreement under the United Nations Convention on the Law of the Sea (UNCLOS) and development of the International Seabed Authority (ISA) regulatory framework for seabed mining.

Credit: NOC, Southampton

Credit: Giovanni Marola

Credit: Australian Maritime College

a) Northern Rockall Bank, showing coral rubble and trawl marks
b) Deep-sea red coral, *Corallium* sp.
c) Orange roughy and bycatch on the deck of a research trawler

Research drivers for deep ocean governance

A significant proportion of Europe's marine territory is deeper than 200m, especially when outermost regions and pending submissions to increase Continental Shelf Extensions are taken into account. In addition, 64% of marine waters are in ABNJ, much of which is deep sea, and considerable challenges remain 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"). **Achieving greater transparency, open data access and appropriate governance of deep-sea resources requires a stronger science advisory process** including adequate representation of scientific expertise contributing to developing legal and policy frameworks addressing deep-sea resources[1].

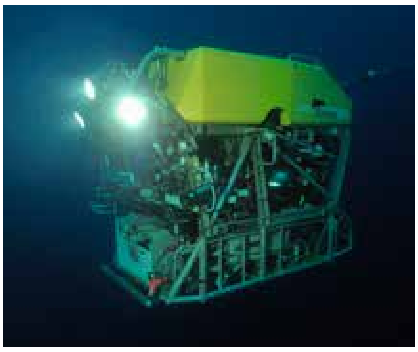
Scientific knowledge is essential to determine baselines, observe and understand changes in the marine environment and the pressures driving those changes, and develop ecosystem restoration protocols. Some areas of international ocean governance that could benefit from better availability of integrated deep-sea scientific knowledge include, *inter alia*:

- **Improving Environmental Impact Assessment (EIA) procedures.** EIAs are an essential mechanism for regulating exploitation activities in the deep sea. To effectively conduct EIAs requires fundamental knowledge of marine ecosystems and of the drivers, pressures and impacts affecting these ecosystems;
- **Sustainable exploitation of marine resources.** This requires interdisciplinary knowledge of the geological, biological, chemical and physical characteristics of the deep-sea environment to assess the resilience of biological resources and inform decisions on fisheries quotas, to identify sensitive habitats and ecosystems, and to support conservation and marine spatial planning in the deep sea;
- **Improving resilience to natural disasters.** This requires marine knowledge of the seafloor and sub-seafloor, reducing risk and uncertainty.

Building a 21st century deep-sea research and technology capability

European investment in deep-sea research

Europe is currently at the forefront of global deep-sea research and a world leader in scientific publications in this domain. Over the past three decades there have been significant levels of annual investment in marine and maritime research at both EU and national level. However, despite a clear demand for knowledge from public and private stakeholders, only a small fraction is dedicated to deep-sea research[2]. In addition, in many countries, national funding for deep-sea research is decreasing. Falling levels of funding will inevitably affect the opportunities and training available for the next generation of researchers, resulting in a loss of expertise in deep-sea research and related fields across Europe.


Credit: Ifremer


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

Left: ROV *Victor* in the Atlantic Ocean
Right: North Atlantic hooded seal fitted with an ocean sensor pack.

Deep-sea research themes

Based on a review by deep-sea experts and wider stakeholders, key research questions that require urgent attention include:

- What are the patterns of biodiversity in the deep sea?
- What are the patterns of connectivity between deep-sea ecosystems and between the deep and shallow waters?
- How do deep-sea ecosystems function and how can we quantify the ecosystem services they provide?
- How do human activities impact on the deep ocean and how can we best monitor such impacts?
- What is the role of deep-ocean circulation in transporting material (e.g. organic matter and pollutants) in the ocean?
- What biogeochemical processes are critical controls on elemental cycles in the deep sea?
- How are deep-sea mineral resources formed and what is their distribution?
- What is the threat posed by deep-sea marine geohazards to industry and humankind?

Connecting the deep-sea with society

The transition to sustainability requires a transformational shift towards more holistic and systemic science. To support such a shift, capacities needing further development include:

- Social science, legal and economic research;
- Improved mechanisms to achieve inter- and transdisciplinary approaches to complex research questions;
- Knowledge for assessments, indicators and baselines;
- Effective interfaces between science, policy, and society;
- Bridging the gap between academia and industry;
- Training the current and future generations of scientists and practitioners across science, policy and management;
- Deep ocean literacy and citizen science.


Credit: DSCC

Deep-sea conservation outreach project at Warsaw Zoo.

Developing a world class deep-sea research infrastructure

Europe has world-leading capabilities in maritime infrastructure and technology development which represents a significant opportunity for the blue economy. However, availability of large infrastructure (e.g. ocean-going ships) and state-of-the-art sampling and observing platforms (e.g. gliders, remotely operated vehicles) is not matching the growing requirements of the deep-sea scientific and wider stakeholder community, for example to underpin marine monitoring (MSFD) and blue growth. It is critical that the current infrastructure for deep-sea research is maintained and, where possible, increased.

Emerging technology areas driving deep ocean exploration include:

- "Ultra deep" platforms and sensors (below 2000m);
- Autonomous and miniaturized ocean sensors for biogeochemical, biological and ecosystem variables;
- Machine-to-machine communication and underwater positioning systems;
- LED-technology driving advancements in underwater optical communication;
- 3D habitat heterogeneity mapping and visualization;
- *In situ* molecular tools and ecological experiments to investigate unknown biodiversity and functions;
- The use of animal platforms as novel ocean observatories.

A comprehensive strategy is also required for a **Deep Ocean Observing System**, identifying essential ocean variables for the deep sea, building on developments coordinated by the Global Ocean Observing System (GOOS) and the Framework for Ocean Observations.

New approaches to information and data management, storage and architecture are also required, e.g. machine learning and computational analyses, to deal with the potential dramatic increase in the gathering of image data (video and stills), 2D and 3D seismic data and molecular data.

[2] Between 2003-2014, European public funding for marine and maritime research was on average 25 times higher than for deep-sea research (based on an assessment of open-source data from EurOcean Knowledge Gate 2.0 including EC Framework 6 and 7 programmes, LIFE and LIFE+ and Interreg. See EMB Position Paper 22 for more details).

Recommendations and key action areas

Increasing our fundamental knowledge of the deep sea

Science-based knowledge, expertise and skills are the enablers for all economic activities in the seas and oceans. However, in the deep sea, technology development and commercial interest is moving at a pace that outstrips ongoing 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. There remain serious deficiencies in the basic knowledge required for sustainable development and ecosystem-based management of the deep sea. In particular, a greater understanding of deep-sea ecosystems is necessary to establish environmental baselines, inform environmental impact assessments and underpin innovative, science-based governance models for managing deep-sea resources. Stakeholders have identified a critical lack of knowledge on biodiversity, ecosystem functioning, resilience and connectivity of the whole deep sea and the need for a better understanding of the links and interactions within and between the water column and seabed. Further gaps identified include mapping deep-sea terrain and habitats; 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.

Other key action areas include:

- **Assessing drivers, pressures and impacts in the deep sea** as a crucial step towards developing a comprehensive set of environmental targets and associated indicators for achieving good environmental status in the deep sea, particularly in ABNJ;
- **Promoting cross-disciplinary research and cross-sector research collaboration to address complex deep-sea challenges,** bringing together natural and social sciences, marine law and governance with expertise from the public and private sectors;
- **Innovative funding mechanisms,** including public-private partnerships, to address knowledge gaps, establish or maintain long-term time-series and advance internationally coordinated mapping of the deep seabed;
- **Advanced technology and infrastructure for deep-sea research and observation,** supporting industry-academia collaborations to drive innovations in platform and sensor design and improved computational modelling capacities;
- **Fostering human capacities in deep-sea research,** promoting and expanding training and career opportunities for scientific, technical and socio-economic research, policy and industry, and embedding cross-disciplinary, problem-oriented approaches in the training of early career researchers;
- **Promoting transparency and open data access and appropriate governance of deep-sea resources,** strengthening the science advisory process to develop legal and policy frameworks addressing deep-sea resources and deep-sea ecosystem restoration protocols;
- **Deep-ocean literacy to inspire and educate society to value deep-sea ecosystems, goods and services,** embedding ocean literacy approaches into deep-sea research projects and promoting science communication.

Taken as a coherent whole, these actions can form the basis for a European integrated framework to underpin sustainable development of deep-sea activities, support blue growth and contribute to developing a forward-looking strategy for ocean governance in Europe and beyond. Where possible, these activities should be done in a timeframe that will complement and keep track with industrial expansion in the deep sea.

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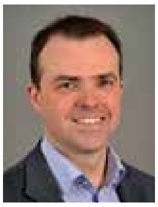

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Keywords

deep sea, deep ocean, habitat, ecosystem, biodiversity, ocean governance, blue growth, blue economy, offshore industry, ocean technology, ocean observation.

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Suggested further reading

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EMB policy briefs provide a high-level summary of the key research needs and priorities on topics of strategic and emerging importance in seas and ocean science from a European perspective. Policy briefs are normally (but not always) summary versions of full EMB position papers, produced by EMB expert working groups.

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

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