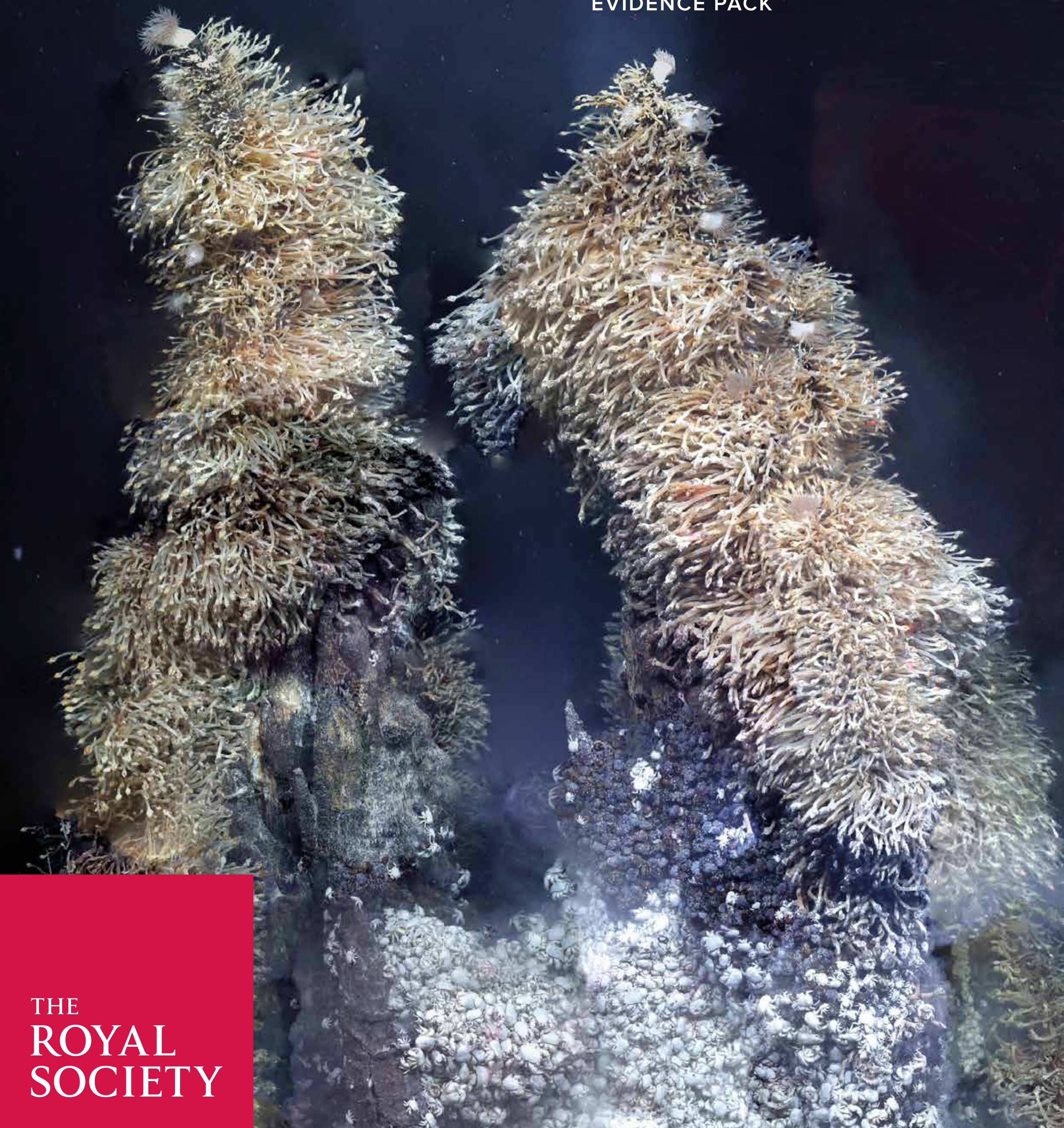
Future ocean resources

Metal-rich minerals and genetics

EVIDENCE PACK



THE ROYAL SOCIETY

This Royal Society evidence pack draws on the expertise of Fellows of the Royal Society, and other scientists with relevant expertise, to provide a rapid and authoritative synthesis of current evidence regarding two novel classes of marine resource. While not presenting any specific recommendations, we lay out the current state of knowledge and the questions that remain to be answered.

This work originated from a project to inform the Foresight Future of the Sea project undertaken by the UK Government Office for Science.

List of abbreviations used throughout report:

ABNJ Areas Beyond National Jurisdiction
CCZ Clarion-Clipperton Zone
EEZ Exclusive Economic Zone
ISA International Seabed Authority
MGR Marine Genetic Resources
MPA Marine Protected Area
UNCLOS United Nations Convention on the Law of the Seas

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Cover image
'Carwash' hydrothermal vent chimney, E9 Vent Field, East Scotia Ridge, Southern Ocean, latitude 60 degrees South, depth 2400 metres; discovered during Voyage 42 of RRS James Cook in February 2010. Mosaic image obtained by the UK's deep-diving remotely operated vehicle Isis, using precision seafloor videography techniques developed during the NERC Chemosynthetic Ecosystems of the Southern Ocean (ChEsSo) research programme (Marsh *et al.*, 2012, Deep-Sea Research II, 92: 124-135); all animal species shown were new to science in 2010. © University of Southampton.

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Introduction to minerals and genetic materials as future ocean resources

The ocean provides humanity with many resources and is an important source of food, transport, energy and recreation. In recent years there has also been rising interest in two more novel classes of ocean resource with potential societal and economic benefits: minerals from mining on the deep-ocean floor, and novel chemicals – particularly drugs – derived from the genetic diversity of marine life.

Sustainable use of these novel resources could have significant benefits, but involves interaction with a natural environment that is challenging to access and less well understood than that on land. Accessing new sources of metal-rich minerals could help address concerns about the supply of metals considered at risk of supply disruption because of increasing use and geopolitics. The high biodiversity in the ocean, including species adapted to a range of extreme environments, provides a substantial resource for development of new chemicals, including antibiotics and cancer treatments. In the deep ocean particularly, these resources are often co-located which raises questions about conflict of access.

These two resources differ, in that exploitation of genetic information is likely to have minimal environmental impact, while mining may have substantial environmental consequences. But these resources are also environmentally linked; any loss of marine biodiversity imposed by mining will decrease the potential for discovery of useful biological materials.

Exploration for minerals and new sources of chemicals from the oceans is now active in many parts of the world, and it is likely that activity will increase significantly in the coming years. Although they are currently marginal activities, advances in technology and forthcoming clarification of international law mean we may soon have the capability to exploit these resources on a larger scale. The economics of both resource classes are also presently uncertain and changeable, but both have the potential to grow into multi-billion pound industries.

Assessing the potential and challenges of exploitation of both these novel resources will rely on improved understanding and surveying of the ocean environment. Despite significant scientific research and discovery, and many years of use, the ocean environment remains relatively unknown and undisturbed, particularly in the deep ocean where mineral and genetic resources are thought to be abundant. Many new marine species are discovered every year, and potential mineral wealth is highly uncertain in most areas.

This report explores these novel marine resources, including a summary of the economic, technological and environmental considerations that will be fundamental in determining the extent to which they are exploited.

Left
© JackF.

SUMMARY

- Advances in understanding and technology combined with legislative change mean that deep-sea mining and marine genetic resource utilisation are likely to increase significantly within the next ten years.
- These resources share challenges in complexity of access, and can be co-located, but differ in the environmental impact that their access would involve.

MINERALS

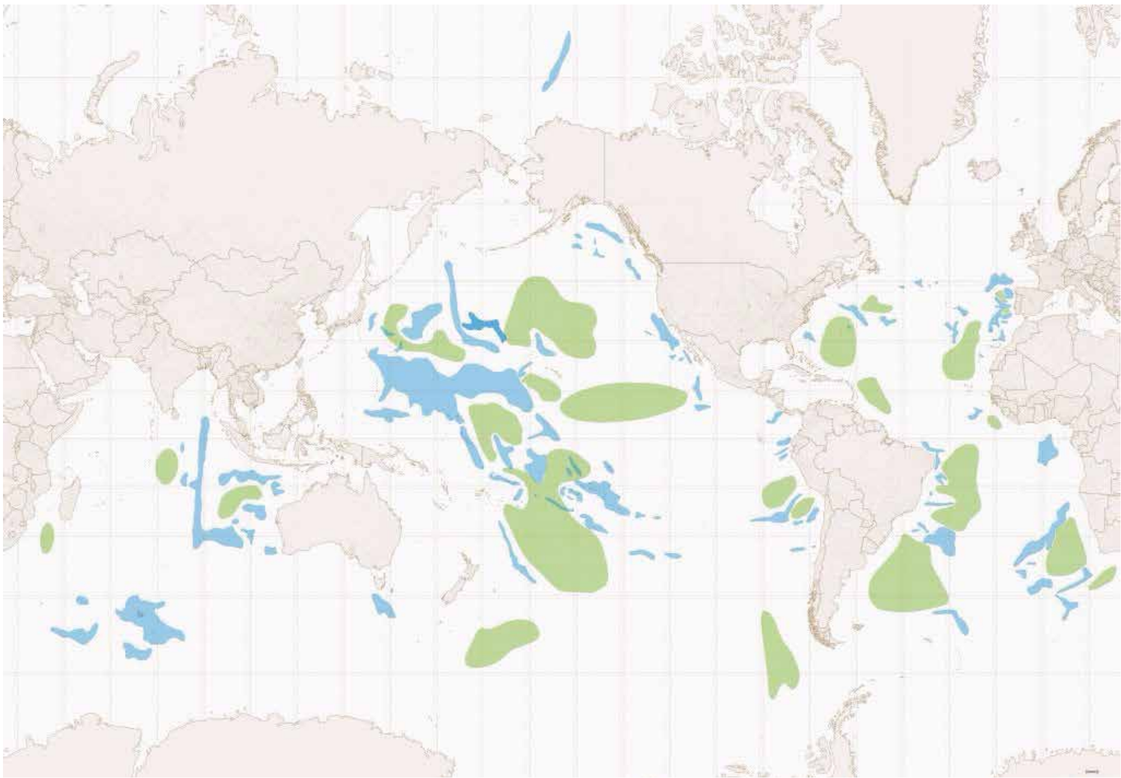
- Significant deposits of metal-rich minerals are known to exist on the sea floor.
- Commodity price changes, technological progress, and changes in international agreements are likely to make deep-sea mining possible.
- Exploration activity is in progress. Exploitation of this resource is likely to begin within the next ten years.
- Environmental impact of deep-sea mining is likely to be significant.
- Regulations for exploitation beyond national jurisdictions are now in development. Processes to predict, monitor and limit damage are yet to be established, but will play an important role in this process.

GENETIC MATERIALS

- Ocean environments hold promise for useful chemical/biological compounds for drugs or household products.
- A small number of marketed products already exist from marine genetic resources, with some showing significant economic returns.
- The market could soon increase due to advances in surveying and gene sequencing technology.
- Legal considerations within national waters are well agreed, but the regulatory status of marine genetic resources outside national jurisdiction is not settled and is subject to active international discussion.

FIGURE 1

Global permissive areas for polymetallic nodules and ferromanganese crusts. Permissive areas are here defined as those with conditions appropriate to allow high-grade deposits and neither guarantee economically viable deposits nor cover all possible deposit sites.



KEY

- Ferromanganese crusts
- Polymetallic nodules

Data courtesy of James R Hein, USGS.

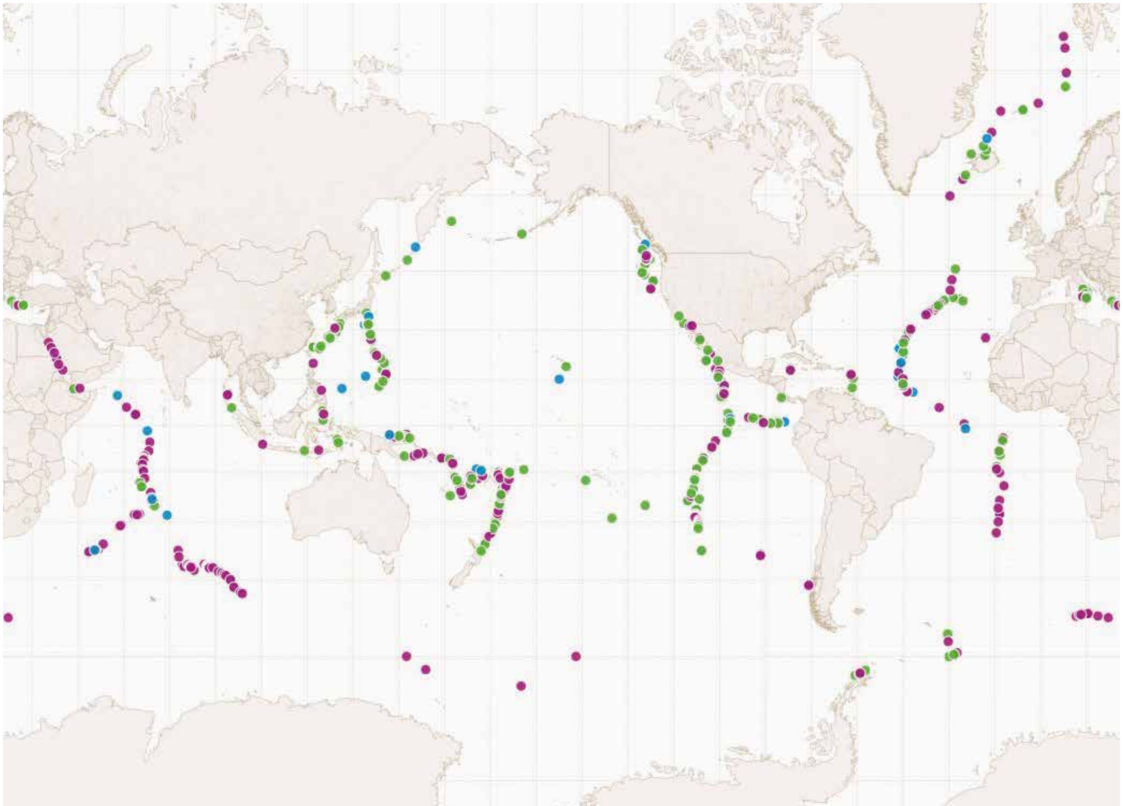
Image created using: © CARTO.

FIGURE 2

Sites of known active and inactive hydrothermal vents on the mid-ocean ridges. These are often sites of potential mineral resources and specific marine ecosystems. In many areas, lack of vents on the map reflects lack of exploration rather than their physical absence, though active vents are expected to be found in areas of active volcanism.

KEY

- Active, confirmed
- Active, inferred
- Inactive

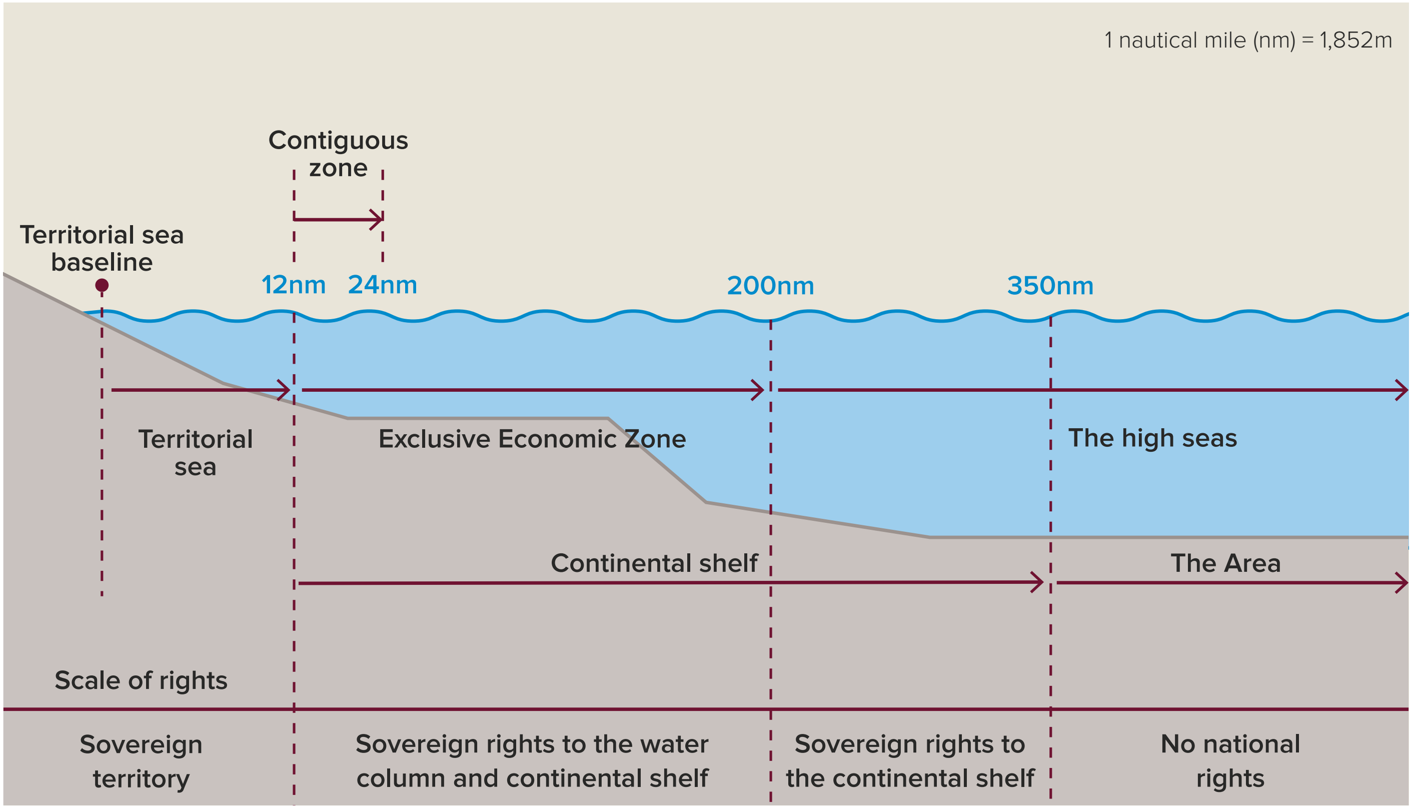


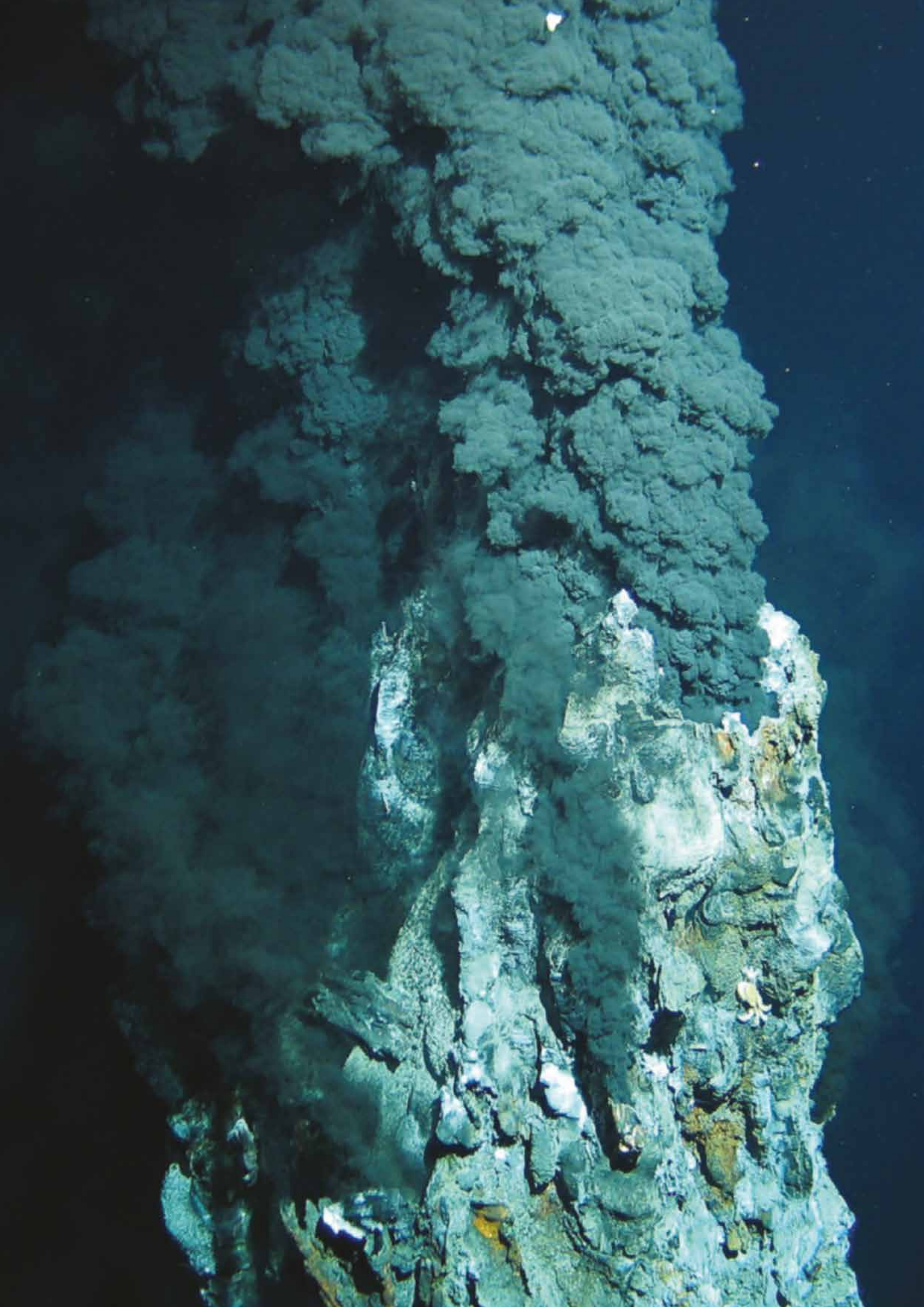
Data courtesy of InterRidge.

Image created using: © CARTO.

FIGURE 3

Jurisdictional zones from a nation's coast. For the purposes of this report, 'national jurisdiction' is considered to extend to the limit of the Exclusive Economic Zone unless otherwise stated.





Chapter one
Deep-sea minerals

Left
Black smoker on the mid atlantic ridge south of the equator at about 3,000m depth. © ROV KIEL 6000; Helmholtz-Zentrum für Ozeanforschung Kiel (GEOMAR).

Deep-sea minerals

1.1 Introduction to deep-sea minerals

The deep-sea environment and potential metal resources

The deep-sea floor covers about 60% of the Earth's surface[1], hosting a diverse spectrum of geological environments, geomorphological features and ecosystems. Our knowledge of the deep sea is very poor compared with shallower marine and terrestrial environments, with only about 5% having been explored at the scale necessary to identify mineral resources[2].

The shallow seabed is already an important source of aggregates (eg sand or gravel), diamonds and hydrocarbons. While metal resources on the deep-sea floor have been known of for more than a century, current demand is met from mines on land. It is speculated that the sea floor may contain a metal endowment proportional to its area[3].

Although the deep sea offers huge potential for the extraction of metals, a lack of exploration and data results in great uncertainty about the total size of the resource and its economic value. There is similar uncertainty about the environmental implications of exploiting this resource.

The concept of deep-sea metal mining was first proposed in the 1960s, and the subsequent decades saw numerous government-funded activities and the development of experimental polymetallic nodule recovery systems. Despite this initial optimism, progress has been slow since the 1980s, in part due to an adequate supply of metals from land-based mines, unfavourable economic conditions, and the inherent technological and environmental challenges.

1. Glover AG, Smith CR. The deep-sea floor ecosystem: current status and prospects of anthropogenic change by the year 2025. Environ Conserv. 2003 Sep; 30(3): 219–241. Available from: doi: 10.1017/S0376892903000225.
2. *Op. cit.*, note 1.
3. Hannington M, Jamieson J, Monecke T, Petersen S, Beaulieu, S. The abundance of seafloor massive sulphide deposits. Geology. 2011 Oct; 39(12): 1155–1158. Available from: doi: 10.1130/G32468.1.

Present activity

Over the last decade, deep-sea mining has received renewed interest from governments, policymakers, researchers, investors, and resource companies. No commercial deep-sea mining in international waters has yet taken place, but plans to exploit sea-floor metal deposits have been announced, and the significant global interest is evident from:

- increased deep-ocean mineral exploration activity. (To date the International Seabed Authority (ISA) has approved 26 15-year contracts for exploration for deep-sea minerals)[4]
- granting of the environmental permit and seabed mining lease (2009 – 2011) for deep-sea mining operations off the coast of Papua New Guinea[5]
- ISA regulations issued for 'Prospecting and Exploration' in The Area (see Figure 3) (2000, 2010, 2013)[6]
- government-funded research and resource evaluation programmes in a number of developed countries
- recognition by the European Commission and funding of associated research programmes
- proliferation of research, peer-review publications, popular media, and NGO coverage.

Why now?

Minerals are vital to support economic growth and the functioning of modern society. Increased concern around mineral resource security due to geopolitics and a predicted medium- to long-term rise in metal demand[7] are focusing attention on deep-sea mining. There is particular concern about 'critical' metals (eg rare earth elements, cobalt, tellurium) used in high technology and clean energy applications[8,9]. Some deep-sea deposits may be highly enriched in these metals[10].

Advances in deep-sea technology since mining was first proposed also make deep-sea mineral exploitation increasingly feasible.

Opportunities

The uncertainty and knowledge gaps spanning the entire value chain for deep-ocean minerals, from resource discovery and evaluation through to extraction technologies and the environmental impact of mining, result in significant opportunities for research and innovation.

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4. International Seabed Authority. Deep seabed minerals contractors. 2016 [cited 2017 Feb 24]; Available from: https://www.isa.org.jm/deep-seabed-minerals-contractors
5. Nautilus Minerals. PNG. 2017 [cited 2017 Feb 24]; Available from: http://www.nautilusminerals.com/irm/content/png.aspx?RID=258
6. International Seabed Authority .The Mining Code. 2016 [cited 2017 Feb 24]; Available from: https://www.isa.org.jm/mining-code/regulations
7. Lusty PAJ, Gunn AG. Challenges to global mineral resource security and options for future supply. Geological Society – Special Publication. 2014 Jun; (393): 265–276. Available from: doi: 10.1144/SP393.13.
8. House of Commons Science and Technology Committee. Strategically important metals. Fifth report of Session 2010–2012. London: The Stationery Office; 2011.
9. European Commission. Critical raw materials for the EU: Report of the ad-hoc working group on defining critical raw materials. Brussels: European Commission; 2014.
10. *Op. cit.*, note 5.

1.2 Geology of the deep-sea floor and potential metal resources

The major metal resources in the deep oceans are:

- polymetallic nodules: distributed across the deep seabed (3,500 – 6,500m)
- cobalt-rich ferromanganese crusts: found on hard sediment-free substrates such as seamounts (800 – 4,000m)
- polymetallic sulphides: found in areas of active or formerly active hydrothermal vents (1,000 – 5,000m).

Polymetallic nodules and cobalt-rich ferromanganese crusts are both precipitated very slowly from seawater over tens of millions of years and are widely, but sparsely, distributed across significant areas of the sea floor. Polymetallic sulphides are, in contrast, precipitated at hydrothermal vents which are active at most for tens of thousands of years and are therefore localised at individual active or former hydrothermal vent sites in regions of volcanic activity.

Polymetallic nodules

Polymetallic nodules are typically found as 1 – 12cm diameter manganese and iron-rich concretions over large areas of the deeper ocean floor (Figure 4). They are deposited slowly over millions of years from pore fluids in the sediments and seawater. Metals of economic interest include manganese (circa 30%), nickel, copper (circa 1%), and potentially a range of minor metals (eg molybdenum, cobalt, yttrium, tellurium) which may be economic when co-produced.

Mining polymetallic nodules would require excavating or dredging areas of the surface of the seabed and separating nodules from the sediment. This activity may damage resident ecosystems and emit plumes of sediment potentially toxic to marine life[11].

The Clarion-Clipperton Zone (CCZ) in the central Pacific Ocean has a mean abundance of nodules of circa 7kg/m^2 [12,13] and is currently the primary focus of international nodule mining (see Case Study C). Because polymetallic nodules are found in the deeper parts of the oceans, 80% of this resource is outside national jurisdictions[14].

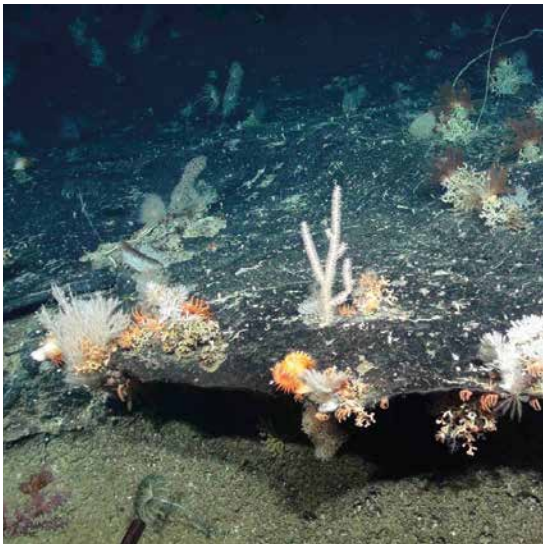
11. Managing Impacts of Deep-Sea Resource Exploitation (MIDAS). (See http://www.eu-midas.net/ accessed 27 February 2017).
12. Schmidt CW. In Search of 'Just Right': The Challenge of Regulating Arsenic in Rice. Environ Health Perspect. 2015 Jan; 123(1): 235–241. Available from: doi: 10.1289/ehp.123-A16.
13. A geological model of polymetallic nodule deposits in the Clarion-Clipperton fracture zone. Kingston: International Seabed Authority; 2010.
14. Petersen S, Krätschell A, Augustin N, Jamieson J, Hein JR, Hannington, MD. News from the seabed – geological characteristics and resource potential of deep-sea mineral resources. Mar Policy. 2016 Mar; (70): 175–187. Available from: doi: 10.1016/j.marpol.2016.03.012.

FIGURE 4

Seafloor covered in nodules (circa 30mm in diameter) with large deep-water prawn (*Bathystylodactyloidea*), Clarion Clipperton Zone. Image shows an area of seafloor approximately 500mm across.

FIGURE 5

Typical sessile fauna on an area of ferromanganese crust pavement on the Tropic Seamount.



© Natural Environment Research Council (NERC).

FIGURE 6

Active hydrothermal vents at the Beebe Vent Field, Cayman Trough (5,000m depth).

© University of Southampton.

Cobalt-rich ferromanganese crusts

Ferromanganese crusts are deposited directly from seawater onto hard rock substrates. They form encrustations on the sea floor up to 25cm thick (Figure 5) and grow at rates of 1 to 5mm/Myr over tens of millions of years. They are mostly found on the flanks of seamounts (extinct underwater volcanoes) and so are often in the Exclusive Economic Zone (EEZ) of island states[15]. Like polymetallic nodules, they contain significant iron, manganese (circa 20%), cobalt, nickel and minor metals.

The variable thickness of the crusts, being attached to a hard rock substrate, and the more rugged topography will make the mining of these deposits more challenging than polymetallic nodules.

Polymetallic sulphides

Polymetallic sulphides (sometimes called seafloor massive sulphides) are deposited where high temperature fluids vent from the seafloor above active magmatic systems. At these sites, cold seawater penetrates the crust to depths of up to 2km where it is then heated by magma. The resulting hot brines strip metals and sulphur from the rocks before being expelled into the ocean. Where the hot fluids emerge from the sea floor they form spectacular sulphide chimneys, termed black smokers, which emit dark sulphide-bearing fluids (Figure 6). An individual hydrothermal vent site may be active for thousands to tens of thousands of years and result in accumulations of sulphides of up to 15 million tonnes. However only 12% of known deposits are more than 2 million tonnes and the median size is 70,000 tonnes[16].

15. *Op. cit.*, note 14.

16. Hannington M, Jamieson J, Monecke T, Petersen S, Beaulieu, S. The abundance of seafloor massive sulphide deposits. Geology. 2011 Oct; 39(12): 1155–1158. Available from: doi: 10.1130/G32468.1.

FIGURE 7

A weathered, inactive sulphide chimney encountered during a HyBIS dive on New Mound, TAG, North Atlantic.

© NERC.

Knowledge of the metal composition of polymetallic sulphides is largely restricted to surface samples, which have indicated economic quantities of copper, zinc, lead, gold and silver[17] as well as minor elements (eg bismuth, cadmium, gallium, antimony)[18].

The localised nature of polymetallic sulphides may make mining logistically simpler than for nodules, as ore can be excavated and extracted to the surface from a comparatively small area. This constrained area may limit the impact to the wider ocean ecosystem, but active vents in particular are often sites of distinct ecosystems which could be damaged by mining.

At present only polymetallic sulphides at extinct vent sites (Figure 7) are being considered for mining. These deposits are likely to be far more numerous than active sites, but their discovery would need dedicated exploration using appropriate geophysical tools.

17. *Op. cit.*, note 16.

18. Secretariat of the Pacific Community. Deep Sea Minerals. Sea-floor massive sulphides: a physical, biological, environmental and technical review. Arendal: GRID-Arendal; 2013.

1.3 Minerals and resource efficiency

Magnitude of the resource

Preliminary estimates of the scale of deep-sea mineral resources suggest that the deep seabed hosts large quantities of metals. If proven to be economically viable it has been suggested that there are quantities of specific metals which could meet global needs for the foreseeable future[19]. For example, preliminary estimates suggest that billions of tonnes of copper may exist on the deep-sea floor[20], which if accessible could meet global copper demand for centuries to come.

Considering only the polymetallic sulphides on the 'easily accessible' ocean floor, there are estimated to be 30 million tonnes of copper and zinc. This is comparable to the annual production of these metals from all land-based mines[21,22], with an estimated *in situ* value of USD125 billion at 2016 metal prices.

Accurate determinations of the total amounts of metal and its recoverability are extremely difficult. Until we have a better understanding of the composition and accessibility of deep-sea mineral deposits they cannot be relied upon as a resource. Current knowledge gaps hinder direct comparisons with land-based deposits and are an impediment to investment in the deep-sea mining sector.

Security of supply of metals

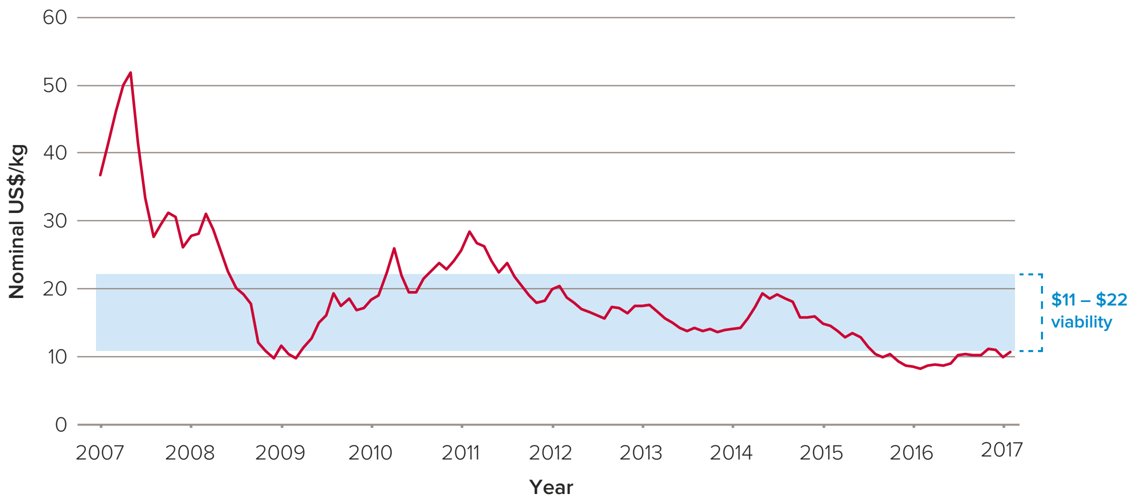
Population increase and economic development raise global concerns over the long-term availability of secure and adequate supplies of minerals[23,24]. Of particular concern are 'critical' metals[25], which are of growing economic importance, owing to their increasing use in high technology applications and low carbon technologies (eg platinum group metals in catalytic converters for cars, tellurium in photovoltaic cells, and rare earth elements in batteries and motors for electric vehicles) and the likelihood of supply shortage (principally resulting from geopolitics and production concentration in a few countries).

Exploiting the critical metals in deep-sea metal deposits could contribute to meeting future demand and diversifying supply. For example ferromanganese crusts in the Pacific are estimated to contain about 22 and 7 times more tellurium and cobalt respectively than land-based 'reserves' of these metals[26].

19. Hein JR, Mizell K, Koschinsky A, Conrad TA. Deep-ocean mineral deposits as a source of critical metals for high and green technology applications: comparison with land- based resources. Ore Geol Rev. 2013 Jun; 51: 1–14. Available from: doi: 10.1016/j.oregeorev.2012.12.001.
20. Cathles LM. Future Rx: optimism, preparation acceptance of risk. Geological Society – Special Publication. 2015 Jan; 393(1): 303–324. Available from: doi: 10.1144/SP393.6.
21. *Op. cit.*, note 16.
22. US Geological Survey. Mineral commodity summaries. [cited 2017 Feb 24]; Available from: https://minerals.usgs.gov/minerals/pubs/commodity/copper/mcs-2016-coppe.pdf
23. *Op. cit.*, note 8.
24. *Op. cit.*, note 7.
25. *Op. cit.*, note 9.
26. *Op. cit.*, note 19.

FIGURE 8

Market price of nickel and estimated economic viability (blue box) as estimated by Martino and Parson[30].



Source: Indexmundi.

The economic landscape: polymetallic nodules

Significant uncertainty in the costs of mining limit confidence in economic analyses, but estimates suggest that in certain circumstances mining of nodules and polymetallic sulphides could be economically competitive with mining on land[27]. Although there are a large number of factors affecting economic viability, metal prices will be a significant driver[28,29].

For example, according to one estimate, nickel prices in the range USD11 – 22/kg would make nodule mining economically viable at an initial rate of return of 15%[30] (Figure 8). In the last decade the nickel price has fluctuated both above and below this value.

27. *Op. cit.*, note 20.

28. Ingham PD. The economic viability of deep-seabed mining of polymetallic nodules. Canberra: Bureau of Mineral Resources, Geology and Geophysics; 1986.

29. Clark A, Lum J, Li C, Icay W, Morgan C, Igarashi Y. Economic and development potential of manganese nodules within the Cook Islands exclusive economic zone (EEZ). Honolulu: East-West Center; 1995.

30. Martino S, Parson LM. A comparison between manganese nodules and cobalt crusts economics in a scenario of mutual exclusivity. Mar Policy. 2012 May; 36(3): 790–800. Available from: doi: 10.1016/j.marpol.2011.11.008.

Furthermore a Korean study suggests that mining of polymetallic nodules with reasonable returns is possible provided the government supports the cost of research and development[31].

Some polymetallic sulphide deposits look promising in terms of the economic viability of exploitation[32] (see case studies), but extraction has yet to commence.

Metal grade and use of energy

The rate of discovery of accessible land-based metal deposits containing high metal concentrations is in decline[33]. Comminution of ore is already an energy intensive process and as ore grade declines more rock is processed to produce the same amount of metal, with associated rises in energy demand and carbon emissions[34].

Some deep-sea deposits contain metal at higher concentrations than currently mined land-based ores. For example the mineral resource estimate for the Solwara 1 polymetallic sulphide deposit indicates that the sulphide dominant part of the deposit (Case Study A) contains over 7% copper[35], significantly above the average 0.6% copper ores now utilised on land[36].

Potential benefits of deep-sea mineral extraction include:

- high-grade ores
- deposits largely exposed at the surface of the seabed
- the polymetallic nature of deposits provides a hedge against commodity price fluctuations
- portability of equipment and infrastructure
- the possibility of applying alternative extraction techniques which may require lower energy input.

Conversely, the potential magnitude and duration of environmental impacts to the deep-sea environment remain much less well understood than those from mining on land (see Section 1.5).

31. International Society of Offshore and Polar Engineers. A study on economics of development of deep-seabed manganese nodules. 1997. Available from: http://www.isope.org/publications/proceedings/ISOPE_OMS/OMS%20 1997/Proc-OMS-97-abst%20only/M97P105Ham.pdf
32. Bertram C, Krätschell A, O'Brien K, Bruckmann W, Proelss A, Rehdanz K. Metalliferous sediments in the Atlantis II deep – Assessing the geological and economic resource potential and legal constraints. Mar Policy. 2011 Apr; 36(4): 315–329. Available from: doi: 10.1016/j.resourpol.2011.09.001.
33. Beaty R. The Society of Economic Geologists. The declining discovery trend: people science or scarcity? 2010. Available from: https://www.segweb.org/SEG/Views/SEG/Views.aspx?hkey=39da3963-4fd3-46cd-9415-0f89a4519f07
34. Mudd GM. Historical trends in base metal mining: backcasting to understand the sustainability of mining. Ontario: Canadian Metallurgical Society; 2009.
35. Lipton I. Mineral resource estimate Solwara project, Bismark Sea, PNG. Golder Associates Pty Ltd; 2011. Available from: http://www.nautilusminerals.com/irm/content/pdf/SL01-NSG-DEV-RPT-7020-001_Rev_1_Golder_Resource_Report.pdf.
36. Calvo G, Mudd G, Valero A, Valero A. Decreasing ore grades in global metallic mining: a theoretical issue or a global reality? Resources. 2016 Dec; 5(4): 1–14. Available from: doi: 10.3390/resources5040036.

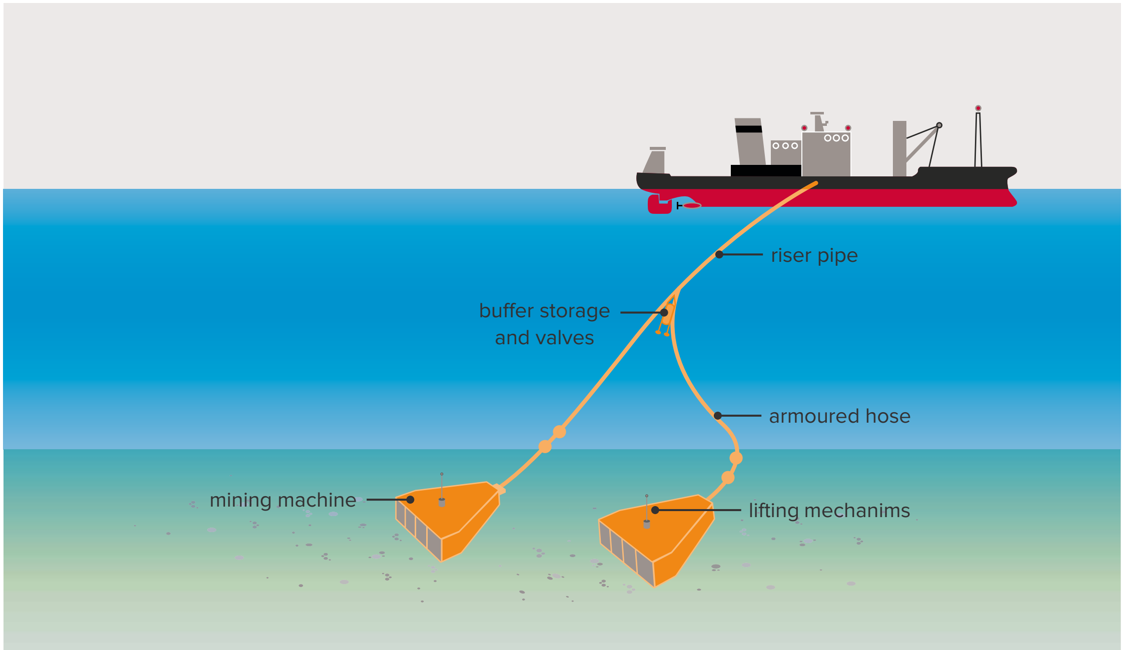
FIGURE 9

Deep-sea mining machines, designed and built by Soil Machine Dynamics for Nautilus Minerals for polymetallic sulphide mining. All three tools would be deployed on the seafloor and operated remotely from a production support vessel. The 'auxiliary cutter' (right) prepares rough terrain before deployment of the 'bulk cutter' (centre), and collection of cut material from the seafloor by the 'collecting machine' (left).

© Soil Machine Dynamics.

FIGURE 10

Diagram showing potential nodule mining methodology.



1.4 Technological assessment and barriers

There has recently been renewed interest in the recovery of metals from deep-sea mineral resources, and there is a prospect of limited commercial-scale exploitation in the near future[37]. Demonstration-scale and full-scale mining tools have been constructed and some of these have been piloted in deep sea; however, significant technological and legislative challenges remain. These challenges are set against a backdrop of volatility within the metal minerals market which has an impact on the expected rate of return, and profit margins, for mining contractors.

Current exploration and barriers to resource exploitation:

Apart from the financial, environmental and current legal uncertainty of deep-sea mineral exploitation, particularly in the areas beyond national jurisdiction (ABNJ), significant technical challenges remain for full-scale commercial exploitation.

Polymetallic nodules

As described in Case Study C, the main focus for mining polymetallic nodules is the CCZ in the Pacific Ocean.

Current exploration for nodule resources in this region is being led in Germany through the Bundesanstalt für Geowissenschaften und Rohstoffe (BGR), in France by L'Institut Français de Recherche pour l'Exploitation de la Mer (IFREMER), in the UK through UK Seabed Resources Ltd (a subsidiary of Lockheed Martin UK), and in the Republic of Korea through the central government.

Barriers to exploitation include the remoteness – the CCZ begins circa 500 to 2,500 nautical miles south and east of Hawaii – and the depth of the resource (circa 5,000m). Technological challenges include the low predicted longevity of mining tool operation in these extreme environments and the need for the development of robust riser technology to lift ore slurry to the surface. These must be addressed before commercial-scale mining can begin. Moreover the safe transfer at sea of dewatered ore slurry from the mining vessel to the bulk ore carrier also presents significant technical challenges.

Cobalt-rich ferromanganese crusts

These seamount metal mineral resources have been considered for their potential in many desk-based studies[38], but have received limited interest from industry due to challenges associated with mapping the thickness and quality/composition of the resource, and technical issues around mining crusts of variable thickness on steep faces and surfaces.

Since 2013, four contracts for the exploration of ferromanganese crusts within the ABNJ have been granted by the ISA to Russia, China, Japan and Brazil[39].

Polymetallic sulphides

The proximity of some hydrothermal polymetallic sulphide deposits to ports, their sometimes shallower depth (circa 800 – 4,000m) and rich metal composition, have made these resources attractive targets for deep-sea mining. Within the ABNJ, the ISA has approved six contracts for the exploration of polymetallic sulphides to China, South Korea, France, Russia, India and Germany[40].

37. *Op. cit.*, note 5.
38. *Op. cit.*, note 14.
39. *Op. cit.*, note 14.
40. *Op. cit.*, note 14.

High-profile interest has been generated by a Canadian company, Nautilus Minerals Inc, in the EEZ of Papua New Guinea as highlighted in Case Study A. The first three mining tools were delivered to Nautilus in 2016 and construction of the Production Support Vessel started in China in 2015.

1.5 Environmental and legal considerations

The process for regulating international deep-sea mining exists in principle through the ISA, established under the United Nations Convention on the Law of the Seas (UNCLOS), though final exploitation regulations are yet to be set. Technological uncertainties and agreement of rigorous criteria for environmental impact assessments remain a barrier to exploitation, and will inform the regulatory process.

National waters

Within national jurisdiction, environmental and fiscal agreements are determined locally. Examples of this include:

- the Nautilus Minerals Inc agreement to mine at Solwara 1 (Case Study A)
- the refusal to give Chatham Rock Phosphate Ltd mining permission in New Zealand, in part due to concerns with the environmental impact assessment[41].

Areas beyond national jurisdiction

Mining regulation beyond national jurisdiction is determined by UNCLOS and administered by the ISA. UNCLOS is legally binding only on the 166 states (and the EU) which are party to UNCLOS, which means that nearly 30 states – including most significantly the United States of America – are not legally bound by UNCLOS and are thus not governed directly by its provisions. The ISA regulates and licenses prospecting and exploration on the sea floor subject to an environmental impact assessment. As the resources on the seabed are defined as 'the common heritage of mankind', exploration licences explicitly include mechanisms for benefit sharing with less developed nations.

To date, only licences for exploration have been issued. Exploitation regulations are at an early stage of consultation. These exploitation regulations will need agreement on: requirements for environmental impact assessments; regional management plans; area-based management; monitoring, evaluation and reporting; emergency response; supervision; and enforcement. No exploitation will proceed until agreement on these requirements is reached at the ISA. Limited understanding of the deep-ocean ecosystems, and particularly of the seabed, may make it difficult for such regulations to ensure environmental sustainability with much confidence. Such environmental sustainability also relies on consideration of the combined influence on ecosystems of multiple activities, such as cable laying and fishing, in addition to deep-sea mining.

Transparent policies will be needed to ensure there is appropriate access to information and decision making[42].

41. Environmental Protection Agency. EPA refuses marine consent application by Chatham Rock Phosphate Ltd. 2015 [cited 2017 Feb 24]; Available from: http://www.epa.govt.nz/news/epa-media-releases/Pages/EPA-refuses-marine-consent-application-by-CRP.aspx

42. Ardron JA. Transparency in the operations of the International Seabed Authority: an initial assessment. Mar Policy. 2016 Jul; Available from: doi: 10.1016/j.marpol.2016.06.027.

FIGURE 11

Actinostolid anemones and mats of filamentous bacteria at the world's deepest known hydrothermal vents, 5,000m deep on the Mid-Cayman Spreading Centre, British Overseas Territories.

Environmental impacts

Terrestrial mining activity has had significant local and regional environmental impacts. These impacts are now mostly strongly regulated and mitigated against during all stages of exploration and exploitation. The deep-sea ecosystem is however, unusual, fragile, and under-studied, but provides many valuable ecosystem services[43].

Both mining and shipboard processing could have a significant, and potentially permanent, impact on local and regional deep-sea ecosystems. Harvesting of nodules from the deep-ocean, for instance, could have similarities with bottom trawling in its likely perturbation to the seafloor, depending upon the methodology used. Such bottom trawling is banned in many regions due to its negative environmental impacts, and is known to be particularly damaging below 600m water depth; significantly shallower than nodule-rich regions where mining might occur[44].

43. Le JT, Levin LA, Carson, RT. Incorporating ecosystem services into environmental management of deep-seabed mining. Deep-Sea Res Pt II. 2016 Aug; Available from: doi: 10.1016/j.dsr2.2016.08.007.

44. Clarke J, Milligan RJ, Bailey DM, Neat FC. A Scientific Basis for Regulating Deep-Sea Fishing by Depth. Current Biology. 2015 Sep; 25(18): 2425 – 2429. Available from: doi: 10.1016/j.cub.2015.07.070.

Rigorous impact assessments and monitoring requirements will be essential to limit the scale of negative impacts. However, future mining and processing mechanisms are not well constrained, resulting in high uncertainty around potential impacts.

Existing voluntary codes of marine environmental management, such as the InterRidge[45] statement of commitment to responsible research practices at deep-sea hydrothermal vents, are adhered to by the research community and could provide a starting point for mining codes of practice. These include limiting impact during sampling, no transplanting of fauna between sites, and cooperating with other interested parties to maximise sample and data sharing.

An environmental impact assessment process consists of three basic stages[46]:

1. Scoping of the mineral resource using standardised approaches.
2. A baseline environmental survey using standardised sampling methodologies.
3. A risk assessment for the local and regional ecology and environment.

This is then paired with an environmental management plan which will include monitoring plans for mining areas before and after operations.

Local, point-source, and regional distributed impacts can be significantly different. The broader impact of mining a single polymetallic sulphide site is likely to be limited, but the cumulative impact of multiple, adjacent activities is unknown and difficult to predict from pilot or lab-based studies.

Major local and long-term impacts of simulated mining of metal resources have been identified by a number of experiments[47] and include:

- polymetallic nodules: removal of the unique sea-floor habitat over a wide area, dispersion of sediment plumes from mining activity, sediment compression limiting recolonization and toxicity from substrate break-down
- cobalt-rich ferromanganese crusts: similar to nodules, but less is known. *In situ* toxicity is difficult to predict
- polymetallic sulphides: potential acute toxicity of the mining by-products and tailings, substrate disturbance, and removal of unusual geological features of potential scientific interest.

Regional impacts for all three resources include sub-lethal effects on the ecosystem and individuals, dispersion of sediment plumes, and possible bioaccumulation of metals in the ecosystem. The impact of particle plumes derived from disruption of the sea floor by the collector vehicle and by dewatering of the ore and return of material from shipboard activity may be significant, and may occur over 1 – 2km from the site of extraction[48].

45. InterRidge. InterRidge statement of commitment to responsible research practices at deep-sea hydrothermal vents. 2006 [cited 2017 Feb 24]; Available from: http://www.interridge.org/irstatement

46. Collins P, Kennedy B, Copley J, Boschen R, Fleming N, Forde J, et al. Ventbase: developing consensus among stakeholders in the deep-sea regarding environmental impact assessment for deep-sea mining. Mar Policy. 2013 Nov; 42: 334–336. Available from: doi: 10.1016/j.marpol.2013.03.002.

47. Jones DOB, Kaiser S, Sweetman AK, Smith CR, Menot L, Vink A, et al. Biological responses to disturbance from simulated deep-sea polymetallic nodule mining. PLoS ONE. 2017 Feb; 12(2): e0171750. Available from: doi: 10.1371/journal.pone.0171750.

48. *Op. cit.*, note 47.

Marine Protected Areas and designated 'Significant Areas of Particular Environmental Interest' will play an important role in conserving deep-sea ecosystems. In the CCZ, polymetallic nodule exploration is subject to a management plan which creates zones where mining will not occur, but the effectiveness of this system is not yet known, particularly in terms of connectivity and recolonisation post mining. In general, the CCZ management plan is hampered by significant unknowns in the ecology and biogeography of these unique deep-sea biological communities[49]. These uncertainties highlight the continuing importance of a precautionary approach[50] and the need for regional scale testing of mining activity impact on the environment and ecosystem function over long timescales[51]. For the effectiveness of Marine Protected Areas (MPAs) designated in areas beyond national jurisdiction, a further limiting factor is the difficulty of effective monitoring and enforcement.

Marine protected areas (MPAs)

Marine protected areas exist in waters around the world and are primarily set up to help conserve or restore significant or representative examples of marine biodiversity, including threatened or declining species and habitats. They can exist in both national maritime zones or beyond national jurisdictions (though the latter case requires a treaty or other arrangement for their establishment) and depending upon objectives will restrict a range of activities.

Worldwide, a target of the Convention on Biological Diversity is to protect 10% of coastal and marine areas by 2020, partly by designating Very Large MPAs. MPAs can only achieve full effectiveness if they are large, fully protected (including fisheries no-take zones or equivalent set-aside areas), and linked together into ecologically coherent (international) networks of protected sites. Connectivity helps ensure that multiple species and habitats can cope with climate change and other pressures like acidification, and contain meta-populations large enough to have sufficient biodiversity[52].

49. Copley JT, Marsh L, Glover AG, Huhnerbach V, Nye VE, Reid WDK, et al. Ecology and biogeography of mega fauna and macro fauna at the first known deep-sea hydrothermal vents on the ultraslow-spreading Southwest Indian Ridge. Sci Rep. 2016 Dec; 6, 39158. Available from: doi: 10.1038/srep39158.

50. Wedding LM, Reiter SM, Smith CR, Gjerde KM, Kittinger JN, Friedlander AM, et al. Managing mining of the deep seabed. Science. 2015 Jul; 349(6244): 144–145. Available from: doi: 10.1126/science.aac6647.

51. *Op. cit.*, note 47.

52. Selkoe KA, Gaggiotti OE, Treml EA, Wren JLK, Donovan MK, Toonen RJ. The DNA of coral reef biodiversity: predicting and protecting genetic diversity of reef assemblages. P Roy Soc Lond B Bio. 2017 Apr; 283(1829), 20160354. Available from: doi: 10.1098/rspb.2016.0354.

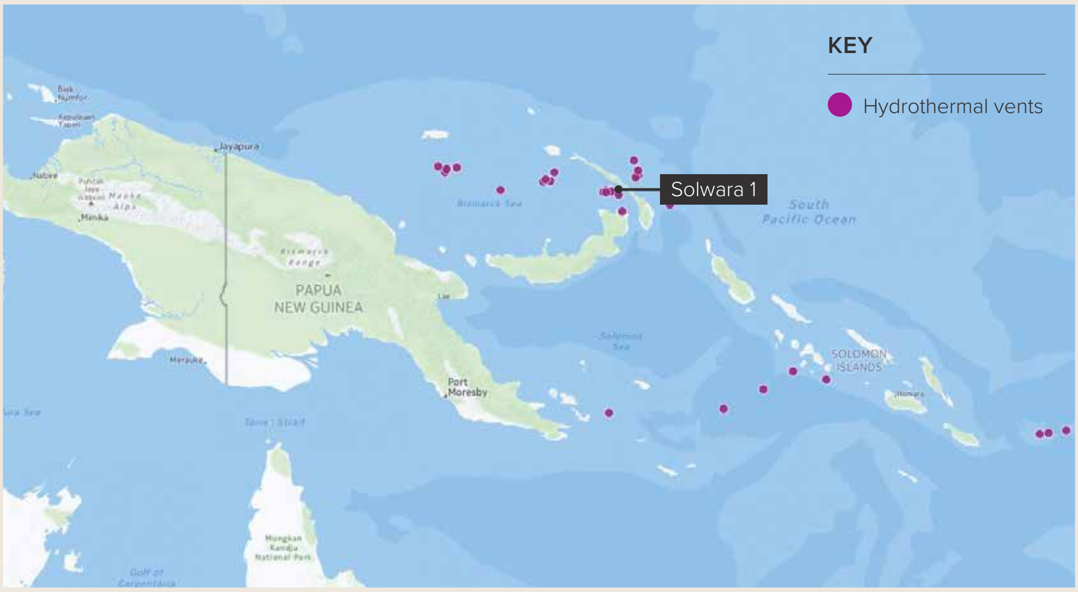
CASE STUDY A

Polymetallic sulphides in the south-west Pacific

Currently, polymetallic sulphides in the EEZs of countries in the south-west Pacific appear to represent the most likely near-term proposition for deep-sea mining, owing to their relatively shallow water depths (<2,000m) and high copper and gold concentrations, which make them economically attractive.

Solwara 1 in the Bismarck Sea, Papua New Guinea, is a relatively advanced deep-sea mining project, undertaken by Nautilus Minerals Inc, and one of only a few deep sea metal deposits with a mineral resource estimate that is compliant with an internationally recognised reporting standard[53]. The approximately one million tonne resource, rich in copper, zinc, gold and silver, has an estimated in situ value of about USD650 million. The capital costs for the offshore production system were estimated to be USD383 million[54], with sea-floor mining equipment manufactured by Soil Machine Dynamics Ltd (UK).

Although Solwara 1 is high grade, in common with other sea-floor polymetallic sulphide deposits, it is relatively small when compared to similar deposits being mined on land. The land-based deposits frequently contain several to tens of millions of tonnes of ore, and the ‘Indicated Mineral Resource’ at Solwara 1 represents less than six months ore production for a large polymetallic sulphide mine on land. However, the mobile nature of deep-sea mining equipment improves the economic feasibility of extracting smaller deep-sea ore-bodies, as it could permit mining operations to move between relatively low tonnage deposits, which frequently occur in clusters.



Hydrothermal vents including Solwara 1, a relatively advanced deep-sea mining project, in the south-west Pacific near Papua New Guinea. Image created using © CARTO. Data courtesy of InterRidge.

53. *Op. cit.*, note 36.

54. *Op. cit.*, note 36.

CASE STUDY B

The southern Mid-Atlantic Ridge: a target for future polymetallic sulphide exploration

Ascension is an isolated volcanic island in the equatorial waters of the South Atlantic, located about 1,600km from the coast of Africa. It forms part of the British Overseas Territory of Saint Helena, Ascension and Tristan da Cunha. The Mid-Atlantic Ridge (where oceanic plates are moving apart) lies 80km to the east of Ascension, running through the UK EEZ. Hydrothermal activity and polymetallic sulphide deposition in association with volcanic activity and heat production along the Mid-Atlantic Ridge have been documented since the 1970s[55]. However, the Southern Mid-Atlantic Ridge remained poorly explored until the early 2000s[56].

Initial surveys provided strong evidence for hydrothermal activity on this section of the ridge with the largest water column anomalies (indicative of active vents) identified in the ridge segment closest to Ascension Island[57]. Subsequent exploration has verified the presence of active and inactive hydrothermal vents and hydrothermal precipitates to the south-east of Ascension Island[58]. However, little is known about potentially related polymetallic sulphide deposits or their economic significance.

Mid-Atlantic Ridge, a potential source of polymetallic sulphide deposits. Image created using © CARTO.

55. Rona PA, Thompson G, Mottl MJ, Karson JA, Jenkins WJ, Graham D, et al. Hydrothermal activity at the trans-Atlantic geotraverse hydrothermal field, Mid-Atlantic Ridge crest at 26°N. J Geophys Res. 1984 Dec; 89(B13): 365–377. Available from: doi: 10.1029/JB089iB13p11365.

56. German CR, Parson LM, Murton BJ, Bennett SA, Connelly DP, Evans AJ, et al. Hydrothermal activity on the southern Mid-Atlantic Ridge: tectonically and volcanically hosted high temperature venting at 2–7 degrees S. American Geophysical Union, Fall Meeting 2005. 2005 Dec. Abstract #OS21C-04.

57. University of Hamburg. Summary of the RV meteor cruise m62.5 (7.11–29.12.04). Available from: https://www.ldf.uni-hamburg.de/meteor/wochenberichte/wochenberichte-meteor/m62/m62-5-scr.pdf

58. Melchert B, Devey CW, German CR, Lackschewitz KS, Seifert R, Walter M, et al. First evidence for high-temperature off-axis venting of deep crustal/mantle heat: The Nibelungen hydrothermal field, southern Mid-Atlantic Ridge. Earth Planet Sc Lett. 2008 Oct; 275(1–2): 61–69. Available from: doi: 10.1016/j.epsl.2008.08.010.

CASE STUDY C

Polymetallic nodules in the Clarion-Clipperton Zone

The Clarion Clipperton Zone (CCZ) lies in the Pacific Ocean between the west coast of Mexico and Hawaii and is the most thoroughly studied area for polymetallic nodules in terms of geological models, resources and industrial activity.

Within the CCZ, mineral resources extend over 9 million square kilometres (similar to the land area of the United States) in water depths of 4,000 – 6,000m and reaching concentrations of 44kg/m^2 (though dropping far below that in places). A conservative estimate suggests there are 21,000 million tonnes of nodules in the CCZ with consequently significant quantities of copper, nickel and cobalt[59].

The UK is engaged in the CCZ through UK Seabed Resources, a subsidiary of Lockheed Martin UK. UK Seabed Resources, in partnership with the Department for Business, Energy & Industrial Strategy, has received licences and contracts to explore two areas of 58,000km^2 and 75,000km^2 of the CCZ for polymetallic nodules.

59. *Op. cit.*, note 19.

KEY

Belgium	Germany	Naura	Tonga
China	Interoceanmetal	Republic of Korea	United Kingdom
Cook Islands	Japan	Russian Federation	Reserved zones
France	Kiribati	Singapore	Areas of particular environmental interest

Clarion-Clipperton Zone, licensed areas for exploration and areas of particular environmental interest.
Image created using CARTO: © OpenStreetMap contributors, © CARTO. Data courtesy of ISA.

Chapter two
Marine genetic resources

Left
Coral reef with hard corals
in tropical sea. © mychadre77.

Marine genetic resources

2.1 Introduction to marine genetic resources (MGRs)

What are MGRs?

The oceans are home to a hugely diverse range of biological materials. These include marine genetic resources such as units of heredity (eg genes), their products (eg proteins) and substances synthesised by biological processes such as antibiotics and biomaterials. MGRs include substances directly isolated from marine organisms and their derivatives (*in/ex situ* and *in vitro*). These can then potentially be synthesised by chemical, biotechnological or engineering approaches such as synthetic biology. For the purposes of this report we will not consider the simple harvesting for food of stocks such as fish, shellfish and seaweeds within our discussion of MGRs.

Genes and natural products from marine organisms

Natural products have found a range of uses including Estée Lauder's skincare brand Resilience which utilises an anti-inflammatory extract from a Caribbean octocoral[60], and Prialt, a painkiller based on the synthetic derivative of a cone snail[61]. The genes that underpin the synthesis of natural substances, eg enzymes and antibiotics can therefore also gain a high commercial value and so are often protected by patents.

Patents for marine-derived genes and natural products have been in a distinct minority compared to those of terrestrial origin. However, the number of annually reported marine natural products is rapidly increasing (Figure 12), particularly those of microbial origin which are considered a sustainable source of novel antibacterial, antiviral, antiparasitic and antifungal compounds[62].

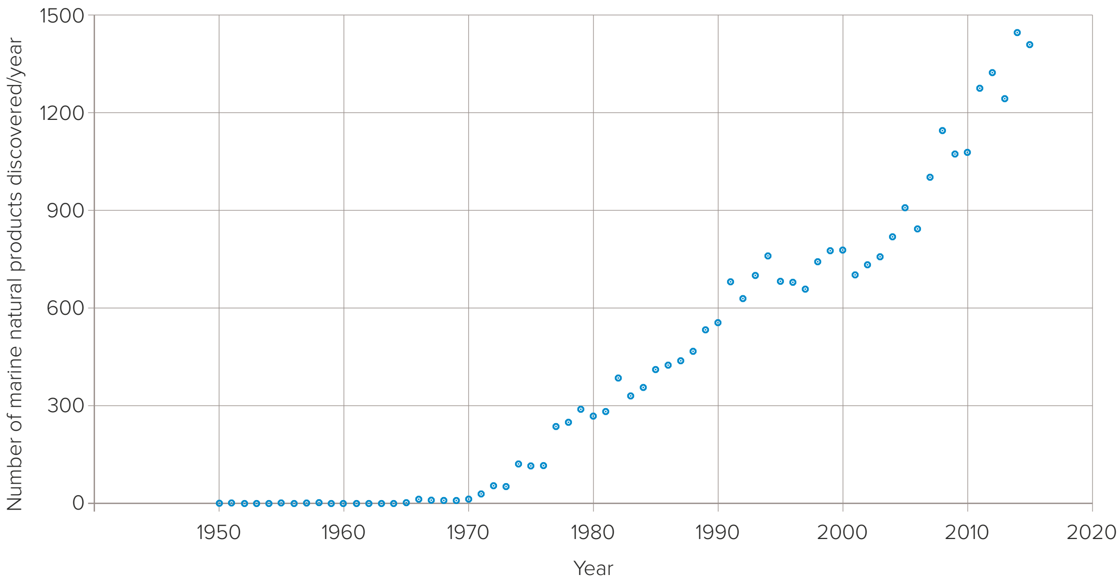
Why are MGRs distinctive and interesting?

There is evidence that life originated in the ocean in deep-sea hydrothermal vents about 3.7 billion years ago[63]. The long period since then has allowed the evolution of genetic and chemical diversity that is unparalleled on land. The oceans contain more than 90% of animal phyla known today, of which about 50% are exclusively present in the marine environment[64]. Much less is known about marine microbes, but recent surveys document unprecedented genetic diversity, especially in extreme habitats such as the deep sea and polar oceans[65]. As the oceans are the largest and least explored ecosystem on Earth, with exceptionally high biological diversity, they provide significant opportunities to discover new life forms and novel MGRs. Unique adaptations could be used to obtain valuable antibiotics, anticancer drugs and nutritional supplements.

60. Lasker HR. Recruitment and resilience of a harvested Caribbean octocoral. PLoS ONE. 2013 Sep; 8(9): e74587. Available from: doi: 10.1371/journal.pone.0074587.
61. Machalek AZ. National Institutes of Health Record. Sea Snail Venom Yields Powerful New Painkiller. 2005 [cited 2017 Feb 24]; Available from: https://nihrecord.nih.gov/newsletters/2005/03_01_2005/story03.htm
62. Arrieta JM, Arnaud-Haond S, Duarte CM. What lies underneath: Conserving the oceans' genetic resources. P Natl Acad Sci USA. 2010 Oct; 107(43): 18318–18324. Available from: doi: 10.1073/pnas.0911897107.
63. Martin W, Baross J, Kelley D, Russell MJ. Hydrothermal vents and the origin of life. Nature Rev Microbiol. 2008 Nov; 6, 805–814. Available from: doi: 10.1038/nrmicro1991.
64. Margulis L, Schwartz KV. Five kingdoms: Illustrated guide to the phyla of life on earth. New York: W.H. Freeman and Co; 1998.
65. Tian Y, Li Y, Zhao F. Secondary Metabolites from Polar Organisms. Marine Drugs. 2017 Feb; 15(28). Available from: doi: 10.3390/md15030028.

FIGURE 12

Annual number of newly discovered distinct natural products from marine organisms.



Source: RSC MarinLit database, February 2017.

Exploitation and access

Discovery of MGRs is achieved by identifying new organisms, and gaining natural products from those organisms by bioprospecting[66], ie searching for animals[67], plants and microbes from which valuable compounds and materials can be obtained. Selecting a broad range of habitats, including extreme environments, can increase the chances of finding novel materials. Furthermore, new autonomous vehicles have allowed exploitation of previously unexplored areas of the ocean such as the deep sea or ice-covered oceans whereas in the past, damaging dredging operations would have been required to obtain organisms.

Exploitation of MGRs is likely to have little or no impact on ocean ecosystems and environments. Although screening of many species is required for the identification of genes and natural products, the mass of biological material required for this work is small. Advances in genomics and sampling techniques have also helped in this area. For instance, genetic materials from organisms or communities can be investigated for the sections which encode enzymes to produce biomolecules such as antibiotics. Predicting this behaviour directly is currently challenging, but novel computational approaches are being developed alongside high-throughput small molecules identification to tackle that challenge.

66. Bhatia P, Chugh A. Role of marine bioprospecting contracts in developing access and benefit sharing mechanism for marine traditional knowledge holders in the pharmaceutical industry. Global Ecology and Conservation. 2015 Jan; 3(C): 176–187. Available from: doi: 10.1016/j.gecco.2014.11.015.

67. Mioso R, Marante FJT, Bezerra RS, Borges FVP, Santos BVO, Laguna IHB. Cytotoxic Compounds Derived from Marine Sponges. Molecules. 2017 Jan; 22(208). Available from: doi: 10.3390/molecules22020208.

2.2 Key environments for MGRs

The marine environments contain diverse habitats that support an abundance of marine life which emerged here billions of years before spreading to land. The fact that life in the ocean shows more diversity than on land suggests a great resource of interest for commercial use[68].

We know that almost every type of marine organism, from sponges and sea urchins to bacteria and algae, has evolved interesting adaptations to thrive in a range of habitats. To date most novel natural products have been found within highly productive and/or extreme environments[69], where there is a need for organisms to adapt either in response to competition or to create mechanisms to deal with adverse conditions. The range of adaptations in these regions of the ocean therefore represent the greatest opportunity to access marine genetic resources of use for design of novel chemicals.

Highly productive environments

These are characterised by enhanced biomass and biodiversity resulting from either the combination of nutrient-rich waters and availability of light stimulating the growth of microalgae (tiny free-floating plant-like organisms) which provide food for the rest of the marine food chain (eg in shelf seas and upwelling zones), or the provision of safe habitat allowing marine organisms protection from predators and safe spawning grounds (eg coral reefs and seamounts).

Extreme environments

From the cold, high-pressure environments and volcanically induced corrosive water of hydrothermal vents at the bottom of our seas to the extremely cold and saline conditions within sea ice, 'extreme' environments present a wide variety of features and characteristics. The life found in these environments is equally diverse, having had to adapt to difficult conditions and multiple stressors. Microbial extremophiles are the most extreme of all organisms. Some can grow at temperatures as high at 113°C, others at temperatures as low as -18°C. They can live under acidic or alkaline conditions, under extreme pressures of up to 110MPa (1,100 times atmospheric pressure), in the complete absence of oxygen, in salt brines and even in conditions of nearly absolute energy starvation[70].

Organisms living in extreme environments must cope with higher levels of stressors and mutagenic agents than normal. Consequently they have developed mechanisms that confer a higher degree of resistance to damaging agents/conditions. Investigating these properties brings the opportunity to develop new potential products relevant to biotechnology, remediation, pharmaceuticals and cosmetics for the benefit of human health and economic growth.

Some illustrative examples of ecosystems considered of interest for MGRs follow.

68. Heips C, McDonough N. Marine biodiversity: a roadmap for Europe. Belgium: European Marine Board; 2012. Marine board future science brief #1.

69. Querellou J, Borresen T, Boyen C, Dobson A, Hofle M, Ianora A, et al. Marine biotechnology: a new vision and strategy for Europe. Strasbourg: European Marine Board; 2010. European Science Foundation.

70. Walter N, Amils R, Blix A, Danson M, Ebel C, Ellis-Evans C, et al. Investigating life in extreme environments: a European perspective. Strasbourg: European Science Foundation; 2006.

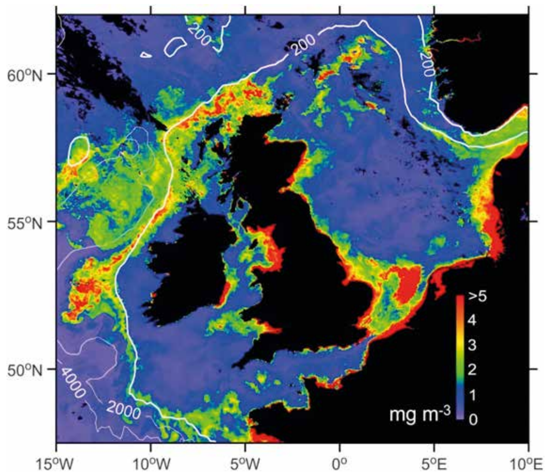
Productive surface waters – shelf seas and upwelling zones

Shelf seas are relatively shallow waters, generally less than 140m in depth, close to the continent. Upwelling of nutrient-rich deeper waters to the surface occurs along coastlines and at the boundaries between the open ocean and the shelf seas, and leads to two to five times higher productivity than in the interior of the large ocean basins. The resulting abundance of microalgae form the basis of a rich and complex food web made up of a wide diversity of marine organisms.

Marine algae have been the source of between 50 and 100 new compounds per year between 1985 and 2008, while microorganisms, including phytoplankton, yield an increasing number of compounds, reaching 600 found between 2014 and 2015[71].

FIGURE 13

Satellite map of the distribution of phytoplankton around the UK in summer.



Data courtesy of NEODAAS, Plymouth Marine Laboratory.

71. Blunt JW, Copp BR, Keyzers RA, Munro MH, Prinsep MR. Marine natural products. Nat Prod Rep. 2016 Feb; 33, 382–431. Available from: doi: 10.1039/c5np00156k.

Coral reefs

Coral reefs are diverse underwater ecosystems held together by calcium carbonate structures secreted by corals. Coral reefs are built by colonies of tiny animals found in marine waters that contain few nutrients.

Tropical corals occupy less than 1% of the world's ocean surface; they are mostly found at shallow depths and rely on microalgae that provide carbon for growth through photosynthesis. Tropical corals are considered to be biodiversity hotspots – there can be 1,000 species per m^2. They provide a home for at least 25% of all marine species including fish, molluscs, worms, crustaceans, echinoderms, sponges and tunicates.

Cold water coral habitats range from near surface to below 2,000m. Cold water corals do not need sunlight but capture food from the water as it passes by. Reefs support a rich community of associated fauna and are feeding grounds and nurseries for various commercial fish.

The main sources of new compounds between 1985 and 2008 were marine invertebrates such as sea sponges and corals, with over 300 compounds per year described from 1995 to 2008[72]. It is now understood that most invertebrate-derived compounds are in fact produced by symbiotic microorganisms[73].

FIGURE 14

Cold water corals surrounded by sea stars in a submarine canyon system in the north-east Atlantic.

© National Oceanography Centre.

72. *Op. cit.*, note 71.

73. Wilson MC, Mori T, Ruckert C, Uria AR, Helf MJ, Takada K, et al. An environmental bacterial taxon with a large and distinct metabolic repertoire. Nature. 2014 Feb; 506, 58–62. Available from: doi: 10.1038/nature12959.

Deep sea

The seabed between 700m and 11,000m deep in seas and oceans is made up of lightless abyssal plains, covering 50% of the Earth's surface, with seamounts, deep-sea trenches and submarine canyons. The temperature is low (less than 4°C) and the pressure high (up to 110MPa, ie 1,100 times atmospheric pressure). Abyssal plains are currently believed to be a major reservoir of biodiversity. Recent oceanographic expeditions from the Census of Diversity of Abyssal Marine Life found a high level of biodiversity on abyssal plains, with up to 2,000 species of bacteria, 250 species of protozoans, and 500 species of invertebrates (worms, crustaceans and molluscs), at single abyssal sites. Many unique taxa of nematode worms have also been recently discovered on abyssal plains.

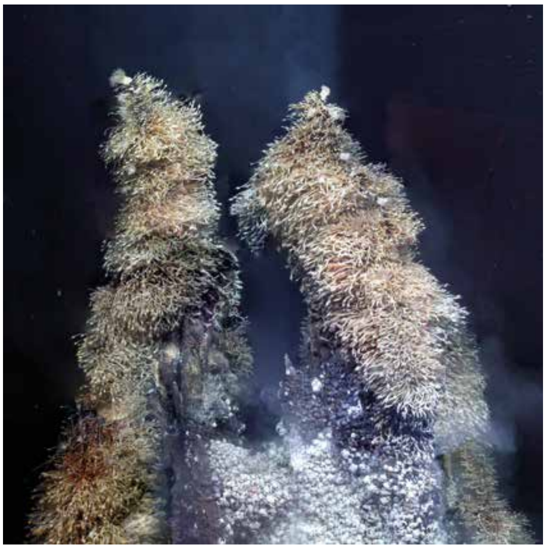
Hydrothermal vents

Hydrothermal vents are sparsely distributed on geoactive sea floors, and of relevance as a potential source of minerals (Section 1.2). The temperature at vent chimneys is up to 420°C, while it is low in the surrounding waters, and there are high concentrations of toxic chemicals, and acidic, low-oxygen conditions.

The bacteria that live at hydrothermal vent chimney sites exist in darkness. They use energy from oxidation of chemicals, such as sulphur, exuded from the Earth's crust, to produce food. The bacteria are either a direct or indirect food source for specially adapted tubeworms, clams, mussels and shrimp that also live on the vents. This is considered a rich environment for genetic adaptations to conditions not found in the sunlit surface environment[74].

FIGURE 15

'Carwash' hydrothermal vent chimney, Southern Ocean (depth 2,400m), discovered in 2010.



© University of Southampton.

74. *Op. cit.*, note 68.

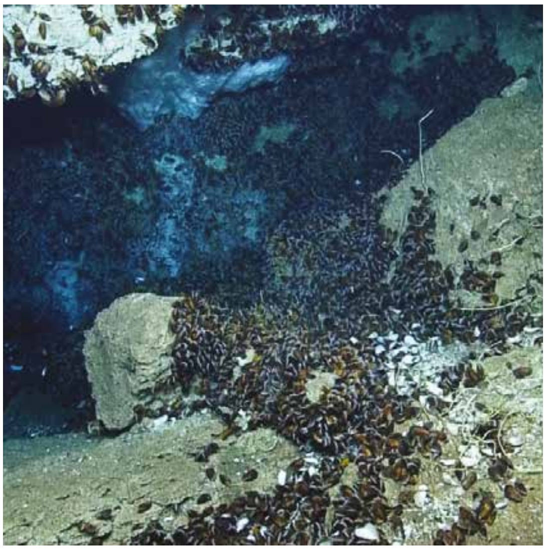
Cold seeps

Cold seeps occur on the sea floor close to the margins of continents at depths between 400m and 8,000m. They are usually associated with oil and gas reservoirs under the seabed or 'subduction zones' where the Earth's rigid outer plates collide to form trenches. The temperature is low, 2 – 4°C, the pressure is high to very high, depending on seep depth, and there can be low oxygen and high salinity brines.

Cold seeps are characterised by seeping of cold fluids containing methane. Some have high levels of sulphide in the sediments. Animals found at cold seeps include clams, mussels and tubeworms, and many survive in a relationship with bacteria that use chemicals as a food source. The deepest known cold seep community exists at 6,500m in the Sea of Japan.

FIGURE 16

Cold seep with methane hydrates (white material) and chemosynthetic mussels close to Trininad and Tobago.



Polar regions – sea ice

Sea ice ecosystems occur in both the Arctic and Antarctic and on average cover about 7% of the world's oceans. Temperatures are around or below -1.8°C, and the ecosystems are dark in winter months, with 24-hour daylight in summer. There is low oxygen and high salinity brines. Sea ice is a unique habitat for specialised algae, protozoa and bacteria. Because of its interior brine channel network, sea ice has the capacity to retain liquid pockets containing nutrients and organic resources down to -35°C. Metabolic activity such as respiration and functional protein synthesising machinery has been detected at -20°C in sea ice. Massive blooms of algae form each spring within ice, below ice and in the surrounding waters at the edge of the retreating ice, providing the base of the food web for many polar species from zooplankton to seals.

Because bacteria and microalgae living within the sea ice have a high degree of biochemical and physiological adaptation to cold and changeable salinity conditions, they have a high potential for biotechnological applications. Two examples are the production of polyunsaturated fatty acids and the production of cold-active enzymes[75].

FIGURE 17

Photograph of sea-ice flows (upside down) from the Ross Sea (At McMurdo Research Station), Southern Ocean. Brown colour is caused by dense populations of algae at the interphase between sea ice and sea water.

© James A Raymond.

75. Leary D. Bioprospecting in the arctic. Tokyo: United Nations University Institute of Advanced Studies; 2008.

2.3 Turning life into novel drugs and products

What could this be worth?

Ocean environments provide opportunities to discover novel MGRs for antibiotics, anticancer drugs, nutritional supplements, and enzymes used in biotechnology, but market costs and value remain uncertain. The discovery-based nature of MGR makes the potential market size inherently difficult to assess. However, publicly available information suggests that global sales of marine biotechnology products are presently >USD1 billion per annum[76]. This value is dominated by pharmaceutical and cosmetic industries and the market appears to be growing at a single-digit rate per annum.

A blockbuster anticancer drug is 'Halaven' (see Case Study D) and there are several important non-pharmaceutical products that generate significant revenue such as the skincare product 'Venuceane' (Sederma) which contains a substance from a vent bacterium to filter out infrared radiation, and the DNA polymerase 'Vent' (New England BioLabs) which has a 5 – 15-fold higher fidelity than conventional Taq polymerases. Essential omega-3 fatty acids from marine microalgae are used in diets for babies (eg Nordic Naturals, Baby's DHA) to support proper brain and visual development.

76. Leary D, Vierros M, Hamon G, Arico S, Monagle C. Marine genetic resources: A review of scientific and commercial interest. Mar Policy. 2009 Mar; 33(2), 183–194. Available from: doi: 10.1016/j.marpol.2008.05.010.

CASE STUDY D

Halaven

Halaven (eribulin mesilate) is the trade name for an anti-cancer drug marketed by Eisai Co. The active substance is eribulin which is a full synthetic macrocyclic analogue of the marine natural product Halichondrin B, which inhibits microtubule dynamics. Halochondrin B was isolated in 1986 from the marine sponge Halichondria okadai. Structural simplification led to eribulin mesilate. The drug was first approved in the United States in 2010 and is currently approved in the EU for the treatment of adult patients with locally advanced or metastatic breast cancer who have progressed after at least one prior chemotherapeutic regimen for advanced disease.

A report published in Nature Reviews Drug Discovery in 2011 predicted sales for eribulin in the range of USD340 million to 680 million. The latest figures from Evaluate market intelligence for 2014 and 2015 indicate global sales of Halaven being between USD300 and 350 million per annum with a sales growth of circa 3.6% for 2015.

Marine sponge Halichondria from which Halichondrin B was isolated for use in anticancer drug Halaven. © Eisai Co.

A roadmap to market

1. *In situ* bioprospecting to discover novel MGRs.
2. *In vitro* screening to identify a potential substance with appropriate property (eg new antibiotic based on growth inhibition of bacteria).
3. Isolation and purification of active substance followed by structural analysis.
4. *Ex situ* synthesis of either original substance by means of bioengineering, synthetic biology, or chemical synthesis of derivatives.
5. Laboratory tests, clinical trials, and regulatory approval.
6. Product ready for market.

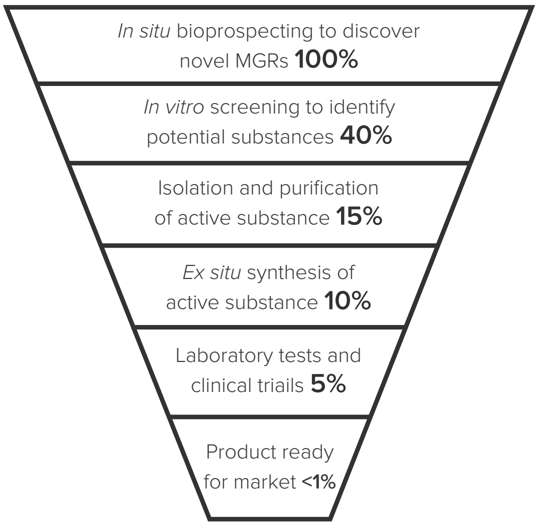
Timeline:
>Ten years for drugs with current approaches (Figure 18). However, the time to develop non-pharmaceutical products such as the 'Vent' DNA polymerase may be shorter as they do not need to be tested by clinical trials.

Rates of success

No comprehensive information is available on the extent and types of commercial uses of marine genetic resources. Drug development is an expensive process with a high failure rate (Figure 18), so while a large number of promising lead chemicals are found, conversion to products cannot be guaranteed (Figure 19). From a total of 30,000 marine-derived small molecules discovered to date, nine pharmaceutical products have been approved, a further 28 are in clinical trials and 250 are undergoing preclinical evaluation[77].

FIGURE 18

Different phases from the discovery of novel MGRs to products ready for the market. Less than 1% of novel MGRs will be approved after clinical trials[78].



77. Malve H. Exploring the ocean for new drug developments: marine pharmacology. J Pharm Bioall Sci. 2016 Mar; 8(2), 83–91. Available from: doi: 10.4103/0975-7406.171700.

78. *Op. cit.*, note 77.

FIGURE 19

Key challenges of biotechnology marketing[79].

2.4 Technological assessment and barriers

Scientific and technological advances are increasing our knowledge of MGRs and facilitating their use in the development of new products and processes. Advances in fields such as sensors and imaging, satellite technologies, big data analytics and autonomous systems contribute to improvements in access and understanding of MGRs. Significant advances in molecular biology, genomics, and bioinformatics have improved MGR identification and the latent potential of their genes for product and process development. Barriers to the application of MGRs do however remain, not least an uncertain regulatory and legal environment in areas beyond national jurisdiction.

Who is using MGRs and what are they doing?

MGRs are being used by a variety of organisations from higher education research institutions through to industry.

Research institutions typically focus on the early stages of the MGR discovery process. These involve MGR collection and identification, basic biological and ecological studies of MGRs, extraction of genes/molecules and assessment of their function and potential application. There are a number of leading institutions around the world including the Centre for Marine Biotechnology and Biomedicine in the USA, GEOMAR-Biotech in Germany and the Marine Biodiscovery Centre in the UK.

79. Rajamäki H. Anticipating and managing the challenges of biotechnology marketing. J Commer Biotechnol. 2008 Jul; 14(3), 225–231. Available from: doi: 10.1057/jcb.2008.13.

Innovative work is being undertaken at the Small and Medium Enterprise level by companies such as Jellagen in the UK, using MGRs for collagen production, and ArcticZymes in Norway, using marine enzymes for DNA processing. The Spanish mid-sized company PharmaMar is developing several products based on MGRs and has successfully commercialised the MGR-based cancer treatment Yondelis.

Large-scale companies in the field include Croda, which develops speciality chemicals based on MGRs for cosmetics and personal care products, and Unilever which integrates MGRs in a variety of products including food, beverages and cleaning agents.

Barriers limiting application of MGRs

The development of new MGR-based products follows the process discussed in Section 2.3. Despite a number of successful products, barriers remain associated with each step, from access to commercialisation, and there are a number of overarching issues that need to be addressed for the full value of MGRs to be realised.

A first barrier affects the collection of MGRs. The main route of access to MGRs is by research vessels with collection equipment including deep-water winches, corers and remotely operated vehicles[80]. These vessels are costly and access to them competitive, often involving shared research cruises with multiple research projects. Reducing the cost and enabling increased sampling frequency will be of major benefit to many marine research communities.

A second barrier to access concerns the current lack of legal certainty for MGRs beyond national jurisdiction[81]. This position is discussed further in Section 2.5.

Taxonomic identification of marine organisms can be challenging as there are insufficient experts in global marine organism taxonomy and systematics. Molecular techniques will play a role in addressing this challenge, but are not sufficient[82], and microbial MGRs in particular will require methods for isolating and cultivating unique taxa selectively[83].

Development of some research tools for MGRs lags behind that for terrestrial genetic resources. Chemical methodology and biological assay capability are identical for marine and terrestrial genetic resources, with both areas benefiting from recent improvements in isolation, identification, interpretation and downstream testing. Similarly to genes of terrestrial origin, current bioinformatic databases lack accurate annotations for numerous genes of marine origin, though the problem is particularly acute for 'marine only' taxa (see Section 2.2).

Scaling up promising materials for clinical trials and industrial use currently presents a significant further challenge, though advanced technologies such as synthetic biology are expected to accelerate this process in the future.

80. Long R. The marine strategy framework directive: a new European approach to the regulation of the marine environment, marine natural resources and marine ecological services. Journal of Energy and Natural Resources Law. 2015 Jun; 29(1), 1–44. Available from: doi: 10.1080/02646811.2011.11435256.

81. Lallier LE, McMeel O, Greiber T, Vanaqt T, Dobson ADW, Jaspars M. Access to and use of marine genetic resources: understanding the legal framework. Nat Prod Rep. 2014 Mar; 31, 612–616. Available from: doi: 10.1039/C3NP70123A.

82. House of Lords Science and Technology Committee. Systematics and taxonomy: Follow-up. London: The Stationery Office; 2008.

83. Ling LL, Schneider T, Peoples AJ, Spoering AL, Engels I, Conlon BP, et al. A new antibiotic kills pathogens without detectable resistance. Nature. 2015 Jan; 517, 455–459. Available from: doi: 10.1038/nature14098.

The first set of overarching issues concerns people, facilities and funding. A range of techniques developed for terrestrial genetic resources can be applied to MGRs, but it is also crucial to get researchers with relevant skills involved in investigating MGRs and training the next generation of interdisciplinary researchers[84].

The second overarching theme covers long-term maintenance of materials and data[85]. Some good practices exist, but these are not always followed. Best practice for MGR repositories/biobanks includes: curating marine macro- and microorganisms under conditions that allow multiple types of downstream use[86]; storing MGR extracts and compounds[87]; and maintaining a comprehensive data infrastructure that contains sample metadata and is linked to genetic sequence data, gene annotations, macromolecular and small molecule data and associated functions/activities.

A final issue consists of making MGR-derived products and processes attractive to industry. This is not the case at present due to a lack of corporate risk-taking and increased regulatory stress, especially on SMEs, when products are being registered[88].

2.5 Environmental and legal considerations

Environmental considerations

The environmental considerations for MGRs depend on the sampling method and the way in which natural products are obtained. In general, however, the environmental impacts of bioprospecting are limited by the comparatively small amount of biomass that needs to be harvested for use. MGR products, although originally discovered in living organisms, are typically synthesised, rather than requiring the organisms themselves as a source. In the development stages, through to clinical trials, generally kilograms rather than tonnes of a material are needed.

In some cases, however, the desired natural products are present in such low concentrations that large amounts of the source organism must be collected and there is potential for over-exploitation. An exceptional and extreme example is the development of the anticancer agent Dolastatin 10 from the sea hare *Dolabella auricularia*: extracts were present at such low chemical concentrations that two tonnes of the sea hare were collected in Mauritius in the 1980s to obtain the first milligramme of the chemical[89]. Analogues have since been synthesised and marketed as Adcetris – other sources and improvements in chemistry will reduce the need for such excessive collection in future.

84. *Op. cit.*, note 68.

85. Research Councils UK. RCUK Common principles on data policy. 2015 [cited 2017 Feb 24]; Available from: http://www.rcuk.ac.uk/research/datapolicy/

86. Markbank Biobank of Marine Organisms. [cited 2017 Feb 27]; Available from: http://www.imr.no/marbank/en

87. Griffith University. Nature Bank. [cited 2017 Feb 27]; Available from: https://www.griffith.edu.au/institute-drug-discovery/nature-bank

88. Glaser KB, Mayer AM. A renaissance in marine pharmacology: From preclinical curiosity to clinical reality. Biochem Pharmacol. 2009 Sep; 78(5), 440–448. Available from: doi: 10.1016/j.bcp.2009.04.015.

89. Molinski TF, Dalisay DS, Lievens SL, Saludes JP. Drug development from marine natural products. Nat Rev Drug Discov. 2009 Jan; 8, 69–85. Available from: doi: 10.1038/nrd2487.

Some of the most valuable products still rely on continued harvesting of natural resources to extract the product. In 2014, of nine prescription and over-the-counter marine-derived drugs available, six were synthesised chemically and/or produced by microbial fermentation, but three still relied on extracting the genetic resource from natural environments[90]. The octocoral *Antillogorgia elisabethae* is harvested by fishers in the Bahamas under government guidelines, and is used for a skincare product. Branches are cropped from large sexually mature colonies, without killing them, which has provided an unusual opportunity to research the population biology of this soft coral. Growth increases after cropping but reproductive output of female colonies is reduced, with more research needed to determine whether this affects populations[91].

The principles of the Convention on Biological Diversity ensure that the overarching goals of international marine conservation efforts include sustainable use of the components of biological diversity. High biodiversity areas are associated with discovery of more valuable MGRs[92]. Marine protected areas play an important role in protecting biodiversity. Provided that designated MPAs are respected, there is sufficient data to conclude that bioprospecting for MGRs is not, in general, an intrinsically damaging maritime activity.

Legal considerations within national jurisdiction

In national waters, authority to determine access to genetic resources rests with national governments. Such implementation must be in accordance with the Nagoya Protocol on Access to Genetic Resources and the Fair and Equitable Sharing of Benefits for the 96 parties (including the EU) to the Protocol. Access to genetic resources can involve high investment costs and technical requirements. As such only more affluent countries currently have the capacity to undertake research and development. When developed countries undertake exploration in areas that belong to developing nations this is often under agreement of some benefit sharing, whether direct (monetary) or indirect (capacity building).

90. Meyer H, Fey L, Brinkmeyer W. Relevance of marine bioprospecting for ABS frameworks. Bonn and Eschborn: Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH; 2014.
91. Page CA, Lasker HR. Effects of tissue loss, age and size on fecundity in the octocoral Pseudopterogorgia elisabethae. J Exp Mar Biol Ecol. 2012 Dec; 434–435, 47–52. Available from: doi: 10.1016/j.jembe.2012.07.022.
92. *Op. cit.*, note 86.

CASE STUDY E

Sponges in the Faroe-Shetland MPA

The Faroe-Shetland sponge belt Nature Conservation MPA was designated by Marine Scotland in 2014 for aggregations of deep-sea sponges (*Hexactinellida* and *Demospongiae*) west of the Shetland Islands, where they live at depths of 250 – 1,300m, in plough marks from Ice Age icebergs. The communities are very susceptible to bottom fishing, and a possible threat from bioprospecting has also been noted by OSPAR. Protecting the biodiversity of these ecosystems enhances their value for conservation and for sustainable exploitation using appropriate sampling methods: sponges (*Porifera*) are particularly valuable sources of bioactives from the sponge itself or its associated microbes.

Legal considerations outside of national jurisdiction

In areas outside of national jurisdiction, the Nagoya Protocol does not apply, and while UNCLOS governs mineral resources it does not currently cover MGR.

At present, no international organisation has the mandate to regulate access to MGRs beyond national jurisdiction which currently falls under an open access regime based on 'the freedom of the high seas'. Preparations are underway for a legally binding instrument on biodiversity in areas beyond national jurisdiction within the UNCLOS legal framework (current UN Preparatory Committee for diplomatic conference from 2018) with consideration of some form of access and benefit sharing.

The role of marine protected areas and environmental impact assessments, including in ABNJ, are also part of the package to be negotiated.

Key issues:

- Whether, and if so how, to regulate access to MGRs outside of national jurisdiction.
- Material scope of such a regime (access to resources *ex situ* and *in silico*, and derivatives, in an access and benefit-sharing regime).
- The lack of knowledge of the deep-sea environment limits full confidence that there are minimal environmental impacts of MGR extraction, particularly in locations where other human actions may contribute to environmental perturbation.
- The applicability of MPAs in areas outside of national jurisdiction and effective monitoring and enforcement.
- The material and geographic scope of environmental impact assessments.

Key concerns:

- To ensure that access is conducive to freedom of scientific research and that excessive administrative burdens are avoided.
- That marine protected areas contribute to integrated marine management and are established on a consultative basis with appropriate scientific input.
- That environmental impact assessments cover activities and impacts across maritime zones.

Chapter three
The relationship between pursuit of mineral and genetic resources from the ocean

Left
Actinostolid anemones and mats of filamentous bacteria at the world's deepest known hydrothermal vents, 5,000m deep on the Mid-Cayman Spreading Centre, British Overseas Territories. © University of Southampton.

The relationship between pursuit of mineral and genetic resources from the ocean

Extraction of metals from submarine mineral deposits represents a geological, chemical and – particularly – an engineering challenge, associated with the risk of environmental damage. In contrast, seeking useful products from the genes and molecules of marine species relies on biological, biochemical and medical expertise, and presents much less risk to the ocean environment. Despite these apparent contrasts, many challenges are shared by the pursuit of mineral and genetic resources from the ocean, coupled directly through their involvement of ocean ecosystems.

3.1 Two resources with similar challenges

Assessing the potential and challenges of both resources relies on understanding the ocean environment, particularly the deep ocean, much of which remains underexplored. Surveying and study of the ocean will form part of the process of exploration for these resources, and is required before environmental risk assessments can be made and these resources fully exploited. Surveying and exploring for the two resources together could reduce costs, improve economic viability and allow more comprehensive assessment of environmental issues.

It is challenging to accurately assess the economics of exploiting mineral and genetic resources from the sea. Both resource classes have the potential to become multi-billion pound industries, but it is not yet clear that their pursuit is economically viable at a large scale given present market conditions, and alternative sources of similar resources.

Another challenge in exploitation of both classes of resource is that, in ABNJ, they are subject to international legal agreements under active discussion through UN bodies. Until these are clarified, there remains uncertainty about the extent to which both resources can be pursued, and the transnational implications of doing so. International agreement will need to consider the environmental impact of activities – exploitation of metal resources will require international agreement on the nature of a formal environmental impact assessment, while the low level of impact for utilisation of genetic resources may not require this level of formality.

Although they differ markedly in the potential impact they might impose on deep-sea ecosystems, both resources require the presence of marine protected areas to reduce environmental and ecosystem damage.

FIGURE 20

Remote Operating Vehicle Isis being deployed.

© NERC.

FIGURE 21

Autosub 6000 being launched from the RRS James Cook to undertake a 24-hour multibeam, side scan sonar and sub-bottom profile survey.

© NERC.

3.2 Two resources coupled through their interactions with deep-ocean ecosystems

The major threat posed by deep-sea mining of metals is from the impact it might have on pristine and poorly understood deep-sea ecosystems. There is the potential for irreversible change and accelerated loss of unique species. Lack of knowledge about deep-ocean ecosystems, and about the precise nature of mining activity, make it challenging to quantify the extent of environmental degradation that mining would impose on this environment, or compare it to the impact of mining on land. Mining of metals is, however, expected to lead to environmental impacts both locally, and at greater distance through the formation of sediment plumes and the perturbation of natural cycles of toxic metals and nutrients.

Such ecosystem damage and potential for biodiversity loss has direct implications for future discovery and use of marine genetic resources. Metal-rich minerals occur in unusual marine settings with a diverse ecosystem adapted to local conditions. Reduction in biodiversity imposed by mining could decrease the capacity for exploitation of genetic resources, before we yet know the extent or value of this resource.

Both these novel classes of resource present challenges in their potential for exploitation that require continued scientific, technological, and governance advance.

CASE STUDY F

Potential for ferromanganese crusts on the UK Continental Shelf

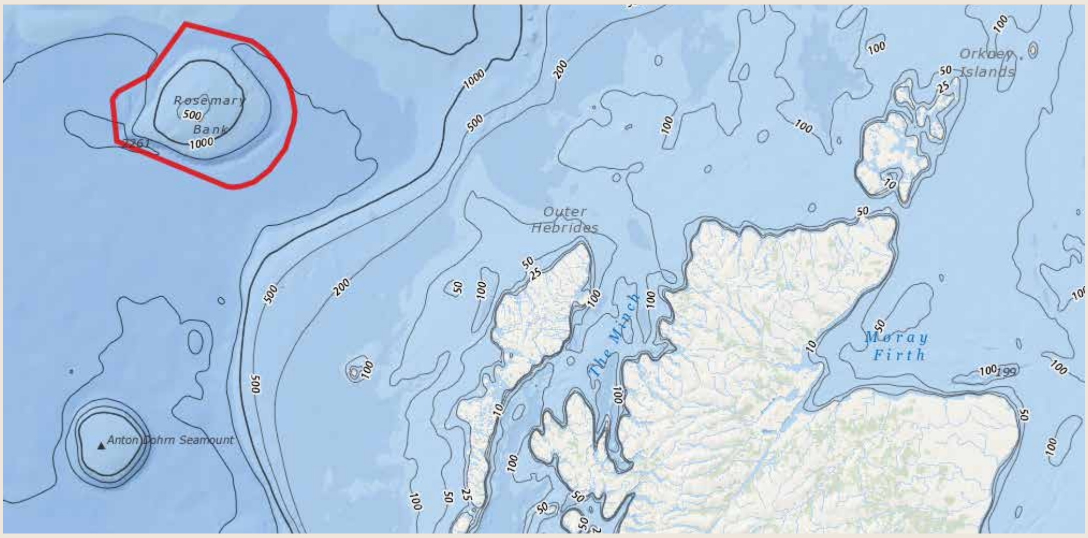
Seamounts in the open ocean disrupt currents and cause cold, oxygenated and nutrient-rich waters to move towards the surface where they enhance nutrient supply and bioproductivity. These currents support diverse and abundant ecosystems, which are considered to be vulnerable to human activity[93], and prevent sediment accumulation, making the surface well suited for the formation of metal deposits[94].

Several seamounts occur to the west of the Hebrides, in the Rockall Trough area of the UK Continental Shelf. Based on conceptual models these seamounts are likely to be covered by ferromanganese crusts and represent possible targets for future exploration. Detailed surveying and sampling of prospective areas, using autonomous and remotely operated underwater vehicles, will be required to confirm the presence and assess the size and grade of the assumed deposits.

The largest seamount of the UK Continental Shelf is Rosemary Bank which has an area of 5,400km^2 and extends to water depths in excess of 2,000m. It has been designated under the Marine and Coastal Access Act 2009 as a Nature Conservation Marine Protected Area as it is home to a significant number of seamount communities including reef framework-forming colonial scleractinian corals, soft coral species, deep-water sponges and seamount-associated sediments. It has been estimated that around 88 million sponges are present in the area[95]. All of these species can take several decades to reach full size and are considered to be threatened and/or declining across the north-east Atlantic, with fishing being the biggest current threat[96].

93. Alder J, Woods L. Managing and protecting seamounts ecosystems. Vancouver, Canada: Fisheries Centre; Fisheries Centre Research Reports 12(5).
94. Hein JR, Koschinsky A, Bau M, Manheim FT, Kang J, Roberts L. Cobalt-rich ferromanganese crusts in the Pacific: Chapter 9. London: CRC Press; 1999. Coastal and Marine Geology Program.
95. McIntyre FC, Drewery J, Eerkes-Medrano D, Neat FC. Distribution and diversity of deep-sea sponge ground on the Rosemary Bank Seamount, NE Atlantic. Mar Biol. 2016; 163(143). Available from: doi: 10.1007/s00227-016-2913-z.
96. OSPAR Commission. Background document for deep-sea sponge aggregations. London: OSPAR Commission; 2010.

Sessile biology including corals growing on a ferromanganese crust substrate on Tropic Seamount, north-east tropical Atlantic. © NERC.



Coastal waters surrounding Scotland including Rosemary Bank seamount and MPA (red line). Image created using ArcGIS. Credit: Esri, General Bathymetric Chart of the Oceans, DeLorme, NaturalVue, Joint Nature Conservation Committee, NOAA National Centers for Environmental Information, Natural Earth, Flanders Marine Institute (2014), marineregions.org.


JAMES COOK

Chapter four
The UK perspective

Left
RRS James Cook,
launched in 2007.
© NERC.

The UK perspective

The UK has stewardship of, or potential access to, large areas of the oceans. These waters cover a wide variety of environments and ecosystems and have potential to offer significant economic benefit from pursuit of deep-sea mining and marine genetic resources.

The UK HMS Challenger expedition in 1872 is considered the first modern oceanography expedition and the UK now boasts a modern and highly specified fleet including RRS James Cook, RRS Discovery, cutting-edge research submarines and automated vehicles, and, from 2019, the RRS David Attenborough. UK research in oceanography, geology, ecology and robotics is recognised as internationally excellent. In combination with significant mineral extraction, pharmaceutical and biotechnology industries, they provide the opportunity to research and pursue these novel resources.

The UK has also taken a significant role in ensuring sustainable use of the ocean, having assigned 23% of UK national waters, and large areas of UK overseas dependencies as marine protected areas (MPAs)[97]. The Chagos no-take reserve and the South Georgia and Sandwich Islands MPA alone cover 1,000,000km^2.

Mining

UK jurisdictions are thought to contain polymetallic nodules, polymetallic sulphides and cobalt-rich crusts though no known deep-sea mining is planned.

The UK is leading and engaged in a number of international research programmes on deep-sea mining in international waters (eg MIDAS[98], Blue Mining[99] and MarineE-tech[100]); and has an interest in mining instrument development via the VAMOS[101] project and SMD Ltd.

As a party to UNCLOS the UK has the ability to bid for mining rights in the area beyond national jurisdiction and in partnership with UK Seabed Resources Ltd (a subsidiary of Lockheed Martin UK) holds exploration licences for two blocks within the CCZ. While the sponsored entity must be based in a state which is party to UNCLOS, this includes subsidiaries established by companies headquartered in non-party states (eg the United States of America).

97. Joint Nature Conservation Committee. Contributing to a Marine Protected Area Network. Available from: http://jncc.defra.gov.uk/default.aspx?page=4549
98. Managing Impacts of Deep-Sea Resource Exploitation (MIDAS). [cited 2017 Feb 27]; Available from: http://www.eu-midas.net/
99. Blue Mining. [Cited 2017 Feb 27]. Available from: http://www.bluemining.eu/
100. National Oceanography Centre. Marine E-tech. [cited 2017 Feb 27]; Available from: http://projects.noc.ac.uk/marine-e-tech/
101. Viable Alternative Mine Operating System (VAMOS). [cited 2017 Feb 27]; Available from: http://vamos-project.eu/

Marine genetic resources

The UK's jurisdictions (especially those of the Overseas Territories) span a wide variety of the ecosystems high in biodiversity or considered likely to give rise to interesting genetic adaptations.

Along the pipeline to product development, the UK has particular strengths in advanced screening of genetic mechanisms, bioinformatics, synthetic biology and, through facilities like the Centre for Process Innovation, scale up for clinical trials and industrial use.

The UK is also host to significant biotechnology, pharmaceutical and consumer goods industries (eg Oxford Nanopore Technologies, Croda and Unilever) that will play an important role in bringing marine genetics to market. Eisai Co, the developers of Halaven featured in Case Study D, have a significant footprint in the UK.

Figure 22 (top): RRS James Cook, launched in 2007. © NERC.

Figure 23 (bottom): RRS Sir David Attenborough, which will be launched in 2019. © NERC.

Appendices

Left
Aerial view of the Great
Barrier Reef, Australia.

Appendix

Working Group members

The members of the Working Group involved in producing this report are listed below. The Working Group members acted in an individual and not organisational capacity and declared any conflicts of interest. They contributed on the basis of their own expertise and good judgement. The Royal Society gratefully acknowledges their contribution.

Chair	
Professor Gideon Henderson FRS	University of Oxford
Members	
Professor Michael Bickle FRS	University of Cambridge
Professor Angela Hatton	National Oceanographic Centre, University of Southampton
Dr Christopher Hauton	National Oceanographic Centre, University of Southampton
Professor Marcel Jaspars	University of Aberdeen
Paul Lusty	British Geological Survey
Professor Christine Maggs	Bournemouth University
Professor Rachel Mills	University of Southampton
Professor Thomas Mock	University of East Anglia
Professor Catherine Redgwell	University of Oxford

Royal Society staff

Many staff at the Royal Society contributed to the production of this evidence pack. The project team are listed below.

The Royal Society Science Policy staff	
Elizabeth Surkovic	Head of Policy – Resilience and Emerging Technologies
Dr Richard Walker	Senior Policy Advisor and Project Lead
Laurie Smith	Senior Policy Advisor
Hélène Margue	Policy Advisor
Lindsay Taylor	Policy Advisor
Giles Barrett	Policy Intern

Review Panel

This report has been reviewed by three independent experts. The Review Panel members were not asked to endorse the conclusions of the report, but to act as independent referees of its technical content and presentation. Panel members acted in a personal and not an organisational capacity and were asked to declare any potential conflicts of interest. The Royal Society gratefully acknowledges the contribution of the reviewers.

Review Panel	
Professor John Shepherd FRS	University of Southampton
Professor Corinne Le Quere FRS	University of East Anglia
Professor Mervyn Bibb FRS	John Innes Centre

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Professor Alexander Halliday FRS, Vice-President of the Royal Society
Harriet Harden-Davies, University of Wollongong
Dr Lea-Anne Henry, University of Edinburgh
Dr Kerry Howell, University of Plymouth
Jack Laverick, UK Government Office for Science
Professor Peter Liss FRS, University of East Anglia
Professor Georgina Mace FRS, University College London
Professor Alex Rogers, University of Oxford
Christopher Williams, Lockheed Martin UK

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For further information
The Royal Society
6 – 9 Carlton House Terrace
London SW1Y 5AG

T +44 20 7451 2500
E science.policy@royalsociety.org
W royalsociety.org

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