Report on the value of ecosystem services and natural capital of the Area

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1. Background

The International Seabed Authority (ISA) is an international organisation established under the 1982 United Nations Convention on the Law of the Sea and the 1994 Agreement relating to the Implementation of Part XI of the United Nations Convention on the Law of the Sea. The ISA is the organisation through which States Parties to the Convention shall, in accordance with the regime for the seabed and ocean floor and subsoil thereof beyond the limits of national jurisdiction (the Area) established in Part XI and the Agreement, organize and control activities in the Area, particularly with a view to administering the resources of the Area. The ISA is required to take the measures necessary to ensure effective protection for the marine environment from harmful effects, as set out in the Convention.

In July 2018, the Council of the ISA established an open-ended working group to discuss a financial model and payment mechanism for deep-sea mineral resource exploitation. At its fourth meeting (November 2022), the working group decided to request the Secretary-General of the ISA to commission a study on the environmental costs of exploitation activities, including how to internalize the costs associated with environmental externalities. The outcome of this study does not in any way prejudice the decision of the Council of ISA, to be taken at a later stage, whether the exploitation regulations shall include a mechanism for the internalisation of environmental costs.

2. Introduction

This report addresses the identified need for information on the economic value of ecosystem services and the potential loss of this value through potential exploitation activities in the Area. Such information can be used to set fees for damage to natural capital (i.e., internalisation of external costs of activities), determine compensation payments to beneficiaries facing loss of ecosystem services, and to optimise mitigation efforts in mining operations by protecting high value ecosystem services.

The three objectives of this assignment are to provide:

1. A valuation of ecosystem services and natural capital of the Area. The focus of this valuation is on biotic natural capital (ecosystems) and not on abiotic natural capital (minerals and fossil fuels).
2. Estimates of environmental costs of potential mineral exploitation activities in the Area. Quantification of how the value of ecosystem services might change over time due to exploitation of seabed minerals in the Area.
3. Methodological guidance for the economic valuation of the environmental costs of an individual mining concession.

The report is organised as follows: Section 3 provides the conceptual framework in terms of economic value, ecosystem services and natural capital; Section 4 outlines the proposed valuation approach, namely the use of value transfers from existing studies; Section 5 sets out the literature review process used to collect existing data and information; Section 6 describes the expert consultation process used to collect advice, information and insights; Section 7 identifies the ecosystem services provided by ecosystems in the Area; Section 8 summarises the available primary value estimates for ecosystem services from the deep-sea; Section 9 reviews the available information on potential environmental impacts of deep-sea mining activities; and finally Section 10 provides conclusions in terms of key findings;

uncertainties, gaps and limitations; recommendations for future research; and next steps in terms of developing guidance on economic valuation of ecosystem services to contractors.

3. Conceptual framework

3.1 Economic value

Economic value is a measure of how important the things that people use are to their well-being, including use of the natural world or "natural capital" (Pearce, 1993). For conventional goods and services that are traded in markets, their economic value can be inferred from traded quantities and prices. Ecosystem services from the marine environment, such as biodiversity and carbon sequestration, are generally not traded in markets and there are no prices that reflect their economic value. As a consequence, the economic value of ecosystem services tends not to be taken into consideration in decisions regarding the use or conservation of the marine environment.

Economic valuation of ecosystem services involves identifying and quantifying the contribution of natural capital to human well-being, usually in monetary terms; and incorporating this information into decision-making and the design of financing mechanisms and policy instruments. Economic valuation methods do not stand alone but are generally used in combination with other methods for assessing environmental change and the provision of ecosystem services. The added value of using economic valuation methods is that the importance of ecosystem services is expressed in terms of human welfare and measured in a common unit (i.e. money), allowing values to be aggregated across ecosystem services and directly compared with the values of other goods and services in the economy. Such information can be used to raise awareness of the economic importance of marine ecosystems, set fees for the use of marine ecosystems, or determine compensation payments for environmental damage.

The concept of Total Economic Value (TEV) is used to describe the comprehensive set of utilitarian values derived from an ecosystem or natural resource. The concept is useful for identifying the different types of value that may be derived from an ecosystem. TEV comprises of "use values" and "non-use values". Use values are the benefits that are derived from some physical use of the resource. "Direct use values" may derive from on-site extraction of resources (e.g. genetic material, ornaments) or non-consumptive activities (e.g. nature based tourism). "Indirect use values" are derived from off-site services or other processes that are impacted by the resource (e.g. carbon sequestration). "Option value**"** is the value that people place on maintaining the option to use a resource in the future (e.g. the option to extract genetic resources). "Non-use values" are derived from the knowledge that an ecosystem or biodiversity is maintained without regard to any current or future personal use. "Non-use values**"** may be related to altruism (maintaining an ecosystem for use by others), bequest (for future generations) and existence (preservation unrelated to any use) motivations. The constituent values of TEV are represented in Figure 1. It should be noted that the "total" in Total Economic Value refers to the *inclusion of all components* of value rather than the sum of all value derived from a resource.

We emphasise here that the analysis presented in this report employs an economic definition of value in which human preferences for all ecosystem services can be measured in monetary units. This allows the aggregation of values across ecosystem services and the comparison of values for ecosystem services with the values of other goods and services in the economy (Dasgupta, 2021). It should be noted, however, that some ecosystem services may be very difficult to quantify in monetary terms (e.g. non-use values) and that other conceptualizations of 'value' (e.g. non-anthropocentric concepts of intrinsic values for nature) fall outside of this theoretical framework. Other concepts of value may, in some contexts, be useful for informing sustainable use and management of natural capital (IPBES, 2022). We further note that currently there is no internationally agreed framework for the economic valuation of ecosystem services. The System of Environmental Economic Accounting—Ecosystem Accounting (SEEA EA) framework (UN Statistical Division, 2021) represents a significant step towards an international standard but the development of monetary accounts requires further testing and specification (Edens et al. 2022).[1]

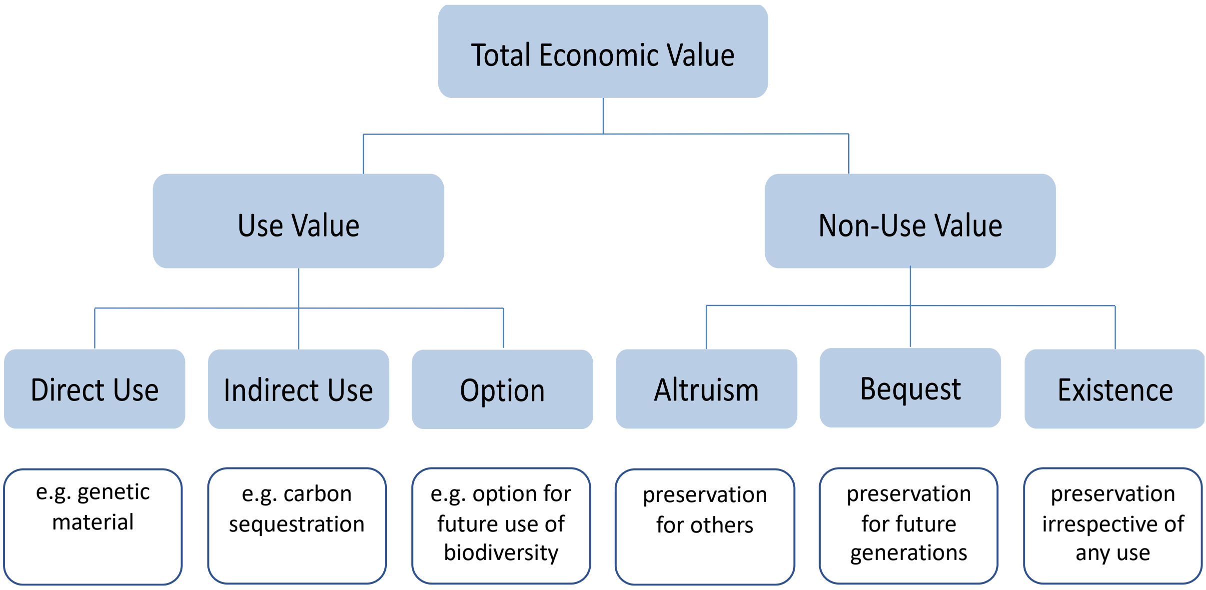

Figure 1: Components of Total Economic Value with examples related to deep sea ecosystems

3.2 Ecosystem services framework

The concept of ecosystem services provides a useful framework to identify the importance of the natural environment to humans. The term "ecosystem services" has been defined in a number of different ways (see summary of definitions in Box 1) but put most simply, they are the variety of benefits that humans obtain from the environment.

Ecosystems contribute to human well-being in a variety of ways and the processes by which ecosystems provide benefits to people has been described as an "ecosystem services cascade" in which bio-physical structures and processes ("ecosystem functions") can deliver inputs (ecosystem services) to the production of goods and services that are consumed by people (see Figure 2).

[1] The accounting framework and the physical accounts have been approved as an international statistical standard, whereas chapters on monetary valuation and integrated accounting for ecosystem services and assets are described as internationally recognised statistical principles and recommendations.

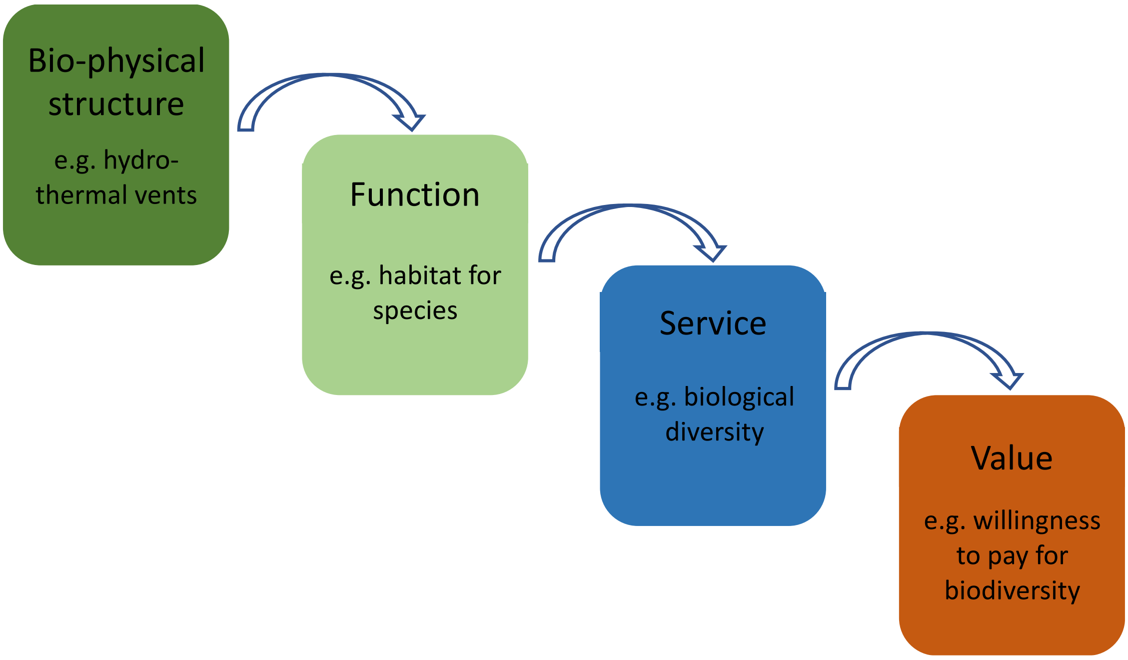

Figure 2. Ecosystem services "cascade". Adapted from Haines-Young and Potschin (2010).

Box 1. Defining ecosystem services

The conceptualization and understanding of ecosystem services has gradually been refined over the past 20+ years and a number of different definitions have been provided by different initiatives. These include:

- Ecosystem services are the benefits that ecosystems provide for people (Millennium Ecosystem Assessment – MA 2005).
- Ecosystem services are the direct and indirect contributions of ecosystems to human well-being (The Economics of Ecosystems and Biodiversity – TEEB; Kumar 2012)
- Ecosystem services refer to those contributions of the natural world that are used to produce goods which people value (UK National Ecosystem Assessment – UKNEA, 2011).
- Ecosystem services are the contributions that ecosystems make to human well-being (Common International Classification of Ecosystem Services – CICES; Haines-Young and Potschin 2012).
- The US Environmental Protection Agency (US EPA) use the term "final ecosystem goods and services" (FEGS) to mean "components of nature, directly enjoyed, consumed or used to yield human well- being" (Landers and Nahlik, 2013).
- The EU Mapping and Assessment of Ecosystems and their Services (MAES) working group defines ecosystem services as "the contributions of ecosystem structure and function (in combination with other inputs) to human well-being" (Burkhard and Maes, 2017)
- The International Panel of Biodiversity and Ecosystem Services (IPBES) introduced an additional term for ecosystem services – "nature's contributions to people" (NCP) – to describe the contributions, both positive and negative, of living nature (diversity of organisms, ecosystems, and their associated ecological and evolutionary processes) to people's quality of life (Diaz *et al*., 2018).

3.3 Natural capital

Ecosystem services can also be viewed as the flow of benefits received from "ecosystem capital" – see Figure 3. Ecosystem capital is a component of natural capital, which can be defined as the stock of natural assets that provide society with renewable and non-renewable resources and a flow of ecosystem services (Dasgupta, 2021). Natural capital includes abiotic assets (e.g. fossil fuels, minerals, metals) and biotic assets (ecosystems that provide a flow of ecosystem services). The biotic component of natural capital is termed ecosystem capital. Natural capital is analogous to built capital (e.g. transport infrastructure), human capital (e.g. a skilled and educated work force) or social capital (e.g. rules, norms and trust) as an input to the production of goods and services that humans consume. Natural capital may be both a complement to other forms of capital (i.e. used in combination with them to produce goods and services) or a substitute (used instead of other forms of capital). In the present study, the focus is on the ecosystem capital of abyssal plains, seamounts, and hydrothermal vents in the Area.

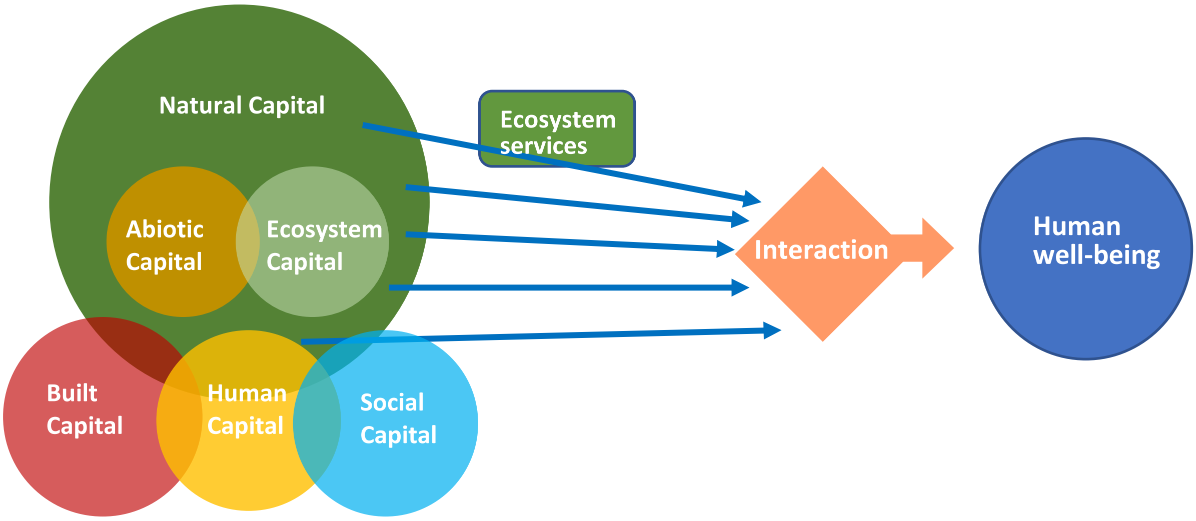

Figure 3. Interactions between natural, abiotic, ecosystem, built, human and social capital to contribute to human well-being. Adapted from Costanza *et al.* (2014).

4. Valuation approach

Given the global scale of the analysis and the time available to complete the assignment, it is not considered feasible to conduct new primary valuation studies. Application of primary valuation methods involves collecting new data, usually through surveys, which is beyond the scope of the present assignment. The proposed valuation approach for the analysis in this report is to make use value transfer methods. Value transfer is the use of research results from existing primary studies at one or more sites or policy contexts (study sites) to predict welfare estimates or related information for other sites or policy contexts (policy sites). Value transfer is also known as benefit transfer but since the values that are transferred may be costs as well as benefits, the term value transfer is more generally applicable. The use of value transfer methods is common in ecosystem service assessments, particularly for valuations across large geographic scales, but requires careful application ensure that the transferred values represent the characteristics and diversity of policy sites (Brander, 2013).

In addition to the need for an expeditious analysis for this report, value transfer methods enable the scaling up of information from relatively small study sites to large numbers of policy sites over large geographic scales, which would be the case for the valuation of ecosystem services in the Area.

The potential for conducting value transfers is directly related to the availability of relevant primary valuations. The first step in the present analysis is therefore to review the existing literature on the value of ecosystem services from deep-sea ecosystems.

The alternative methods of conducting value transfer are briefly outline here:

1. Unit value transfer uses values for ecosystem services at a study site, expressed as a value per unit (usually per unit of area or per beneficiary), combined with information on the quantity of units at the policy site to estimate policy site values. Unit values from the study site are multiplied by the number of units at the policy site. Unit values can be adjusted to reflect differences between the study and policy sites (e.g. income and price levels).
2. Value function transfer uses a value function estimated for an individual study site in conjunction with information on parameter values for the policy site to calculate the value of an ecosystem service at the policy site. A value function is an equation that relates the value of an ecosystem service to the characteristics of the ecosystem and the beneficiaries of the ecosystem service.
3. Meta-analytic function transfer uses a value function (see above) estimated from the results of multiple primary studies representing multiple study sites in conjunction with information on parameter values for the policy site to calculate the value of an ecosystem service at the policy site. Since the value function is estimated from the results of multiple studies it is able to represent and control for greater variation in the characteristics of ecosystems, beneficiaries and other contextual characteristics.

5. Literature review

The literature review is intended to provide a comprehensive overview of existing information on the economic value of ecosystem services provided by natural capital in the Area. The literature review targeted three related aspects of the topic:

1. Ecosystem services provided by biotic natural capital in the Area;
2. Economic values of ecosystem services provided by biotic natural capital in the Area;
3. Impacts of deep-sea mining on the provision of ecosystem services.

The review includes peer reviewed journal articles, working papers, research reports, academic dissertations/theses, NGO publications, and government reports. The review builds on relevant existing reviews (e.g. Armstrong et al. 2012; Folkersen et al., 2018) and databases of the ecosystem services valuation literature (e.g. The Ecosystem Services Valuation Database - www.ESVD.info).

The literature review was conducted using a variety of sources to ensure a comprehensive collection of studies was obtained. Traditional online literature tools and libraries such as Google Scholar, Scopus, ResearchGate, Mendeley, and institutional libraries were utilized to gather relevant published literature. Reports and studies that cited a large number of sources were subsequently used as a source of references, which helped to identify additional relevant literature. To further enhance the literature review, individual contacts were made with recognized experts in the area of deep-sea ecosystem research.

Combinations of search terms were used to encompass a literature that uses a diversity of terminology. The combinations used were in-part dependent on the search options available. Search terms for each sub-topic include:

Ecosystem Services:

- Ecosystems: Abyssal plains, Nodules, Seamounts, Crusts, Hydrothermal vents, Sulphides, Water column, Mid-water, Deep sea
- Food, fisheries, Genetic resources, Bio-mimicry, Carbon sequestration and storage, Biogeochemical cycling, Bequest value, Biodiversity, Existence value, Aesthetic, Tourism and recreation, Historical archive, Biodiversity.

Economic Valuation:

- Valuation methods: Contingent valuation, Market prices, Hedonic pricing, Replacement cost
- Value terms: Willingness to pay, Producer surplus, Consumer surplus, Total Economic Value, Net present value, Benefit
- Ecosystems: Abyssal plains, Nodules, Seamounts, Crusts, Hydrothermal vents, Sulphides, Water column, Mid-water, Deep sea

Deep Sea Mining impacts:

- Deep sea mining, Seabed mining, Mining impacts, Mining technology, Mining regulations, Mining management, Mining policy, Mining sustainability, Mining economics, Environmental impacts, Biodiversity impacts, Ecosystem services impacts, Habitat loss, Sediment plumes.

Collected literature were screened and selected using a two-step process. First, a preliminary review of titles and abstracts was used to eliminate studies that were clearly irrelevant. Second, a full-text review of the remaining studies was used to select those that meet the inclusion criteria:

- Publication type: All types of publications were considered, including journal articles, working papers, conference papers, dissertations, theses, NGO reports, and other grey literature.
- Year of value estimate: Studies and value estimates from any year were included, without any limitation to studies conducted after a certain year.
- Geographic location and scale: Study sites could be located at any scale, ranging from small habitat parcels to global biomes.
- Ecosystem/biome: We focused on studies that addressed Abyssal plains (nodules), Seamounts (crusts), Hydrothermal vents (sulphides), and the water column/mid-water.
- Valuation metric (for valuation studies): We included only studies that reported values measured in monetary units, not values measured in qualitative or bio-physical units.

- Valuation method (for valuation studies): We included only studies that applied primary valuation methods and excluded studies that used value transfers from other sources.

In total we identified 17 studies that identify ecosystem services from deep-sea ecosystems; 7 studies that provide monetary values for deep-sea ecosystem services; and 82 studies that address the potential environmental impacts of deep-sea mining activities.

6. Expert consultation

Expert consultations were undertaken to identify the key ecosystem services provided by habitats in the Area, collect relevant literature and gain a broad understanding of the issues and developments in the field. Relevant experts were identified based on the published literature and suggestions from other experts. Due to the limited time available for this study, the number of experts contacted is limited. Of the 25 experts contacted by email, 10 responded positively and agreed to an interview (see list in Table 1)

We recognise that the sample of experts that participated in the consultation may not be generally representative of the full spectrum of potential views and perspectives from all ISA stakeholders. Most of the experts that participated in the consultations are based in developed countries and some have expressed a position about potential future activities in the Area, which may lead to potential biases in the opinions.

The consultations were conducted in the form of in-person and online key informant interviews. The interviews varied in duration between 0.5-1.5 hours and were semi-structured around three questions that were shared by email beforehand:

1. What are the key ecosystem services provided by ecosystems in the Area?
2. What are the likely impacts of mining operations in the Area on ecosystems and their services?
3. What information (reports, articles etc.) is available on the economic value of deep-sea ecosystem services and biotic natural capital?

Table 1. List of experts consulted

Expert	Expertise	Affiliation
Sian Owens	Economics	Deep Sea Conservation Coalition
Matthew Gianni	Oceans/Marine Conservation	Deep Sea Conservation Coalition
Diva Amon	Marine biology	University of California, Santa Barbara
Matthias Haeckel	Marine/biogeochemical science	JPI Oceans
Phil Weaver	Geology/micro-palaeontology	SeaScape Consultants

Jeff Drazen	Ecology	University of Hawaii
Lisa Levin	Biological oceanography and marine ecology	Scripps Institute of Oceanography
Peiyuan Qian	Marine biology	Hong Kong University of Science and Technology
Nathalie Hilmi	Environmental economics	Centre Scientifique de Monaco
Bernado Bastien	Geography/environmental economics	Scripps Institute of Oceanography

7. Ecosystem services per seabed habitat

Based on the results of the literature review, existing reviews published in the literature (e.g., Armstrong et al. 2012) and the results of the expert consultations conducted for this report, Table 2 provides an overview of the ecosystem services provided by the three target seabed ecosystems in the Area. The references supporting this table are provided in Annex 1. Seabed habitats in the Area are recognised to provide a broad range of ecosystem services. In order to provide some prioritization, consulted experts were invited to identify "key" ecosystem services that are of potentially high economic value. There is reasonable consensus in the responses, with multiple respondents identifying genetic resources and existence/bequest values for unique biodiversity as being of particular importance. We also note that multiple respondents commented that the ecosystem service of carbon sequestration is likely to be of relatively low importance in terms of the incremental quantity of carbon added to the stock stored in seabed sediments. The stock of stored carbon itself is recognised to be very large but the quantity of additional carbon added to the stock each year by seabed ecosystems is likely to be relatively small.

Table 2. Ecosystem services provided by seabed habitats in the Area. Colours indicate expert opinion on level of importance: green = high importance; yellow = low importance; no colour = no identified consensus on level of importance.

	Abyssal plains (nodules)	Seamounts (crusts)	Hydrothermal vents (sulphides)
Provisioning			
Food (fisheries)		Seamounts support diverse fish communities, including species with high commercial value, such as tuna and billfish.	Hydrothermal vent communities support several species of fish, including the deep-sea anglerfish and zoarcid fish, which are commercially valuable.
Genetic resources (pharmaceutical etc)	Microbes that live in the abyssal plain are a potential source of novel biologically active compounds, such as antibiotics and anticancer agents.	Seamounts host genetic resources, including novel enzymes and proteins with potential applications in medicine and biotechnology.	Hydrothermal vents host unique microbial communities that can produce biologically active compounds, including enzymes, proteins, and antibiotics. These resources may have potential applications in medicine, biotechnology, and other industries.
Bio-mimicry	Organisms such as deep-sea sponges and other invertebrates have unique adaptations that can inspire technological advancements.	Organisms that have adaptations to the unique geological features of seamounts can inspire technological advancements.	Hydrothermal vents host unique ecosystems that can inspire the development of new materials and technologies, such as heat-resistant materials and sensors.
Regulating			

	Abyssal plains (nodules)	Seamounts (crusts)	Hydrothermal vents (sulphides)
Carbon sequestration and storage	The deposition of sediments and organic matter on the seafloor contributes to the long-term storage of carbon.	Seamounts are home to a diverse range of species that sequester carbon through photosynthesis and through the production of calcium carbonate shells, which eventually sink to the seafloor and contribute to carbon storage.	Hydrothermal vents are sites of active mineral precipitation and deposition, which can lead to the sequestration and storage of carbon. The minerals that form at these vents can trap carbon dioxide and other greenhouse gases.
Biogeochemical cycling	Abyssal plains are important sites for the cycling of nutrients and the remineralization of organic matter, which contributes to the production of nutrients that can support the growth of other organisms. The cycling of nutrients also plays a role in the biogeochemical cycling of carbon and other elements.	Seamounts are hotspots of biodiversity and play an important role in the cycling of nutrients and organic matter. The upwelling of nutrient-rich water around seamounts supports the growth of phytoplankton and other organisms, which in turn support the food web and contribute to the cycling of nutrients.	Hydrothermal vents are important sites for biogeochemical cycling, as they support chemosynthetic bacteria that are capable of using inorganic compounds to produce organic matter. These bacteria form the base of the food web at hydrothermal vents and contribute to the cycling of nutrients and other elements.
Cultural			
Existence and bequest value (biodiversity)	Abyssal plains provide habitat for a diverse range of species, including many that are not found anywhere else on Earth. The number, diversity and characteristics of species in the abyssal plain is largely unknown. People may place a value on the on the continued	Seamounts are biodiversity hotspots that provide habitat for many species of fish, invertebrates, and corals. People may place a value on the on the continued existence of this unique biodiversity and its conservation for future generations.	Hydrothermal vents are home to unique and specialized species that are adapted to the extreme conditions found in these environments. People may place a value on the on the continued existence of this unique biodiversity and its conservation for future generations.

	Abyssal plains (nodules)	Seamounts (crusts)	Hydrothermal vents (sulphides)
	existence of this unique biodiversity and its conservation for future generations.		
Aesthetic	The aesthetic nature of abyssal plains, although only indirectly accessible to the public through media, is of high value for those who appreciate the mysterious and awe-inspiring wonders of the deep ocean.	Seamounts host diverse and vibrant ecosystems and topographical magnificence, provide significant aesthetic value for those who are intrigued by the beauty and complexity of the marine environment.	Hydrothermal vents possess distinct aesthetic qualities due to their unique and specialized biological communities that have adapted to thrive in the extreme and dynamic conditions of the vent environments.
Tourism and recreation	Abyssal plains are not accessible for tourism and recreation due to their depth and remote location.	The tourism and recreation service of seamount ecosystems in the Area is limited due to their remote and extreme location.	The tourism and recreation service of hydrothermal vents ecosystems is limited due to their remote and extreme location, as well as their fragility.
Historical archive	Abyssal plains have the potential to serve as important archives of Earth's history, as sediment cores can provide information about past climates and environmental conditions.	Seamounts have the potential to serve as important archives of Earth's history, as they are often associated with past tectonic activity and can provide information about the geological history of the seafloor.	Hydrothermal vents ecosystems provide a valuable historical archive of the Earth's geologic and biological evolution. The minerals and chemical compounds deposited around hydrothermal vents preserve evidence of past geologic events and the evolution of life on Earth. Scientific study of these archives can provide valuable insights into the history and functioning of our planet.
Supporting			

	Abyssal plains (nodules)	Seamounts (crusts)	Hydrothermal vents (sulphides)
Biodiversity (microbes etc.)	Abyssal plains support biodiversity by providing a stable habitat for diverse deep-sea organisms, including microbes, many of which are unique to this ecosystem and contribute to the overall health and functioning of the global ocean.	Seamounts support biodiversity by providing a unique and diverse habitat for a wide range of marine organisms, including many endemic species that are adapted to the specific conditions of the seamount environment.	The biodiversity and microbial communities that inhabit hydrothermal vents ecosystems are incredibly diverse and specialized, performing critical functions such as nutrient cycling and energy production.

8. Ecosystem service values

From the literature review we identified only seven studies that provide estimates of economic values for ecosystem services provided by sea bed or deep-sea ecosystems. The results of these studies are summarised in Table 3 below.

The first observation on the available information is that the limited number of existing studies are for deep-sea ecosystems located in national EEZs. There are currently no studies that explicitly estimate values for the target ecosystems (abyssal plains, seamounts, hydrothermal vents) in ABNJ. This absence of representation in the literature is a major limitation to using existing information to estimate ecosystem service values for the Area.

Regarding the coverage of ecosystem services, we found value estimates for only four services: food provisioning, genetic resources, carbon sequestration, and existence and bequest values. The remaining ecosystem services identified in the preceding section are kept in Table 3 in order to highlight the gaps in available information. We note, however, that there are value estimates available for the two services that were identified as being of particular importance in the expert consultation (i.e., genetic resources and existence and bequest values).

Regarding genetic resources, this service has been valued using two different approaches that capture different components of value. The first is the market value of seven pharmaceutical compounds derived from deep-sea organisms that were traded in 2014 (Ottaviani, 2020). This estimate provides a measure of the current value of extracted genetic material but does not reflect the potential future or option value of genetic resources in seabed ecosystems. The second value estimate for genetic resources attempts to reflect the option value of future potential use through a discrete choice experiment in which the public are asked to state their willingness to pay for an increase in the potential for medicinal products derived from deep-sea organisms (Jobstvogt et al., 2014). We emphasise here the importance of assessing these separate components of total economic value derived from genetic resources, i.e. the direct use value of *current* applications derived from genetic material and the option value of maintaining genetic resources for *potential future* use. The future use of genetic resources from the seabed is unknown but there is a current value in maintaining the option to use them and develop an inventory and organismic library of microbes from the deep sea.

The ecosystem service for which there is a relatively large number of value estimates in the literature is the value that people place on the continued existence of biodiversity or for bequest to future generations. These valuations have applied stated preference methods (contingent valuation and discrete choice experiments) in which survey respondents are asked to state their willingness to pay for specified changes in biodiversity conservation. The level of biodiversity conservation has generally been framed in terms of the number or percentage of species protected or the extent of protection through marine protected area coverage.

To explore the possibility of applying these existing estimates of existence and bequest values to the context of the Area, we discuss here the necessary steps and considerations to transfer values:

1. Currency and year of value. The first step in synthesizing value estimates is to convert reported values to a common currency and price level. In Table 4 we convert values reported in other currencies to US$ using purchasing power parity adjusted market

exchange rates; and to 2020 price levels using deflators from the World Bank World Development Indicators.

2. Scale and scope of biodiversity conservation. The reported value estimates are for different scales of biodiversity conservation in terms of the area of the ecosystems considered and different scopes in terms of the type and number of species protected. This is a major challenge for transferring values to the Area since we expect the scale and scope to have a significant bearing on the values that people place on biodiversity conservation, although this is not always observed in the literature (Burrows et al., 2017). It is notable that the values obtained from the literature are generally of the same order of magnitude irrespective of the scale and scope of the resource.
3. Number of beneficiaries for aggregation. The estimated values from stated preference studies are generally reported in the form of average willingness to pay per household per year. To aggregate these values requires information on the total number of households that hold existence and bequest values for biodiversity in the Area. This is difficult to assess, but globally it is potentially a very large number of households. An initial consideration in determining the market size for existence and bequest values is the proportion of respondents to the reviewed primary valuation studies that express a positive willingness to pay. This information is summarised in Table 4 and ranges from 55-77%. Applying the mean proportion (67%) to the global number of households would imply that 1.38 billion households could hold existence and bequest values for biodiversity in the Area.
4. Variation in household values. The amount that individual households are willing to pay for biodiversity conservation is likely to vary substantially with household characteristics including income and knowledge for marine biodiversity. The existing value data are for high income countries and could potentially be adjusted downward to reflect lower incomes in other countries. An additional potential influence on household willingness to pay is the proximity of the resource. The effect of distance on values for existence and bequest values for biodiversity has been explored and generally there is little evidence of distance decay effects (Rolfe and Windle, 2012). The ecosystems of the Area, however, are extremely remote, which could affect the values that households place on their conservation.

In addition to the review of existing value data, we explored the possibility of using a published meta-analytic value function to estimate ecosystem service values for the Area. Folkersen et al. (2018) provide a systematic review and meta-analysis of values for marine ecosystem services. This analysis, however, faces substantial challenges in terms of limited sample size and inconsistency in the definition of the valued ecosystems and services. As a consequence, the authors do not recommend using the estimated value function for the purposes of predicting values.

In conclusion, given the very limited existing data on the value of ecosystem services provided by deep-sea ecosystems, it is currently not feasible to conduct robust value transfers to estimate global values for the Area. There is a need to conduct new primary valuation studies that are specifically designed to estimate the key ecosystem services provided by abyssal plains, seamounts and hydrothermal vents in the Area. Recommendations are outlined in Section 11.3.

Table 3. Summary of ecosystem service values from deep-sea ecosystems

Ecosystem Service		ES description	Ecosystem	Method	Value estimate	Reference
Provisioning	Food (fisheries)	Market value of deep-sea commercial fisheries in ABNJ	Deep-sea	Market prices	USD 443 million/year	Ottaviani (2020)
	Genetic resources (pharmaceutical etc)	Market value of seven pharmaceutical compounds derived from deep-sea organisms	Deep-sea	Market prices	USD 2.3 billion/year	Ottaviani (2020)
		High potential for medicinal products from deep-sea organisms	Deep-sea	DCE	GBP 35.43 household/year for increase in potential for medicinal products from deep-sea organisms from "unknown" to "high"	Jobstvogt et al (2014)
	Bio-mimicry	-	-	-	-	-
Regulating	Carbon sequestration and storage	Sequestration of carbon in deep-seas in ABNJ (0.1 GtCO2/year)	Deep-sea	Social cost of carbon[2] (USD 217 tCO2-eq)	USD 21,700 million/year	Ottaviani (2020)
	Biogeochemical cycling	-	-	-	-	-
Cultural	Existence and bequest value (biodiversity)	Willingness to pay (WTP) for the restoration of the Dohrn deep-	Sea canyon	CV	EUR 34.69 household/year	O'Connor et al (2020)

[2] The social cost of carbon is the monetary value of damages caused by emitting one tonne of CO_2 in a given year. The social cost of carbon (SCC) therefore also represents the value of damages avoided for a one tonne reduction in emissions (Pearce, 2003).

		sea canyon in the Bay of Naples to "high" biodiversity				
		Willingness to pay for expansion of MPAs to conserve seamounts and canyons	Sea mounts and canyons	DCE	USD 26 household/year for 2.27% increase in MPA coverage	Wallmo and Edwards (2008)
		Increase from 1000 to 1300 species protected	Deep-sea	DCE	GBP 22.48 household/year for 30% increase in species numbers	Jobstvogt et al (2014)
		WTP for protection of a percentage of deep-sea species in Mediterranean	Deep-sea	DCE	EUR 10.125 household/year increase deep-sea species protection from 5% to 10%	Carlesi et al (2023)
		WTP for protection of a percentage of marine species of the Azores	Open ocean	CV	EUR 16 household/year to protect 10% of invertebrates	Ressurreicao et al (2011)
		WTP for protection of deep-sea corals	Deep-sea coral	DCE	EUR 1 household/year to increase MPAs to cover all deep-sea coral	Wattage et (2011)
	Ornamental	-	-	-	-	-
	Tourism and recreation	-	-	-	-	-
	Historical archive	-	-	-	-	-
		-	-	-	-	-
Supporting	Biodiversity	-	-	-	-	-

Table 4. Summary of existence and bequest values for deep-sea ecosystems

Ecosystem	Area (km^2)	ES description	Valued change	USD/household/ year	% respondents	Reference
Sea canyon in Bay of Naples, Italy	78	Willingness to pay for the restoration of the Dohrn deep-sea canyon in the Bay of Naples	Restoration of deep-sea canyon to "high" biodiversity	29	58%	O'Connor et al (2020)
Sea floor, seamounts and canyons off New England, US	12,720	Willingness to pay for expansion of MPAs to conserve seamounts and canyons	2.27% increase in MPA coverage	26	76%	Wallmo and Edwards (2008)
Deep-sea in Scottish EEZ	22,500	Increase from 1000 to 1300 species protected	30% increase in species numbers	26		Jobstvogt et al (2014)
Deep-sea in Mediterranean	2,500,000	WTP for protection of a percentage of deep-sea species in Mediterranean	5% increase deep-sea species protected (from 5% to 10%)	8	55%	Carlesi et al (2023)
Open ocean and coastal waters of the Azores, Portugal	1,000,000	WTP for protection of a percentage of marine species of the Azores	10% of invertebrates protected	13	77%	Ressurreicao et al (2011)
Deep-sea coral in Irish EEZ		WTP for protection of deep-sea corals	Increase MPA to cover all deep-sea coral	1		Wattage (2011)

9. External costs of potential activities in the Area

The external costs of mining activities in the Area potentially include the negative impacts of resource extraction on ecosystems and their services. Quantifying the economic value of external costs requires an understanding of the impact pathway of mining activities on ecosystems, the provision of services, and their economic value. Any economic valuation of external costs therefore requires the quantification of biophysical impacts.

The geographic scale of contract areas for exploration (currently just over 1.4 million km^2) is relatively small in comparison to the overall size of the Area (less than 2%). And it is recognized that only a small proportion of the areas allocated for exploration are likely to be exploited. For the purposes of providing a complete measurement of external costs, however, the spatial boundary of analysis extends beyond the specific ecosystems from which resources are extracted. Deep-sea mining activities potentially have impacts on other ecosystems, particularly the water column above the resource and over a wider spatial extent through plume effects (Drazen et al., 2020; Weaver and Billett, 2019). It is also possible that downstream processing activities located on land will have impacts on terrestrial and coastal ecosystems that should be considered as external costs but this is considered beyond the scope of this report.

The number of studies on the potential impacts of deep-sea mining on ecosystems is relatively high and for each ecosystem a range of impacts are identified. Tables 5-8 provide overviews of the potential impacts of mining activities on abyssal plains, seamounts, hydrothermal vents and the water column respectively.

The literature emphasises the remaining high uncertainties regarding baseline understanding of the target ecosystems, the extent and duration of impacts, and effects on the provision of ecosystem services. The extent to which it is feasible to mitigate impacts from mining is an additional uncertainty. Some impacts may be unmitigable (e.g., loss of biodiversity in abyssal plains and seamounts) whereas others can potentially be reduced (e.g., plume effects in the water column) (Weaver et al., 2022).

For the purposes of quantifying the impact pathway from mining activities to environmental costs, uncertainties at each step in the pathway are compounded. This means that although some aspects may be relatively well understood (e.g. extent of biodiversity loss and recovery on abyssal plains), the environmental cost remains highly uncertain given lack of information on other aspects (e.g. baseline number and type of species; expected value of genetic material).

The potential loss of ecosystem services in the water column due to mining activities could be of greater economic importance than losses from the mined ecosystems. Potentially impacted ecosystem services in the water column include fisheries, carbon sequestration, and existence and bequest values for megafauna such as whales and turtles.

Table 5. Summary of potential impacts on **abyssal plains**

Impacts	Description	Estimate	Reference
Habitat Destruction and Biodiversity Loss	Deep sea mining has the potential to cause significant biodiversity loss and habitat destruction in the deep ocean. Mining activities can directly damage and destroy deep-sea habitats, as well as alter the surrounding ecosystem. This can result in the loss of unique and vulnerable species that are adapted to the extreme conditions of the deep sea.	The scale of impacts that would be associated with nodule mining in the CCZ may affect 100s to 1000s of km2 per mining operation per year	Wedding et al. (2018)
		Loss of up to 70% of benthic fauna Its full recovery is slow	Vanreusel et al. (2016)
		Loss of more than 167 unique species for each mining site.	Van Dover et al. (2017)
		The nodule extracting equipment will remove and disturb the top 15-40 cm of sediment that provide food for a high diversity of surface deposit-feeding organisms.	Levin et al. (2016)
		0% recovery (Some faunal groups showed no evidence of recovery) 64% of the faunal classes, plus grouped meiofauna and megafauna, showed negative impacts in faunal density relative to the controls < 1 year after disturbance	Jones et al. (2017)
		0% recovery of sessile megafauna	Borowski, C., & Thiel, H. (1998)
			Borowski, C. (2001)
			Bluhm, H. (2001)
			Ahnert, A., & Schriever, G. (2001)
		When mining begins, each strip mining of nodules can disrupt 300-800 km2 of seafloor per year	Smith et al. (2008) Oebius et al. (2001)

Impacts	Description	Estimate	Reference
		Physical influence of exploitation drilling extended to approximately 100 m	Gates & Jones (2012)
		In any given year, nodule mining by one to two contractors could disrupt seafloor communities over areas of 600 to 8,000 km2 15 years of mining could conceivably impact 120,000 km2. of seafloor	Smith et al. (2008)
		Nodules will require millions of years to regrow	Ghosh & Mukhopadhyay, 2000)
		partial megabenthic recovery between 3 and 10 yr post-disturbance.	Jones et al. (2012)
		Mortality amounts to 95% or 99.999% of the total individuals directly in the path of the nodule collector	Jumars (1981)
Re-suspension and disturbance of sediments (i.e. plumes)	The disturbance and redistribution of sediments during mining activities can alter the structure and composition of the seafloor, potentially affecting benthic ecosystems and biogeochemical cycles.	All experiments (7 study sites) resulted in some level of re-sedimentation	Jones et al. (2017)
		300-600km2/year will be disturbed for mining 1.5-3 million metric tonnes of nodules per year	Sharma (1993)
		Disturb the seafloor biota over a very poorly constrained area 2-5 fold larger due to redeposition of suspended sediment (1000-4000 km2) Full sediment-community recovery from major mining disturbance will take much longer than 7 years (and possibly even centuries)	Smith et al. (2008)
		Removal of the top 5 cm of sediment	Oebius et al. (2001)
		The maximum sediment concentration in the plume at that time may be up to 50 times above ambient	Jankowski et al (1996)
		Burial compaction reduces the porosity of bulk sediment (50–90%)	Reghellin et al. (2013)

Impacts	Description	Estimate	Reference
		Plumes could blanket the seabed. It is unknown the distance over which plumes will travel but estimates have been made that this could be up to 100 km from mining sites.	Gjerde et al. (2016)
		Concentrations of sediments tens to hundreds of times higher than they are adapted for.	Volz et al. (2018)
		Megafaunal densities were reduced with high levels of disturbance (from 0.60 m22 to 0.17 m22 ,20 m from the drilling site)	Jones et al. (2012)
		increase in suspended particles of 300% (from 49 to 150 mg m2 day-1)	Sharma et al. (2001)
Carbon sequestration loss	Sea mining can cause disruption of sequestration, which refers to the process by which carbon is removed from the atmosphere and stored in natural sinks such as the abyssal plains, potentially reducing the ocean's capacity to act as a carbon sink.	After 26 years, the carbon stock inside the plough tracks was 54 % of the carbon stock outside plough tracks.	Stratmann et al. (2018)
		Mining nickel on the ocean bed results in 80% less CO2 emissions compared to land-based mining	Deberdt, R., & Le Billon, P. (2022)
Noise pollution	The noise can disturb and potentially harm deep sea animals that rely on sound for communication, navigation, and finding prey. Additionally, the noise can travel long distances in the deep sea and potentially impact a larger area than the mining activity itself.	Seismic surveys altered behaviour of Rock lobster (Crustaceans)	Day et al. (2019)
		Microbial cell numbers were reduced by ~50% in fresh “tracks” and by <30% in the old tracks	Vonnahme et al. (2020)
		Death – a 2-3-fold increase in dead zooplankton overall	McCauley et al. (2017)
		noise from one mine could travel approximately 500 kilometers (roughly 311 miles)	Williams et al., (2022)

Impacts	Description	Estimate	Reference
Removal of ambient water	Most mining scenarios currently involve a closed riser system, which uses large amounts of ambient water for diluting the ground or crushed ore and pumping the slurry to the surface	Estimates of water removal per single mining operation/collector range from > 40,000 m−3 d−1 in SMS deposits , > 50,000 m−3 d−1 in FeMn nodule fields and 400,000 m−3 d−1 in metalliferous sediment of Red Sea brine pools	Christiansen et al. (2020)
Pollution		A single polymetallic nodule mining operation is estimated to discharge to the water column 50,000 meters-cubed of sediment, broken mineral fines, and seawater per day (~8 kilograms per metercubed solids)	Oebiuse et al. (2021)

Table 6. Summary of potential impacts on **seamounts**

Impacts	Description	Estimate	Reference
Habitat Destruction and Biodiversity Loss	Mining methods are expected to destroy the benthic habitats and ecosystems of seamounts, which would likely include corals and sponges that may have taken thousands of years to grow	0% recovery of the mega-benthos after 15 years	Althaus et al. (2009
		after up to 10 years there was no evidence of stony coral regrowth (deep seamount species have high longevity, and slow growth-rates)	Williams et al (2010)
Re-sedimentation and disturbance of sediments / Release of toxic compounds	The mining process can cause sediment plumes that can smother benthic organisms and reduce light availability, leading to changes in the distribution and abundance of marine life. Additionally, sea mining can result in the release of toxic compounds, such as heavy metals or organic chemicals, which can accumulate in	benthic plumes arising from disturbance by deep sea mining of cobalt-rich crusts were limited to within 1.4 km of the mining site and that deposition was limited to within 100m of the disturbance.	Spearman et al. (2020)

Impacts	Description	Estimate	Reference
	the food chain and pose a risk to human health and the environment		
Noise pollution	The noise generated by mining equipment can disturb and displace deep-sea organisms, disrupt their communication, and affect their ability to navigate and locate food sources	Seismic surveys altered behaviour of Rock lobster (Crustaceans)	Day et al. (2019)
		Death – a 2-3-fold increase in dead zooplankton overall	McCauley et al. (2017)
		Reduced catch rates due to Seismic survey – Longline catch rates fell for Greenland haddock (25% decrease)	Løkkeborg et al. (2012)
		Death through stranding of Melon-headed whales (Peponocephala electra) due to 12 kHz multibeam echosounder system	Southall et al. (2013)
		noise from one mine could travel approximately 500 kilometers (roughly 311 miles)	Williams et al., (2022)
Removal of ambient water	Most mining scenarios currently involve a closed riser system, which uses large amounts of ambient water for diluting the ground or crushed ore and pumping the slurry to the surface	Estimates of water removal per single mining operation/collector range from > 40,000 m^{-3} d^{-1} in SMS deposits , > 50,000 m^{-3} d^{-1} in FeMn nodule fields and 400,000 m^{-3} d^{-1} in metalliferous sediment of Red Sea brine pools	Christiansen et al. (2020)

Table 7. Summary of potential impacts on **hydrothermal vents**

Impacts	**Description**	**Estimate**	**Reference**
Habitat Destruction and Biodiversity Loss	Sea mining of hydrothermal vents can lead to significant habitat destruction and biodiversity loss due	At 11 months after drilling, no benthic animals were observed 10 m radius around Hole D/E (original Calyptogena colonies were completely buried by the drilling deposits)	Nakajima et al. (2015)

Impacts	Description	Estimate	Reference
	to physical damage, chemical and thermal changes in the water, and displacement of specialized organisms that have adapted to the extreme conditions of the vents.	Megafaunal density and diversity recovers partially from drilling disturbance after 3 years	
		Reductions in abundance of some species ranged between 71% and 88%, and persisted for less than 4 months after drilling Physical influence of exploitation drilling extended to approximately 100 m	Currie & Isaacs (2005)
Re-sedimentation and disturbance of sediments / Release of toxic compounds / Water quality	Sea mining can cause the re-sedimentation and disturbance of sediments, which can lead to changes in the composition and distribution of benthic communities.	130,000 t of unconsolidated sediment and 115,000 t of competent waste rock will be moved within the mining zones	Blackburn et al. (2010)
		The mean coverage (%) of drilling deposits seen as clay-like white sediments within a 10 m radius of Hole D/E was 60.4 ± 31.2% at 16 months after drilling The horizontal extent of the white drilling deposits in the present study was within 25 m of the drilling.	Nakajima et al. (2015)
		The horizontal extent of the white drilling deposits in the present study was within 10-25 m of the drilling.	Jones et al (2012)
		Increased sedimentation thicknesses of up to 500 mm may occur within 1 km of the discharge site Existing sediment thicknesses at and around Solwara 1 are 6 m deep in places	Gwyther (2008).
		(Water Quality) Unexpected equipment malfunctions could result in the loss of material in the Riser and Lyfting System. The maximum amount of mined ore in the riser pipe at any one time is approximately 11m3 which could be lost	Gena (2013)
		Higher concentration of Cu in the hepatopancreas	Auguste et al. (2016)
Noise pollution	Sea mining of hydrothermal vents can cause noise pollution that can disturb the feeding, mating, and	Seismic surveys altered behaviour of Rock lobster (Crustaceans)	Day et al. (2019)
		Death – a 2-3-fold increase in dead zooplankton overall	McCauley et al. (2017)

Impacts	Description	Estimate	Reference
	communication behaviors of specialized organisms adapted to the extreme conditions of the vents. The noise generated by mining activities can also cause bioturbation, which can alter sediment layers and impact nutrient cycling processes, further disrupting the delicate balance of the vent ecosystem.	Reduced catch rates due to Seismic survey – Longline catch rates fell for Greenland haddock (25% decrease)	Løkkeborg et al. (2012)
		noise from one mine could travel approximately 500 kilometers (roughly 311 miles)	Williams et al., (2022)
		These sounds may be audible at up to 600 km Harmful effect to whales 1.1 km from the source as the levels would be greater than 140 dB	Gena (2013)
Removal of ambient water	Most mining scenarios currently involve a closed riser system, which uses large amounts of ambient water for diluting the ground or crushed ore and pumping the slurry to the surface	Estimates of water removal per single mining operation/collector range from > 40,000 m^{-3} d^{-1} in SMS deposits , > 50,000 m^{-3} d^{-1} in FeMn nodule fields and 400,000 m^{-3} d^{-1} in metalliferous sediment of Red Sea brine pools	Christiansen et al. (2020)
Pollution		Hydrothermal vent operation could discharge to the water column 22,000 to 38,000 meters-cubed per day	Okamoro et al. (2019)

Table 8. Summary of potential impacts on **water column**

Impacts	Description	Estimate	Reference
Habitat Destruction and Biodiversity Loss	Sea bed mining activities can have significant impacts on the water column, affecting the biodiversity of planktonic and nektonic organisms, which play important roles in marine food webs and nutrient cycling	Median zooplankton abundance reduction of 64%	McCauley et al. (2017)

Impacts	Description	Estimate	Reference
Re-sedimentation and disturbance of sediments (i.e. plumes)	Sea bed mining activities can also potentially cause re-sedimentation and disturbance of sediments, resulting in the generation of sediment plumes that can have adverse impacts on the water column and the surrounding environment. These sediment plumes can affect water clarity, light penetration, and nutrient availability, potentially affecting photosynthesis and primary productivity.	The influence of vent plumes can extend into the overlying water column by 200 m or more	Drazen et al. (2020)
		It takes about 1 year for 10 µm sediment to settle to the bottom from the midwater column, over which time sediment can readily be transported up to 1000 km in very different directions by variable ocean currents.	Munoz-Royo et al. (2021)
Noise pollution	Sea bed mining activities can potentially generate underwater noise and vibration that can impact the water column and the marine environment, potentially causing harm to marine life such as whales, dolphins, and other sensitive species. The noise and vibration can travel long distances and disrupt communication, feeding, and migration patterns, potentially leading to changes in behaviour or population decline.	Dredging noise reported the transgression of thresholds for temporary hearing threshold shifts in harbour porpoise (*Phocoena phocoena*) at distances >74 m and behavioural avoidance extending beyond 400 m from the noise source	McQueen et al. (2020)
		Relatively low amplitude source level (135 dB re 1 µPa @ 1m) pingers operating at frequencies from 10 to 12 kHz on gillnets in fisheries in the Pacific Ocean eliminated bycatch of beaked whales, indicating that the whales both detected and avoided these sounds	Carretta et al. (2008)
		Deaths through stranding of at least 3% beaked whales when echosounders, operating simultaneously at the frequencies of 18, 38, 70, 120 and 200 kHz, were active Echosounders can be detected at 800 m depth out to a distance of at least 1.3 km	Cholewiak et al. (2017)
		Pile driving can be heard by cod and herring at distances possibly up to 80 km away	Thomsen et al. (2006)
		Seismic surveys altered behaviour of Rock lobster (Crustaceans)	Day et al. (2019)

Impacts	Description	Estimate	Reference
		Death – a 2-3-fold increase in dead zooplankton overall	McCauley et al. (2017)
		Reduced catch rates due to Seismic survey – Longline catch rates fell for Greenland haddock (25% decrease)	Løkkeborg et al. (2012)
		Altered behaviour of the Harbor porpoise due dredging– avoidance extending >400m from noise source	McQueen et al. (2020)
		Death through stranding of Melon-headed whales (*Peponocephala electr*a) due to 12 kHz multibeam echosounder system (2008)	Southall et al. (2013)
		Noise from one mine could travel approximately 500 kilometers based on model prediction (roughly 311 miles)	Williams et al., (2022)
Removal of ambient water	Most mining scenarios currently involve a closed riser system, which uses large amounts of ambient water for diluting the ground or crushed ore and pumping the slurry to the surface	Estimates of water removal per single mining operation/collector range from > 40,000 m^{-3} d^{-1} in SMS deposits , > 50,000 m^{-3} d^{-1} in FeMn nodule fields and 400,000 m^{-3} d^{-1} in metalliferous sediment of Red Sea brine pools	Christiansen et al. (2020)
Pollution	Sea bed mining activities can potentially release toxic substances such as heavy metals, hydrocarbons, and chemicals into the water column, which can have adverse effects on marine life and the environment.	A study by the Royal Swedish Academy of Science predicted that each mining ship would release about 2 million cubic feet of discharge every day, some of it containing toxic substances such as lead and mercury	Hylton (2020)
	Of particular importance for the water column is the discharge of the tailings from dewatering of the ore, which will introduce sediment and dissolved metals over potentially large areas	A single polymetallic nodule mining operation is estimated to discharge to the water column 50,000 meters-cubed of sediment, broken mineral fines, and seawater per day (~8 kilograms per metercubed solids)	Oebiuse et al. (2021)
		Hydrothermal vent operation could discharge to the water column 22,000 to 38,000 meters-cubed per day	Okamoro et al. (2019)
		Discharges could run continuously for up to 30 years, producing 500,000,000 m^3 of discharge over the lifetime of one operation	Drazen et al. (2020)

Impacts	Description	Estimate	Reference
		Tailings dry solids discharges from mining of massive sulphides have varied from 2 kg/s to 70 kg/s	Hein & Koschinsky (2014) Verichev (2014)

10.Conclusions

10.1 Summary of key findings

Through a review of the available literature, we identified and summarised 17 studies that identify ecosystem services from deep-sea ecosystems; 7 studies that provide monetary values for deep-sea ecosystem services; and 82 studies that address the potential environmental impacts of deep-sea mining activities.

Seabed habitats in the Area are recognised to provide a broad range of ecosystem services. Through consultations with 10 experts (8 organisations) conducted for this study, “key” ecosystem services that are of potentially high economic value were identified. These are genetic resources for use in medicines, biotechnology, and other industries; and the existence and bequest values that people hold for the preservation of unique biodiversity. Such results reflect the views of the limited number of experts consulted, and do not represent the full spectrum of potential views and perspectives from all ISA stakeholders.

The limited number of existing studies on the value of deep-sea ecosystem services are for study sites located in national EEZs and provide estimates for only four ecosystem services: food provisioning, genetic resources, carbon sequestration, and existence and bequest values. There are currently no studies that estimate values specifically for ecosystem services in the Area.

Given the very limited existing data on the value of deep-sea ecosystem services, we conclude that it is currently not feasible to conduct value transfers to estimate robust, or even indicative, global values for the Area. A further consideration is that the intended use of economic value estimates is to design mechanisms for internalising external costs of mining activities, which arguably requires a high degree of certainty. The limited availability of studies and data implies that additional research and knowledge are needed to distil robust solutions which can be used in a policy context.

The external costs of mining activities in the Area potentially include the negative impacts of resource extraction on ecosystems and their services. The boundary of analysis of external costs should extend beyond the specific ecosystems from which resources are extracted and include other impacted ecosystems, in particular those of the water column. Measuring the economic value of external costs requires a quantitative understanding of the entire impact pathway through to ecosystem services. We summarise information on biophysical impacts of deep-sea mining from 82 studies and note that many gaps remain. External costs due to negative impacts on ecosystem services in the water column are potentially high, including reduced carbon sequestration by phytoplankton (Hilmi et al., 2021) and impacts on marine mega-fauna, for which there are high existence and bequest values.

10.2 Uncertainties, gaps and limitations

The measurement of economic values for ecosystem services provided by ecosystems in the Area is pervaded with knowledge gaps and uncertainties. These encompass the bio-physical understanding of these ecosystems and the provision of ecosystem services, which necessarily underlies any economic valuation. Gaps and uncertainties related the understanding of biophysical baselines and processes have been well summarised in the literature (Amon et al., 2022). Filling these gaps will require joint efforts and a sufficient allocation of resources, given the magnitude and expected cost of this research. Focusing specifically on economic analyses, the major gap is the absence of any studies that estimate values for ecosystem services in the Area. Filling this gap would involve conducting primary valuations of the ecosystem services identified in this report at locations that are representative of the diverse ecosystems and contexts that are potentially impacted by seabed mining in the Area. Three specific ecosystem services that, on currently limited information, appear to have potentially high economic values and face high impacts from deep-sea mining: 1. Future values of genetic material for use in pharmaceutical and biotechnology applications; 2. Existence and bequest values for preservation of remote and largely unknown biodiversity in the Area, and the market size for such values globally; 3. The impact of mining activities on carbon sequestration by phytoplankton and other processes in the water column. We also acknowledge here the broad conceptual and perceptual diversity regarding the measurement of values for ecosystem services and biodiversity (IPBES, 2022). The analysis presented in this report uses an economic concept of value, but even within this framework there is diversity and the absence of an international standard (UN Statistical Division, 2021).

10.3 Recommendations for future research

Following from the identification of gaps and uncertainties, we make a number of recommendations for future research. The scale of further research required to fill gaps in the understanding of ecosystems, services, and impacts of activities in the Area is substantial; and the development of the research agenda itself requires time, resources and coordination (Amon et al., 2022). Here we attempt to draw some initial recommendations for future research on the economic valuation of ecosystem services from the Area.

Firstly, there is a need to conduct new primary valuation studies that are specifically designed to estimate the key ecosystem services provided by abyssal plains, seamounts and hydrothermal vents in the Area. For genetic resources, valuations need to capture the expected value of future pharmaceutical and industrial applications. This is challenging given the low probabilities of identifying culturable material and developing marketable applications. Methods developed for decision making under deep uncertainty could potentially be used to represent highly uncertain or unknown distributions of outcomes (Marchau et al. 2019). For the estimation of existence and bequest values for conservation of biodiversity, valuations need to reflect the particular characteristics of the ecosystems in the Area. The remoteness of the ecosystems and the unique and largely unknown characteristics of the biodiversity should be reflected in the design of stated preference valuations. Surveyed members of the public are unlikely to have prior knowledge of deep-sea ecosystems and their biodiversity, particularly since they are to a large extent scientifically unexplored, and so the valuation proposition is to measure willingness to pay for unknown biodiversity. For the purposes of developing information on the external costs of potential activities in the Area, it would be advisable to start with valuing impacts that are relatively well-understood. This appears to be the case for the high rates of biodiversity loss from mining activities in abyssal plains and seamounts. The impacts on biodiversity at hydrothermal vents is arguably characterised by higher uncertainty since mining activities are likely to target non-active vents, although impacts on biodiversity at adjacent active vents is still possible.

In anticipation that research on the economic value of ecosystem services from the Area will develop in the coming years, the sharing, synthesis and transfer of this information would be greatly facilitated by a common reporting standard for primary valuation results. One of the challenges faced in synthesising the current literature and using existing results for value transfers is the incomplete reporting and documentation on methods, valued services, scale and scope of valued changes, and description of the valued ecosystem and its context. We therefore recommend that a common reporting template is developed and adopted to enable an efficient production and sharing of information on economic values.

10.4 Next steps

The next and final component of the present study is to develop clear step-by-step guidance for conducting valuations of the impacts an individual mining concession on ecosystem services. The intention is that the methodology can be applied by applicants for exploitation contracts, tailored to their technical capacity and resources, and the results delivered as part of their plan of work. This guidance document will build on the wealth of existing guidance materials on ecosystem service valuation and tailored to the particular context of seabed mining. The guidance will cover the following steps in the valuation process: 1. Identifying key ecosystem services; 2. Quantifying impacts of seabed mining on the provision of ecosystem services; 3. Selection and implementation of relevant valuation methods; 4. Available data and resources; 5. Communicating results and uncertainty. The guidance on relevant valuation methods will follow a tiered approach to reflect varying levels of complexity and provide information on the time, expertise and budget required to implement alternative methods.

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13.Annex 1: References supporting Table 1 on ecosystem services from the Area

	Abyssal plains (nodules)	Seamounts (crusts)	Hydrothermal vents (sulphides)
Food (fisheries)	Smith, C. R., De Leo, F. C., Bernardino, A. F., Sweetman, A. K., & Arbizu, P. M. (2008). Abyssal food limitation, ecosystem structure and climate change. Trends in Ecology & Evolution, 23(9), 518-528. Bensch, A.; Gianni, M.; Gréboval, D.; Sanders, J.S.; Hjort, A. Worldwide review of bbottom fisheries in the high seas. FAO Fisheries and Aquaculture Technical Paper. No. 522. Rome, FAO. 2008. 145p Morato, T., Watson, R., Pitcher, T. J., & Pauly, D. (2006). Fishing down the deep. Fish and fisheries, 7(1), 24-34. MRAG, MG Otero & PolEM (2008) Analysis of the economic and social importance of Community fishing fleet using bottom gears in the high seas. London: MRAG Ltd. 250 pages Murillas-Maza, A., Virto, J., Gallastegui, M. C., González, P., & Fernández-Macho, J. (2011, May). The value of open ocean ecosystems: A case study for the Spanish exclusive economic zone. In Natural Resources Forum (Vol. 35, No. 2, pp. 122-133). Oxford, UK: Blackwell Publishing Ltd. Pham, C. K., Murillo, F. J., Lirette, C., Maldonado, M., Colaço, A., Ottaviani, D.,	Thurber, A. R., Sweetman, A. K., Narayanaswamy, B. E., Jones, D. O., Ingels, J., & Hansman, R. L. (2014). Ecosystem function and services provided by the deep-sea. Biogeosciences, 11(14), 3941-3963. Bensch, A.; Gianni, M.; Gréboval, D.; Sanders, J.S.; Hjort, A. Worldwide review of bbottom fisheries in the high seas. FAO Fisheries and Aquaculture Technical Paper. No. 522. Rome, FAO. 20 Morato, T., Watson, R., Pitcher, T. J., & Pauly, D. (2006). Fishing down the deep. Fish and fisheries, 7(1), 24-34. MRAG, MG Otero & PolEM (2008) Analysis of the economic and social importance of Community fishing fleet using bottom gears in the high seas. London: MRAG Ltd. 250 pages Murillas-Maza, A., Virto, J., Gallastegui, M. C., González, P., & Fernández-Macho, J. (2011, May). The value of open ocean ecosystems: A case study for the Spanish exclusive economic zone. In Natural Resources Forum (Vol. 35, No. 2, pp. 122-133). Oxford, UK: Blackwell Publishing Ltd. Pham, C. K., Murillo, F. J., Lirette, C., Maldonado, M., Colaço, A., Ottaviani, D., & Kenchington, E. (2019). Removal of deep-sea sponges by bottom trawling in the Flemish	Turner, P. J., Thaler, A. D., Freitag, A., & Collins, P. C. (2019). Deep-sea hydrothermal vent ecosystem principles: identification of ecosystem processes, services and communication of value. Marine Policy, 101, 118-124 Bensch, A.; Gianni, M.; Gréboval, D.; Sanders, J.S.; Hjort, A. Worldwide review of bbottom fisheries in the high seas. FAO Fisheries and Aquaculture Technical Paper. No. 522. Rome, FAO. 20 Morato, T., Watson, R., Pitcher, T. J., & Pauly, D. (2006). Fishing down the deep. Fish and fisheries, 7(1), 24-34. MRAG, MG Otero & PolEM (2008) Analysis of the economic and social importance of Community fishing fleet using bottom gears in the high seas. London: MRAG Ltd. 250 pages Murillas-Maza, A., Virto, J., Gallastegui, M. C., González, P., & Fernández-Macho, J. (2011, May). The value of open ocean ecosystems: A case study for the Spanish exclusive economic zone. In Natural Resources Forum (Vol. 35, No. 2, pp. 122-133). Oxford, UK: Blackwell Publishing Ltd. Pham, C. K., Murillo, F. J., Lirette, C., Maldonado, M., Colaço, A., Ottaviani, D., & Kenchington, E. (2019). Removal of deep-sea sponges by bottom trawling in the Flemish

	Abyssal plains (nodules)	Seamounts (crusts)	Hydrothermal vents (sulphides)
	& Kenchington, E. (2019). Removal of deep-sea sponges by bottom trawling in the Flemish Cap area: conservation, ecology and economic assessment. Scientific reports, 9(1), 15843. Armstrong, C. W., Foley, N., Tinch, R., & van den Hove, S. (2010). Ecosystem goods and services of the deep-sea. Deliverable D6, 2, 68..pdf FAO. 2016. Bottom fisheries in areas beyond national jurisdiction. Rome. 2 pp. (also available at www.fao.org/3/a-i6619e.pdf).	Cap area: conservation, ecology and economic assessment. Scientific reports, 9(1), 15843. FAO. 2016. Bottom fisheries in areas beyond national jurisdiction. Rome. 2 pp. (also available at www.fao.org/3/a-i6619e.pdf).	Cap area: conservation, ecology and economic assessment. Scientific reports, 9(1), 15843. FAO. 2016. Bottom fisheries in areas beyond national jurisdiction. Rome. 2 pp. (also available at www.fao.org/3/a-i6619e.pdf).
Genetic resources (pharmaceutical etc)	Thurber, A. R., Sweetman, A. K., Narayanaswamy, B. E., Jones, D. O., Ingels, J., & Hansman, R. L. (2014). Ecosystem function and services provided by the deep-sea. Biogeosciences, 11(14), 3941-3963. Arico, S. and Salpin, C., 2005. Bioprospecting of genetic resources in the deep-seabed: scientific, legal and policy aspects. Yokohama, Japan, United Nations University-Institute of Advanced Studies: 72.	Thurber, A. R., Sweetman, A. K., Narayanaswamy, B. E., Jones, D. O., Ingels, J., & Hansman, R. L. (2014). Ecosystem function and services provided by the deep-sea. Biogeosciences, 11(14), 3941-3963. Arico, S. and Salpin, C., 2005. Bioprospecting of genetic resources in the deep-seabed: scientific, legal and policy aspects. Yokohama, Japan, United Nations University-Institute of Advanced Studies: 72.	Thornburg, C. C., Zabriskie, T. M., & McPhail, K. L. (2010). Deep-sea hydrothermal vents: potential hot spots for natural products discovery?. Journal of natural products, 73(3), 489-499. Turner, P. J., Thaler, A. D., Freitag, A., & Collins, P. C. (2019). Deep-sea hydrothermal vent ecosystem principles: identification of ecosystem processes, services and communication of value. Marine Policy, 101, 118-124. Martins, A., Tenreiro, T., Andrade, G., Gadanho, M., Chaves, S., Abrantes, M., ... & Vieira, H. (2013). Photoprotective bioactivity present in a unique marine bacteria collection from Portuguese deep-sea hydrothermal vents. Marine Drugs, 11(5), 1506-1523.

	Abyssal plains (nodules)	Seamounts (crusts)	Hydrothermal vents (sulphides)
			Le, J., Amon, D. J., Baker, M., Bravo, M. E., Dobush, B. J., Gertz, B., ... & Yasuhara, M. (2022). What Does the Deep Ocean Do for You?. Armstrong, C. W., Foley, N., Tinch, R., & van den Hove, S. (2010). Ecosystem goods and services of the deep-sea. Deliverable D6, 2, 68..pdf Arico, S. and Salpin, C., 2005. Bioprospecting of genetic resources in the deep-seabed: scientific, legal and policy aspects. Yokohama, Japan, United Nations University-Institute of Advanced Studies: 72. Leary, D., Vierros, M., Hamon, G., Arico, S., & Monagle, C. (2009). Marine genetic resources: a review of scientific and commercial interest. Marine Policy, 33(2), 183-194.
Bio-mimicry	Blasiak, R., Jouffray, J. B., Amon, D. J., Moberg, F., Claudet, J., Søgaard Jørgensen, P., ... & Österblom, H. (2022). A forgotten element of the blue economy: marine biomimetics and inspiration from the deep-sea. PNAS Nexus, 1(4), pgac196.	Blasiak, R., Jouffray, J. B., Amon, D. J., Moberg, F., Claudet, J., Søgaard Jørgensen, P., ... & Österblom, H. (2022). A forgotten element of the blue economy: marine biomimetics and inspiration from the deep-sea. PNAS Nexus, 1(4), pgac196.	Turner, P. J., Thaler, A. D., Freitag, A., & Collins, P. C. (2019). Deep-sea hydrothermal vent ecosystem principles: identification of ecosystem processes, services and communication of value. Marine Policy, 101, 118-124. Blasiak et al 2022 A forgotten element of the blue economy- marine biomimetics and inspiration from the deep-sea.pdf Armstrong, C. W., Foley, N., Tinch, R., & van den Hove, S. (2010). Ecosystem goods and services of the deep-sea. Deliverable D6, 2,

	Abyssal plains (nodules)	Seamounts (crusts)	Hydrothermal vents (sulphides)
			68..pdf Arico, S. and Salpin, C., 2005. Bioprospecting of genetic resources in the deep-seabed: scientific, legal and policy aspects. Yokohama, Japan, United Nations University-Institute of Advanced Studies: 72. Leary, D., Vierros, M., Hamon, G., Arico, S., & Monagle, C. (2009). Marine genetic resources: a review of scientific and commercial interest. Marine Policy, 33(2), 183-194. Blasiak, R., Jouffray, J. B., Amon, D. J., Moberg, F., Claudet, J., Søgaard Jørgensen, P., ... & Österblom, H. (2022). A forgotten element of the blue economy: marine biomimetics and inspiration from the deep-sea. PNAS Nexus, 1(4), pgac196.
Carbon sequestration and storage	Thurber, A. R., Sweetman, A. K., Narayanaswamy, B. E., Jones, D. O., Ingels, J., & Hansman, R. L. (2014). Ecosystem function and services provided by the deep-sea. Biogeosciences, 11(14), 3941-3963. Sweetman, A. K., Smith, C. R., Shulse, C. N., Maillot, B., Lindh, M., Church, M. J., ... & Gooday, A. J. (2019). Key role of bacteria in the short-term cycling of carbon at the abyssal seafloor in a low particulate organic carbon flux region of	Murillas-Maza, A., Virto, J., Gallastegui, M. C., González, P., & Fernández-Macho, J. (2011, May). The value of open ocean ecosystems: A case study for the Spanish exclusive economic zone. In Natural Resources Forum (Vol. 35, No. 2, pp. 122-133). Oxford, UK: Blackwell Publishing Ltd. Armstrong, C. W., Foley, N., Tinch, R., & van den Hove, S. (2010). Ecosystem goods and services of the deep-sea. Deliverable D6, 2, 68..pdf	Turner, P. J., Thaler, A. D., Freitag, A., & Collins, P. C. (2019). Deep-sea hydrothermal vent ecosystem principles: identification of ecosystem processes, services and communication of value. Marine Policy, 101, 118-124. Levin, L. A., & Le Bris, N. (2015). The deep ocean under climate change. Science, 350(6262), 766-768. Le, J., Amon, D. J., Baker, M., Bravo, M. E., Dobush, B. J., Gertz, B., ... & Yasuhara, M. (2022). What Does the Deep Ocean Do for

	Abyssal plains (nodules)	Seamounts (crusts)	Hydrothermal vents (sulphides)
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Biogeochemical cycling	Armstrong, C. W., Foley, N., Tinch, R., & van den Hove, S. (2010). Ecosystem goods and services of the deep-sea. Deliverable D6, 2, 68..pdf	Armstrong, C. W., Foley, N., Tinch, R., & van den Hove, S. (2010). Ecosystem goods and services of the deep-sea. Deliverable D6, 2, 68..pdf	Turner, P. J., Thaler, A. D., Freitag, A., & Collins, P. C. (2019). Deep-sea hydrothermal vent ecosystem principles: identification of ecosystem processes, services and communication of value. Marine Policy, 101, 118-124. Levin, L. A., & Le Bris, N. (2015). The deep ocean under climate change. Science, 350(6262), 766-768. Le, J., Amon, D. J., Baker, M., Bravo, M. E., Dobush, B. J., Gertz, B., ... & Yasuhara, M.

	Abyssal plains (nodules)	Seamounts (crusts)	Hydrothermal vents (sulphides)
			(2022). What Does the Deep Ocean Do for You?. Armstrong, C. W., Foley, N., Tinch, R., & van den Hove, S. (2010). Ecosystem goods and services of the deep-sea. Deliverable D6, 2, 68..pdf
Bequest value (biodiversity)	Murillas-Maza, A., Virto, J., Gallastegui, M. C., González, P., & Fernández-Macho, J. (2011, May). The value of open ocean ecosystems: A case study for the Spanish exclusive economic zone. In Natural Resources Forum (Vol. 35, No. 2, pp. 122-133). Oxford, UK: Blackwell Publishing Ltd. Jobstvogt, N., Hanley, N., Hynes, S., Kenter, J., & Witte, U. (2014). Twenty thousand sterling under the sea: Estimating the value of protecting deep-sea biodiversity. Ecological Economics, 97(C), 10-19 Chen, W., Wallhead, P., Hynes, S., Groeneveld, R., O'Connor, E., Gambi, C., ... & Smith, C. (2022). Ecosystem service benefits and costs of deep-sea ecosystem restoration. Journal of Environmental Management, 303, 114127. Armstrong, C. W., Foley, N., Tinch, R., & van den Hove, S. (2010). Ecosystem	Wattage, P., Glenn, H., Mardle, S., Van Rensburg, T., Grehan, A., & Foley, N. (2011). Economic value of conserving deep-sea corals in irish waters: A choice experiment study on marine protected areas. Fisheries Research, 107(1-3), 59-67. doi:10.1016/j.fishres.2010.10.007 Murillas-Maza, A., Virto, J., Gallastegui, M. C., González, P., & Fernández-Macho, J. (2011, May). The value of open ocean ecosystems: A case study for the Spanish exclusive economic zone. In Natural Resources Forum (Vol. 35, No. 2, pp. 122-133). Oxford, UK: Blackwell Publishing Ltd. Jobstvogt, N., Hanley, N., Hynes, S., Kenter, J., & Witte, U. (2014). Twenty thousand sterling under the sea: Estimating the value of protecting deep-sea biodiversity. Ecological Economics, 97(C), 10-19 Chen, W., Wallhead, P., Hynes, S., Groeneveld, R., O'Connor, E., Gambi, C., ... & Smith, C. (2022). Ecosystem service benefits and costs of deep-sea ecosystem	Murillas-Maza, A., Virto, J., Gallastegui, M. C., González, P., & Fernández-Macho, J. (2011, May). The value of open ocean ecosystems: A case study for the Spanish exclusive economic zone. In Natural Resources Forum (Vol. 35, No. 2, pp. 122-133). Oxford, UK: Blackwell Publishing Ltd. Jobstvogt, N., Hanley, N., Hynes, S., Kenter, J., & Witte, U. (2014). Twenty thousand sterling under the sea: Estimating the value of protecting deep-sea biodiversity. Ecological Economics, 97(C), 10-19 Chen, W., Wallhead, P., Hynes, S., Groeneveld, R., O'Connor, E., Gambi, C., ... & Smith, C. (2022). Ecosystem service benefits and costs of deep-sea ecosystem restoration. Journal of Environmental Management, 303, 114127. Armstrong, C. W., Foley, N., Tinch, R., & van den Hove, S. (2010). Ecosystem goods and services of the deep-sea. Deliverable D6, 2, 68..pdf

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	goods and services of the deep-sea. Deliverable D6, 2, 68..pdf	restoration. Journal of Environmental Management, 303, 114127. Armstrong, C. W., Foley, N., Tinch, R., & van den Hove, S. (2010). Ecosystem goods and services of the deep-sea. Deliverable D6, 2, 68..pdf	
Existence value (biodiversity)	Murillas-Maza, A., Virto, J., Gallastegui, M. C., González, P., & Fernández-Macho, J. (2011, May). The value of open ocean ecosystems: A case study for the Spanish exclusive economic zone. In Natural Resources Forum (Vol. 35, No. 2, pp. 122-133). Oxford, UK: Blackwell Publishing Ltd. Jobstvogt, N., Hanley, N., Hynes, S., Kenter, J., & Witte, U. (2014). Twenty thousand sterling under the sea: Estimating the value of protecting deep-sea biodiversity. Ecological Economics, 97(C), 10-19 Chen, W., Wallhead, P., Hynes, S., Groeneveld, R., O'Connor, E., Gambi, C., ... & Smith, C. (2022). Ecosystem service benefits and costs of deep-sea ecosystem restoration. Journal of Environmental Management, 303, 114127. Armstrong, C. W., Foley, N., Tinch, R., & van den Hove, S. (2010). Ecosystem	Wattage, P., Glenn, H., Mardle, S., Van Rensburg, T., Grehan, A., & Foley, N. (2011). Economic value of conserving deep-sea corals in irish waters: A choice experiment study on marine protected areas. Fisheries Research, 107(1-3), 59-67. doi:10.1016/j.fishres.2010.10.007 Murillas-Maza, A., Virto, J., Gallastegui, M. C., González, P., & Fernández-Macho, J. (2011, May). The value of open ocean ecosystems: A case study for the Spanish exclusive economic zone. In Natural Resources Forum (Vol. 35, No. 2, pp. 122-133). Oxford, UK: Blackwell Publishing Ltd. Jobstvogt, N., Hanley, N., Hynes, S., Kenter, J., & Witte, U. (2014). Twenty thousand sterling under the sea: Estimating the value of protecting deep-sea biodiversity. Ecological Economics, 97(C), 10-19 Chen, W., Wallhead, P., Hynes, S., Groeneveld, R., O'Connor, E., Gambi, C., ... & Smith, C. (2022). Ecosystem service benefits and costs of deep-sea ecosystem restoration. Journal of Environmental	Murillas-Maza, A., Virto, J., Gallastegui, M. C., González, P., & Fernández-Macho, J. (2011, May). The value of open ocean ecosystems: A case study for the Spanish exclusive economic zone. In Natural Resources Forum (Vol. 35, No. 2, pp. 122-133). Oxford, UK: Blackwell Publishing Ltd. Jobstvogt, N., Hanley, N., Hynes, S., Kenter, J., & Witte, U. (2014). Twenty thousand sterling under the sea: Estimating the value of protecting deep-sea biodiversity. Ecological Economics, 97(C), 10-19 Chen, W., Wallhead, P., Hynes, S., Groeneveld, R., O'Connor, E., Gambi, C., ... & Smith, C. (2022). Ecosystem service benefits and costs of deep-sea ecosystem restoration. Journal of Environmental Management, 303, 114127. Armstrong, C. W., Foley, N., Tinch, R., & van den Hove, S. (2010). Ecosystem goods and services of the deep-sea. Deliverable D6, 2, 68..pdf

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	goods and services of the deep-sea. Deliverable D6, 2, 68..pdf	Management, 303, 114127. Armstrong, C. W., Foley, N., Tinch, R., & van den Hove, S. (2010). Ecosystem goods and services of the deep-sea. Deliverable D6, 2, 68..pdf	
Ornamental	Murillas-Maza, A., Virto, J., Gallastegui, M. C., González, P., & Fernández-Macho, J. (2011, May). The value of open ocean ecosystems: A case study for the Spanish exclusive economic zone. In Natural Resources Forum (Vol. 35, No. 2, pp. 122-133). Oxford, UK: Blackwell Publishing Ltd.	Murillas-Maza, A., Virto, J., Gallastegui, M. C., González, P., & Fernández-Macho, J. (2011, May). The value of open ocean ecosystems: A case study for the Spanish exclusive economic zone. In Natural Resources Forum (Vol. 35, No. 2, pp. 122-133). Oxford, UK: Blackwell Publishing Ltd.	Murillas-Maza, A., Virto, J., Gallastegui, M. C., González, P., & Fernández-Macho, J. (2011, May). The value of open ocean ecosystems: A case study for the Spanish exclusive economic zone. In Natural Resources Forum (Vol. 35, No. 2, pp. 122-133). Oxford, UK: Blackwell Publishing Ltd.
Tourism and recreation	Armstrong, C. W., Foley, N., Tinch, R., & van den Hove, S. (2010). Ecosystem goods and services of the deep-sea. Deliverable D6, 2, 68..pdf	Armstrong, C. W., Foley, N., Tinch, R., & van den Hove, S. (2010). Ecosystem goods and services of the deep-sea. Deliverable D6, 2, 68..pdf	Armstrong, C. W., Foley, N., Tinch, R., & van den Hove, S. (2010). Ecosystem goods and services of the deep-sea. Deliverable D6, 2, 68..pdf
Historical archive	Armstrong, C. W., Foley, N., Tinch, R., & van den Hove, S. (2010). Ecosystem goods and services of the deep-sea. Deliverable D6, 2, 68..pdf	Armstrong, C. W., Foley, N., Tinch, R., & van den Hove, S. (2010). Ecosystem goods and services of the deep-sea. Deliverable D6, 2, 68..pdf	Turner, P. J., Thaler, A. D., Freitag, A., & Collins, P. C. (2019). Deep-sea hydrothermal vent ecosystem principles: identification of ecosystem processes, services and communication of value. Marine Policy, 101, 118-124. Le, J., Amon, D. J., Baker, M., Bravo, M. E., Dobush, B. J., Gertz, B., ... & Yasuhara, M. (2022). What Does the Deep Ocean Do for You?. Armstrong, C. W., Foley, N., Tinch, R., & van den Hove, S. (2010). Ecosystem goods and

	Abyssal plains (nodules)	Seamounts (crusts)	Hydrothermal vents (sulphides)
			services of the deep-sea. Deliverable D6, 2, 68..pdf
Biodiversity (microbes etc.)	Amon, D.J., Ziegler, A.F., Dahlgren, T.G., Glover, A.G., Goineau, A., Gooday, A.J., Wiklund, H., Smith, C.R., 2016. Insights into the abundance and diversity of abyssal megafauna in a polymetallic-nodule region in the eastern Clarion-Clipperton Zone. Sci. Rep. 6, 30492 Armstrong, C. W., Foley, N., Tinch, R., & van den Hove, S. (2010). Ecosystem goods and services of the deep-sea. Deliverable D6, 2, 68..pdf	Armstrong, C. W., Foley, N., Tinch, R., & van den Hove, S. (2010). Ecosystem goods and services of the deep-sea. Deliverable D6, 2, 68..pdf	Turner, P. J., Thaler, A. D., Freitag, A., & Collins, P. C. (2019). Deep-sea hydrothermal vent ecosystem principles: identification of ecosystem processes, services and communication of value. Marine Policy, 101, 118-124. Salinas-de-León, P., Phillips, B., Ebert, D., Shivji, M., Cerutti-Pereyra, F., Ruck, C., ... & Marsh, L. (2018). Deep-sea hydrothermal vents as natural egg-case incubators at the Galapagos Rift. Scientific reports, 8(1), 1788. Armstrong, C. W., Foley, N., Tinch, R., & van den Hove, S. (2010). Ecosystem goods and services of the deep-sea. Deliverable D6, 2, 68..pdf