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Depths of uncertainty for deep-sea policy and legislation

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ABSTRACT

In comparison to terrestrial and coastal ecosystems, much remains unknown about the deep sea's ecosystems and their economic value. This is of concern on at least three fronts. First, the deep sea forms the majority of the ocean's marine systems and contributes substantially to global fish stocks (Danovaro et al., 2017; Drazen and Sutton, 2017). Second, it is essential for the functioning of global biogeochemical cycles, and underpins the sustenance of terrestrial ecosystems and human life (Armstrong et al., 2012). Third, the deep sea faces increased pressure from human activity in the form of deep-sea mining (DSM) (The World Bank, 2016). Based upon lessons drawn from a recent systematic review and meta-analysis published in *Marine Policy* (Folkersen et al., 2018), this letter discusses four main directions for future research into economic valuation, policymaking and legislation pertaining to the deep sea. First, the valuation perspective adopted for policy and decision-making on deep-sea resources needs to be defined clearly. Second, strategic environmental assessments (SEAs) and environmental impact assessments (EIAs) of DSM activities need to examine the potential global environmental damage from DSM, rather than examine impacts restricted to the geographical site in which mining takes place. Third, the interdependence between anthropogenic behaviour and economic value generated by the deep sea requires further investigation. Fourth, in addition to the valuation of specific ecosystem goods and services, the ecosystem functioning of the deep sea should also be valued. Improving our understanding of the value that the deep sea provides to human societies can facilitate sustainable resource-use, effective environmental management, and prevent severe and irreversible damage to the deep sea's ecosystems.

1. Introduction

The deep sea, making up 95% of the global oceans (Drazen and Sutton, 2017), forms the largest set of ecosystems on the planet and is fundamental to sustaining terrestrial and coastal ecosystems, and human existence through the provision of supporting ecosystem goods and services (e.g. nutrient cycling, carbon dioxide (CO_2) absorption), and also through its rich biodiversity (e.g. the provision of endemic biological organisms) (Danovaro et al., 2017; Armstrong et al., 2012; Jobstvogt et al., 2014; Van Dover et al., 2014; Davies et al., 2007). For instance, CO_2 concentrations in the atmosphere would be approximately 50% higher in the absence of the global ocean system's ability to absorb carbon. Thus, the deep sea plays a crucial role in regulating the global climate. The deep sea's ecosystems (e.g. hydrothermal vents, abyssal plains, seamounts, deep coral reefs, etc.) represent a considerable knowledge gap in scientific research, particularly in comparison to terrestrial and coastal ecosystems (Aanesen et al., 2015; Armstrong et al., 2012). General patterns and interactions of the deep sea's lifeforms have been observed showing that deep-sea species tend to have much slower metabolisms than their shallow-water counterparts, making them highly vulnerable to external influences (Danovaro et al., 2017). In this perspective article we present four main directions for future deep-sea policy, research and decision-making. The main directions set forth are based upon lessons drawn from a recent systematic review and meta-analysis on the deep sea's economic value, 'The economic value of the deep sea: a systematic review and meta-analysis' published in *Marine Policy* (Folkersen et al., 2018).

2. The dilemma of formulating policies and laws for deep-sea mining

The enormous knowledge gap about the deep sea's ecosystems is a growing problem for the formulation of polices, laws and regulations pertaining to the use of the deep sea, especially for deep-sea mining (DSM) (Van Dover, 2011; Ahnert and Borowski, 2000). DSM is an activity which involves extracting valuable minerals such as gold, silver,

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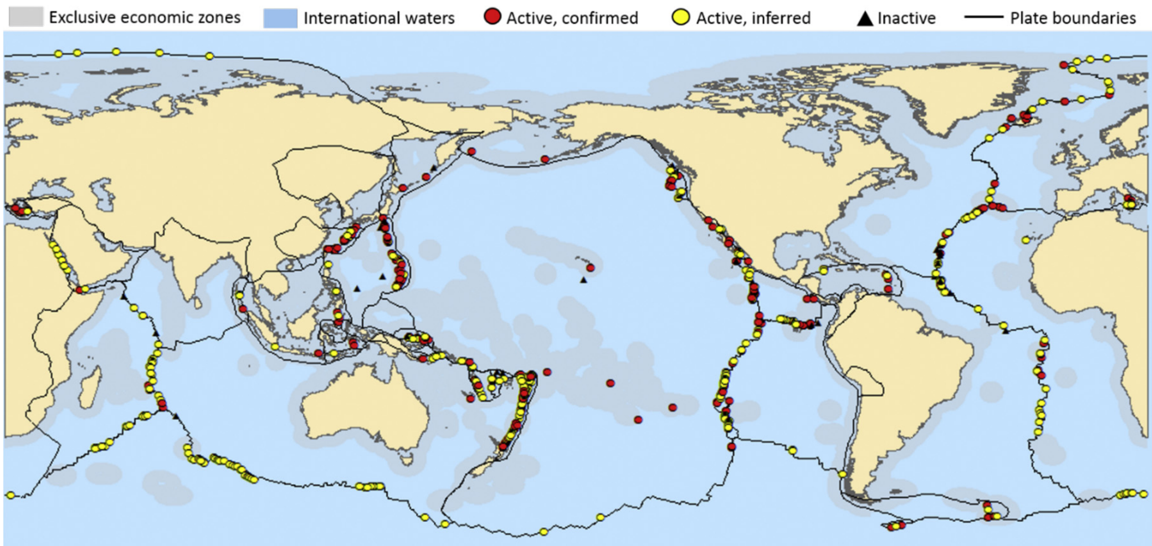

Fig. 1. Global map of tectonic plates and hydrothermal vents (Beaulieu, 2015).

copper and zinc from the deep ocean floor, in particular from hydrothermal vents with large mineral concentrations (Fig. 1).

Policymakers are under increasing pressure to make decisions about the extent to which, and under what conditions, DSM should be allowed. An important component of the decision making process is the accurate estimation of the costs and benefits of potential future DSM operations, e.g. through economic valuation. This is difficult, however, as we have little knowledge of the economic costs or benefits associated with the deep sea's ecosystems and robust evidence on the economic value of protecting these ecosystems remains extremely scarce (Jobstvogt et al., 2014; Smith, 1997). Further, it has not been possible to scientifically evidence the environmental impacts of DSM because of the large scientific knowledge gap pertaining to the deep sea (Ahnert and Borowski, 2000; Thiel et al., 2005). To date, most of the DSM licences that have been granted are for exploration (i.e. identifying mining potential); an exploitation mining license has only been granted for the Solwara 1 project in Papua New Guinea. Nonetheless, the granting of DSM exploration licenses has received criticism from governmental institutions (The World Bank, 2016), NGOs and academia (Van Dover et al., 2014, 2018; Armstrong et al., 2012; Steiner, 2009), as has the quality and validity of the environmental impact assessment (EIA) conducted to obtain the DSM license in Papua New Guinea (Steiner, 2009; Filer and Gabriel, 2018).

3. The economics of the ecosystem services of the deep sea

The 15 studies included in the meta-analysis published in *Marine Policy* yield 35 observations on the value of the deep sea. Of these observations, 13 are focused on areas with active hydrothermal vents surrounding the Pacific island countries, the Red Sea and the Southern Ocean, which indicates an interest in DSM and its value potential. The remaining observations pertain more generally to the ecosystem services provided by the deep sea globally or areas in the North Atlantic Ocean. The annualised economic values, expressed in 2011 International dollars (Fig. 2 panel a) range from as little as I$1 to as much as I$1.4 trillion. Estimates of *provisioning services* based on an *exchange value* perspective are, on average, higher than those based on an economic welfare (*net benefit*) perspective. The net benefit of *regulating services* tends to be distributed at the upper end of the value spectrum, whereas *other services* (those services that could not be categorised as either provisioning, regulating, cultural or total) tend to sit at the lower end of the value spectrum. The wide range of values reported in these studies demonstrate the considerable level of uncertainty, which may be attributable to the large knowledge gap in both the scientific and social understanding of the interrelationships between the deep-sea ecosystems and human welfare. The global distribution of all known hydrothermal vents (Fig. 1), is compared against the collated dataset on the economic value of the deep sea (Fig. 2 panels a and b).

4. Directions for future research, policy and legislation in the deep sea

The four main directions for future research into economic valuation, policymaking and legislation pertaining to the deep sea are outlined below.

First, there is little consensus on whether DSM is likely to yield net benefits or costs. Some studies conclude that DSM will generate positive economic benefits (Cardno, 2016; Bertram et al., 2011; Seidel and Lal, 2010), while others conclude that DSM will generate high economic costs to society, and possibly irreversible damage to the deep sea's ecosystems (Van Dover et al., 2014, 2018; Armstrong et al., 2012). Ironically, the advocates and naysayers of DSM seek to estimate the same thing – economic value – but from opposing valuation perspectives. A cost-benefit-analysis (CBA) conducted for a future business operation will inevitably adopt a private (company focused) frame of reference for their estimation of costs and benefits, failing to estimate the potential social impacts. In contrast, a CBA conducted for a governmental institution is more likely to adopt a social perspective, thereby including the estimation of the costs and benefits for the affected parties within society. A CBA focused exclusively on private profitability of DSM activities should not form the information basis for policymaking or legislation pertaining to the deep sea. Clearly distinguishing private profits from social benefits (or costs) in CBAs of DSM activities can provide a more legitimate picture of whether DSM indeed will yield benefits or costs for society. The valuation perspective adopted for policy and decision-making, therefore, needs to be clearly defined, as it will influence: (i) the magnitude of the economic contribution of the deep sea to societies; and (ii) the ability of the deep sea's ecosystems to be sustained in the long term. This is highly relevant for policymaking and legislation for the resource use of the deep sea because of the great uncertainty associated with DSM and its potential, yet uncertain, impacts on the deep sea's ecosystems. Comprehensive research from different valuation perspectives is needed before evidence-based decisions can be made on whether DSM will yield net economic benefits or costs for society.

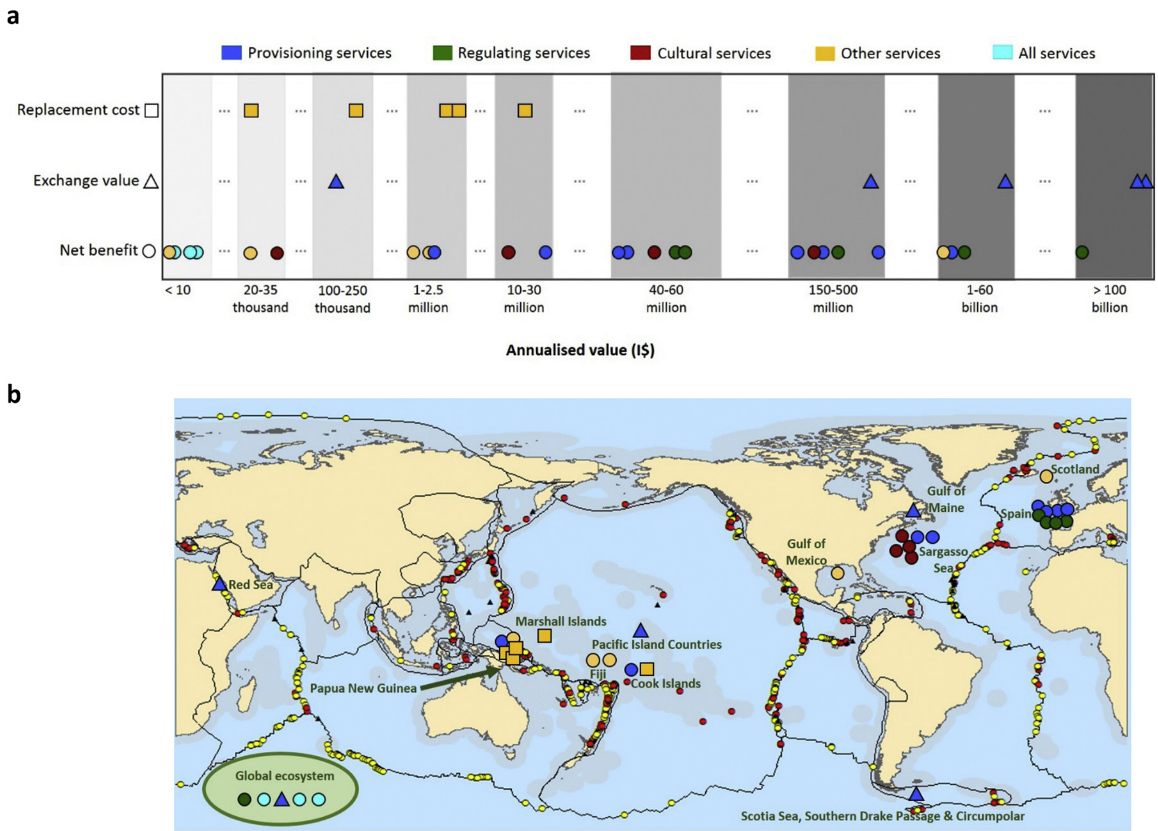

Fig. 2. Results from the meta-analysis. a) Deep sea values according to type of ecosystem service (colour) and valuation perspective (shape); b) Geographic distribution of studies.

Second, dimensions of time and scale need to be incorporated into policy making related to the deep sea, and also into the valuation methodology for estimating the economic value that the deep sea generates. For instance, the geographical scale of the EIA conducted to obtain DSM exploration and exploitation licenses needs to be expanded to include the wider environmental impacts of DSM. However, it may be unrealistic to expect the DSM proponent to take on a task of this magnitude. As such, an SEA, performed or commissioned by the regulator, can investigate and identify the cumulative environmental impacts from DSM. There are concerns that the environmental impacts of DSM may be detected in marine ecosystems further away from the site (SPC – EU Deep Sea Minerals Project, 2012). Restricting the examination of environmental impacts to the area in which the actual mining will take place disregards the inter-connected nature of the ecosystems in the deep sea. Therefore, it may be necessary for the SEA to examine the potential environmental impacts beyond the geographic boundaries of a mining license in order to understand how DSM might affect adjacent deep-sea ecosystems. Similarly, adopting a long-term perspective on estimating economic value and environmental impacts can provide a more comprehensive picture of which anthropogenic actions in the deep sea are likely to generate the greatest net benefits in the long term. The resource use of the deep sea's genetic resources for bioprospecting and pharmaceutical products has the potential to generate USD 50 billion per year, whereas DSM "only" has the potential to generate USD 1 billion per year and has a very short time-span of operation – genetic resource use is likely to have a much longer time-span, if conducted sustainably (Van Dover et al., 2018). Whether or not genetic resource-use of the deep sea's ecosystems can co-exist with DSM activities in the long run remains unknown. However, the harvesting of manganese nodules through DSM can never become a continuous revenue-generating operation, as it takes 10,000 years for manganese nodules to grow 1 mm (Tyler, 2003), meaning that the harvesting of these is only possible at one single point in time on a human time scale. Future EIAs of DSM operations and economic valuations of anthropogenic activities in the deep sea, therefore, need to estimate the "costs" and "benefits" from both short-term and long-term perspectives. Finally, the global impacts that DSM might have on the deep sea's ability to absorb and store carbon should be further assessed, given the public good nature of these ecosystem services. Different dimensions of time and geographical scale need to be assessed in order to produce more realistic and socially legitimate estimates of "benefits" and costs" in EIAs, CBAs and ecosystem valuation of the deep sea.

Third, the interdependence between anthropogenic behaviour and the economic values generated by the deep sea should be explored further. The meta-analysis on the economic value of the deep sea (Folkersen et al., 2018) revealed an important connection between anthropogenic intervention in the deep sea and the economic value derived from it. This means that the magnitude of the economic value derived from the deep sea, by and large, depends on humanity's ability to utilise and sustain its ecosystems. Ecosystem valuation studies often overlook the interdependence between economic, political and environmental systems in generating economic value, which leads to misconceptions about the importance of preserving ecosystems (Costanza et al., 1999). This interdependence is evident from several of the studies included in our systematic review. For example, the economic losses from the Deepwater Horizon oil spill estimated by Sumaila et al. (2012) were created by human behaviour in the deep sea, not by the ecosystems of the deep sea. The net profit of deep-sea fisheries in Sri Lanka, as reported by Hewamanage (2010), is partly influenced by the environmental quality of the deep sea, but more importantly by current market prices, market demand and operating costs. Likewise, the value of krill in the Southern Oceans estimated by Grant et al. (2013) is dependent on several market-based aspects not related to the deep sea's ecosystems. The relationship between the environmental management of current krill stock and the future market value of krill, however, remains largely overlooked in their study. The interdependence between human behaviour and derived economic value needs further research, with due consideration to the policy, legal and market-based mechanisms that influence the magnitude of the derived economic value. Improving our understanding of the interdependence between anthropogenic behaviour and the economic values generated by the deep sea could facilitate a better understanding of how this value might increase or decrease in the future. For instance, how will different actions taken to adapt to climate change in the oceans, or different regulatory mechanisms for deep-sea fishing or DSM, influence the economic value derived from the deep sea? Although an international policy-framework and general laws on DSM exist (United Nations Division For Ocean Affairs And The Law Of The Sea, N.D., Jaeckel, 2017; Page, 2018), there is an urgent need for (i) more specific regulations on the conduct and management of resource-extraction from the deep sea; and (ii) the establishment of comprehensive legal and regulatory frameworks for the countries expected to allow DSM activities in their territorial waters in the future (Jobstvogt et al., 2014). There is currently no regulatory agreement or treaty in place to address the potentially negative cross-border environmental impacts of DSM (SPC – EU Deep Sea Minerals Project, 2012). Thus, the inclusion of legal, policy and regulatory mechanisms into the ecosystem valuation of the deep sea could identify potential pathways for facilitating adequate environmental protection and sustainable resource use of the deep sea's ecosystems.

Fourth, the focus of future ecosystem valuation should be on valuing the ecosystem functioning of the deep sea. One of the most important findings of the systematic review and meta-analysis on the economic value of the deep sea (Folkersen et al., 2018), is that the functioning of the deep sea as an ecosystem is significant in generating economic value, and potentially more so than particular ecosystem goods and services from the deep sea. Previous ecosystem valuation studies have predominantly focused on the final market value of particular ecosystem goods and services. For instance, it might be possible to quantify the final market output of the deep sea in monetary terms (e.g. the revenue from deep-sea fishing or the potential revenue from developing pharmaceutical products from the deep sea's biodiversity and its genetic resources). However, improving the understanding of the economic value of the deep sea's ecosystems functioning would be beneficial in addressing the (constantly changing) value of its ecosystems over time and geographical scales. Beaumont et al. (2008) correctly point to the difficulty of quantifying the "whole of ecosystem cycle" value of marine ecosystems and biodiversity in monetary terms as a significant drawback in ecosystem valuation. The objective behind ecosystem valuation is to improve our understanding of how ecosystem goods and services influence human well-being (Iniesta-Arandia et al., 2014). Given that most of the ecosystem goods and services of the deep sea are public goods as they benefit humans on a global scale (Costanza et al., 1997; Drazen and Sutton, 2017), e.g. through CO_2 absorption and storage, the objective behind valuing the deep sea should be to improve our understanding of how the functioning of its ecosystems influence human well-being. For instance, primary ecosystem services of the deep sea, such as carbon sequestration and nutrient cycling, are non-market ecosystem services that are crucial for human existence, but are rarely quantified in monetary terms despite their importance (Beaumont et al., 2008; Pendleton et al., 2014). A perspective on valuing overall ecosystem functioning could address several environmental challenges currently facing the deep sea, e.g. plastic in the oceans, climate change, deep-sea fishing damaging deep-sea corals, etc. and explore to which extent each of these challenges might diminish the economic value derived from the deep sea, if inadequate – or no – action is taken to address these issues. The ecosystems functioning of the deep sea is complex as it forms numerous ecological processes and is imperative for human existence. Although challenging, it is exactly this complexity that requires further research and exploration in order identify how the economic value of the deep sea can be maximized to benefit as many people as possible – and, more importantly for avoiding irreversible environmental disasters where the deep sea's ability to generate primary ecosystem services are destroyed.

5. Conclusion

Comprehensive research into both scientific and economic aspects of the deep sea's ecosystems is needed to improve our knowledge of how the deep sea supports the functioning of adjoining marine ecosystems, economic output and human welfare, as was concluded in the systematic review and meta-analysis on the economic value of the deep sea (Folkersen et al., 2018). The cornerstone of the problem facing policy makers and global institutions in making decisions and laws about DSM is the complete inability to put the predicted monetary profits into appropriate perspectives, given uncertain environmental and human impacts. Before DSM activities should be allowed, science needs an adequate understanding of how DSM activities in one ecosystem of the deep sea (e.g. hydrothermal vents) affect the ecology and overall ecosystem functioning of other deep-sea ecosystems (e.g. seamounts or deep coral reefs). Future EIAs of proposed DSM activities must incorporate different dimensions of time and geographical scale to fully assess the potentially negative impacts of DSM on marine environments further away from the mining site and also its long-term environmental impacts. The information basis for future policymaking and legislation on deep sea resource-use should be based on a valuation perspective that takes into account the social benefits and costs to provide a more socially legitimate picture of which type of resource use is likely to generate the highest social benefits. More importantly, it should be thoroughly examined how different types of resource extraction in the deep sea will affect its ability to absorb and store carbon before any decisions are made on which resource-use to allow. Policy, legal and market-based mechanisms influencing the magnitude of the economic value of the deep sea could be incorporated into future ecosystem valuation of the deep sea. This could help identify pathways to sustainable resource use and deep-sea conservation through the optimisation of laws and policies. With the four directions for future research into economic valuation, policymaking and decision-making set forth in this article, it is hoped that research scientists, governmental institutions, policy makers and legal bodies will adopt these recommendations in order to ensure the adequate protection and sustainable resource use of the deep sea.

6. Declarations of interest

None

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