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Review

Assessing the impacts of seabed mineral extraction in the deep sea and coastal marine environments: Current methods and recommendations for environmental risk assessment

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ABSTRACT

Mineral extraction from the seabed has experienced a recent surge of interest from both the mining industry and marine scientists. While improved methods of geological investigation have enabled the mapping of new seafloor mineral reserves, the ecological impacts of mining in both the deep sea and the shallow seabed are poorly known. This paper presents a synthesis of the empirical evidence from experimental seabed mining and parallel industries to infer the effects of seabed mineral extraction on marine ecosystems, focusing on polymetallic nodules and ferromanganese concretions. We use a problem-structuring framework to evaluate causal relationships between pressures caused by nodule extraction and the associated changes in marine ecosystems. To ensure that the rationale behind impact assessments is clear, we propose that future impact assessments use pressure-specific expert elicitation. We further discuss integrating ecosystem services in the impact assessments and the implications of current methods for environmental risk assessments.

1. Introduction

The accelerating progress of new technologies is increasing the demand for raw materials (Vidal et al., 2017). The scarcity, declined grades, and conservation of terrestrial natural resources are attracting growing interest in the extraction of minerals from the seabed (Jenkins and Joppa, 2009; Calvo et al., 2016). As a result of rising metal prices and technological advances in mining, offshore mining activities are now being outlined in the deep sea (Hein et al., 2013; Beaulieu et al., 2017). Although a range of mining operations have been active in shallow sea areas for decades, the technological challenges and the high cost of exploration in the high seas are further driving interest in mineral extraction from shelf seas (Hannington et al., 2017). While the improved methods of geological investigation have enabled high resolution mapping of new seafloor mineral reserves, the ecological impacts and large-scale consequences of seabed mining in both coastal seas and the deep sea are still poorly known.

Environmental impact assessment (EIA, Munn, 1979; Glasson et al., 2013) is a key tool in planning and evaluating the effects of human activities on the environment. The obligation to conduct an EIA is determined by a number of international legislative treaties and customs that specify the structure and scale of the assessment (Pérez, 2017). In principle, an EIA is required for activities that are considered to have a significant adverse impact on the environment. In marine areas within national jurisdiction, EIAs are required depending on the country's legislation, both in the territorial waters and Exclusive Economic Zones (EEZs) to indicate what types of activity may be allowed and where. As a result of the increased economic interest in the high seas, EIAs and increased protection measures are called for areas beyond national jurisdiction (Druel, 2013). While a number of international legal and policy instruments require projects to undergo EIAs in international waters, effective enforcement and supervision for such obligations and the content of assessments is lacking (Ma et al., 2016). Similarly, in areas within national jurisdiction, the EIA regulations for the marine environment are often less comprehensive than those for terrestrial activities, and many countries do not require offshore activities to undergo an EIA (Guerra et al., 2015).

To support the ecological component of EIAs in identifying the potential impacts of an activity on specific ecosystems, ecological impact assessments (Treweek, 2009) are increasingly included in the EIA process. Unlike EIAs, the implementation of an ecological impact assessment is not a statutory requirement, and can be used for projects of

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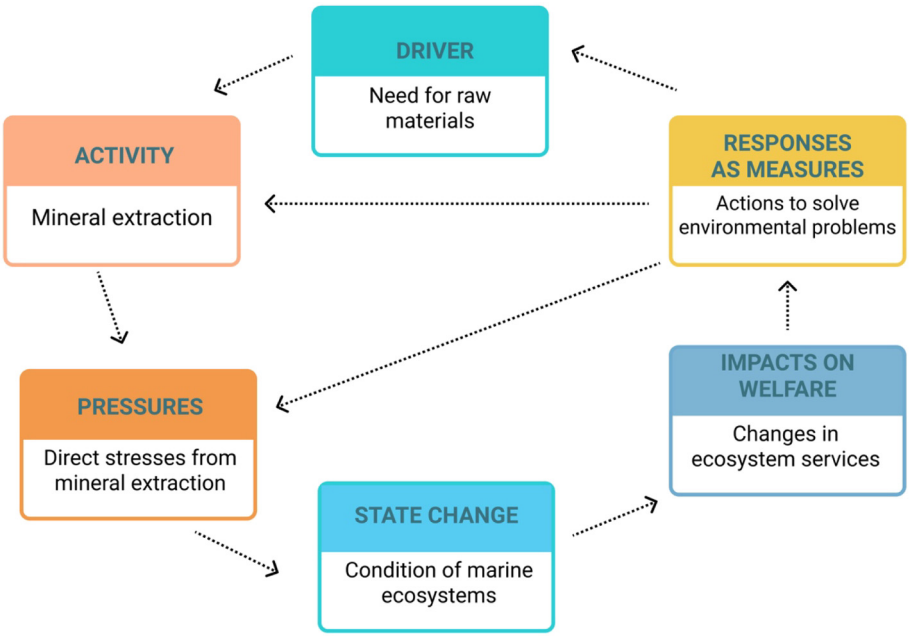

Fig. 1. The DAPSI(W)R(M) framework applied to seabed mineral extraction. The arrows denote causal interactions within the components of the framework. Adapted from Elliott et al. (2017).

any scale. Traditionally, ecological impact assessments have built on knowledge of how ecosystems respond to human-induced disturbances. The risks of adverse effects on ecosystems caused by human activities are assessed based on the prevailing condition of the environment against which the presumed impacts are compared (Therivel, 2012; Glasson et al., 2013). However, in the case of seabed mineral extraction, little previous experience from mining projects has been documented. Moreover, the scarcity of biological and geological baseline data on the deep and shallow seabed is another major issue in evaluating the impacts of physical disturbance (Gjerde, 2006; Wright and Heyman, 2008), and the justification for statements on the severity of the impacts is not always well detailed (Thompson et al., 1997; Drayson et al., 2015).

The findings of ecological and environmental impact assessments are summarized in environmental statements, which should include accurate information on the magnitude and severity of the potential risks of the activity to support decision making (Treweek, 2009). To ensure the transparency of impact statements, more structured approaches for estimating the adverse effects on marine ecosystems are required compared to traditional EIAs. Here, we utilize the Drivers-Activities-Pressure-State changes-Impacts(on Welfare)-Response(as Measures) framework (DAPSI(W)R(M) (Elliott et al., 2017) to evaluate the requirements for ecological impact assessments of seabed mineral extraction in a generalized context. We examine the impacts of marine mineral concretion mining with the aim of improving future quantitative estimations of impacts by comparisons with similar activities and pressures. Moreover, we discuss the critical knowledge gaps and prerequisites for environmental risk assessment for seabed mineral extraction. The focus of this review is on the impacts of mining two types of marine mineral precipitates: deep-sea polymetallic nodules and shallow-water ferromanganese concretions. We will refer to the mining of both mineral concretion types in the review as “mineral extraction”.

Research on the ecological impacts of marine mineral extraction has mostly focused on aggregate extraction (e.g. Newell et al., 1998, 2004) and anthropogenic activities in the deep sea (Newell et al., 1998; Ramirez-Llodra et al., 2011). In coastal seas, the environmental impacts of dredging have been investigated for decades as a result of the intense use of marine aggregates (e.g. De Groot, 1979; Newell et al., 1998; Desprez, 2000; Cooper et al., 2007a,b; Waye-Barker et al., 2015). Regardless of recent concern over the impacts of seabed mining (Boschen et al., 2013; Miller et al., 2018), current knowledge of the pressures from seabed exploitation on ecosystems has not been synthesized, and studies addressing the adverse effects rarely offer empirical evidence of the overall impacts. Rather, previous reviews on the impacts of marine mining have focused on the loss of biodiversity and recovery of benthic fauna (Ellis, 2001; Jones et al., 2017) or on specific ecosystems, such as hydrothermal vents (Boschen et al., 2013; Van Dover, 2014) or polymetallic nodule fields (Vanreusel et al., 2016). While different scenarios of the potential impacts have been envisaged (Van Dover, 2010; Ramirez-Llodra et al., 2011), links between the findings of empirical studies and specific pressures from mining have not been established. The current challenges regarding mineral extraction from the seafloor are how to estimate the impacts on ecosystems before commercial activities start and how to deal with uncertainty stemming from the scarcity of data.

To adequately allocate research and management efforts, it is essential to point out the knowledge gaps in our current understanding of the impacts of marine mineral extraction. Here, we review the empirical evidence concerning the impacts of anthropogenic seabed disturbance on marine ecosystems and evaluate the methods used to assess the impacts. We identify the impacts that have been thus far been examined in in situ experiments or by modeling, and have gathered information on the effects that have been left unaddressed, but are crucial to a comprehensive risk assessment of seabed mining activities. In this review, marine mineral extraction is considered as an activity that causes multiple pressures on different ecosystem and habitat components, resulting in a variety of changes in the state of the ecosystem (Fig. 1). We focus on addressing the causal relationships between the direct stressors from mineral extraction and the observed changes in the environment using the DAPSI(W)R(M) - framework. As commercial nodule and concretion mining activities have not yet started, this provides a unique opportunity to integrate losses to ecosystem services into the risk assessment and environmental management of seabed mining.

2. Application of the framework

We define the impacts associated with seabed mineral extraction using the DAPSI(W)R(M) framework to facilitate more comprehensive