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Incorporating ecosystem services into environmental management of deep-seabed mining

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ABSTRACT

Accelerated exploration of minerals in the deep sea over the past decade has raised the likelihood that commercial mining of the deep seabed will commence in the near future. Environmental concerns create a growing urgency for development of environmental regulations under commercial exploitation. Here, we consider an ecosystem services approach to the environmental policy and management of deep-sea mineral resources. Ecosystem services link the environment and human well-being, and can help improve sustainability and stewardship of the deep sea by providing a quantitative basis for decision-making. This paper briefly reviews ecosystem services provided by habitats targeted for deep-seabed mining (hydrothermal vents, seamounts, nodule provinces, and phosphate-rich margins), and presents practical steps to incorporate ecosystem services into deep-seabed mining regulation. The linkages and translation between ecosystem structure, ecological function (including supporting services), and ecosystem services are highlighted as generating human benefits. We consider criteria for identifying which ecosystem services are vulnerable to potential mining impacts, the role of ecological functions in providing ecosystem services, development of ecosystem service indicators, valuation of ecosystem services, and implementation of ecosystem services concepts. The first three steps put ecosystem services into a deep-seabed mining context; the last two steps help to incorporate ecosystem services into a management and decision-making framework. Phases of environmental planning discussed in the context of ecosystem services include conducting strategic environmental assessments, collecting baseline data, monitoring, establishing marine protected areas, assessing cumulative impacts, identifying thresholds and triggers, and creating an environmental damage compensation regime. We also identify knowledge gaps that need to be addressed in order to operationalize ecosystem services concepts in deep-seabed mining regulation and propose potential tools to fill them.

1. Introduction

The deep sea contains many highly heterogeneous ecosystems that host a vast, but not yet fully quantified wealth of biological, energy, and mineral resources (Ramirez-Llodra et al., 2010; Mengerink et al., 2014). Benefits from these natural resources include food, fuel, raw materials, and non-market benefits (Thurber et al., 2014). As industries begin to use deep-sea resources in order to meet growing demand for food, pharmaceuticals, energy, and minerals, how these benefits are produced and maintained grows increasingly important to understand. However, many knowledge gaps still exist regarding how ecosystem structure and ecological functions translate into benefits to society. Parsing through these relationships is essential to the long-term, sustainable, and effective environmental policy and management of deep-sea ecosystems subject to exploitation.

For much of the past century, deep-sea research has focused on biological community structure by defining abundance, distribution, and diversity (Rex and Etter, 2010). More recently, there has been a shift in emphasis towards how structure, biodiversity in particular, supports ecological functions (Danovaro et al., 2008, 2016; Thurber et al., 2014). Biodiversity is often heralded as necessary to provide most ecosystem services (ES), i.e. the contributions to human well-being from ecosystems, and is used as a proxy for measuring these services (Palumbi et al, 2009; Cardinale et al., 2012). In this paper, biodiversity will be discussed as a component of ecosystem structure because it has been shown to contribute to ecological function and ES capacity (Worm et al., 2006; Harrison et al., 2014; Yasuhara et al., 2016). The relationship between biodiversity and ES remains unclear in many cases (Balvanera et al., 2014; Bennett et al., 2015), perhaps even more so in the deep sea where biodiversity is not yet well characterized

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(Higgs and Attrill, 2015; Sinniger et al., 2016). However, one of the largest anticipated deep-seabed mining (DSM) impacts is loss of biodiversity and its contribution to ES should not be ignored.

Many of the ecological functions that ecosystem structure supports can ultimately be translated into ES. For example, seamount-trapped, vertically-migrating zooplankton (structure) can provide trophic support (function) for fish catch (service) (Clark et al., 2010). Another example is deep-sea infauna (structure) that facilitate the burial of carbon in deep sediments via bioturbation (function), which contributes to carbon sequestration and climate regulation (service) (Xiao et al., 2010). The publication of the Millennium Ecosystem Assessment (MA) (2005) stimulated interest in examining ES and developing ES frameworks for environmental decision-making (Fisher et al., 2009). ES try to associate values with environmental benefits that are linked to human well-being, whether a market exists for the benefit or not. Sustainable management of resources requires that these values are incorporated into environmental regulation.

Deep-sea exploration began in the 1800s but exploitation of its natural resources is a more recent development. There is a growing list of anthropogenic impacts in the deep sea (Ramirez-Llodra et al., 2011) which can result in the loss of ES, including ES yet to be discovered. Fisheries are encroaching deeper into the water column and on the seabed (Morato et al., 2006; Watson and Morato, 2013). The overexploitation of fisheries species by direct targeting or removal as bycatch may cause deep-sea fish populations to decline precipitously. Population declines and crashes may have longer-lasting effects in the deep sea relative to shallow water because life spans are much longer at great depths (Devine et al., 2006; Norse et al. 2012). In addition, trawl fisheries cause physical disturbance and removal of habitat, leaving coral rubble and trawl marks (Roberts, 2002; Puig et al., 2012; Buhl-Mortensen et al., 2015). The removal of three-dimensional habitat structure on the bottom causes loss of associated species that are very slow or unable to recover (Althaus et al., 2009; Williams et al., 2010). Trawling also alters sediment flux and re-suspends sediment in the water column, which can lead to lower biodiversity and ecological function (Martín et al., 2014; Pusceddu et al., 2014; Oberle et al., 2016).

Oil and gas exploration and drilling are now taking place in increasingly deeper waters (Merrie et al., 2014). The infrastructure and extraction of these energy resources have direct impacts on the deep seafloor (Continental Shelf Associates, Inc., 2006). With deeper oil comes an increasing risk of oil spills (e.g. *Deepwater Horizon*, Reddy et al., 2012; Merrie et al., 2014), which have the potential to result in both the loss of deep-sea habitats (White et al., 2012; Fisher et al., 2014), as well as losses of ES in shallow water and coastal systems (Lin and Mendelssohn, 2012).

With accelerating exploration claims in both national and international deep waters, DSM is expected to commence in the near future. Since the first exploration contracts were signed in 2001 (Lévy, 2014), the International Seabed Authority (ISA) has approved 27 contracts in the Pacific, Atlantic, and Indian oceans for polymetallic sulfides, ferromanganese crusts, and polymetallic nodules. Eighteen of these contracts were granted within the last five years (Wedding et al., 2015). The ISA was established by the United Nations Convention on the Law of the Sea (UNCLOS) and governs the minerals and environment in the “Area,” defined as the seabed beyond national jurisdiction (UNCLOS, 1982).

Regulation exists for the exploration of polymetallic sulfides, ferromanganese crusts, and polymetallic nodules, but it is not yet in place to ensure the protection of the environment under commercial exploitation (ISA, 2015, 2016). The ISA has made recommendations regarding baseline data collection and monitoring plans (ISA, 2013a), but environmental regulation is still under development. Because commercial DSM has yet to begin, there is an opportunity to incorporate ES indicators into data-collection requirements in all phases of environmental management and decision-making. An ES framework can provide guidance on how valuable services might be maintained while still yielding benefits from the direct extraction of natural resources.

The objectives of this paper are to (1) review ES associated with deep-sea mineral resources and their host habitats; (2) propose practical steps to build ES into environmental planning of DSM; this includes the identification of potentially vulnerable ES, the role of ecosystem structure and ecological function in providing ES, their use as ES indicators, and the valuation of ES; (3) indicate management phases where ES could be incorporated; and (4) identify scientific knowledge gaps that must be addressed to implement an ES framework for DSM regulation.

2. Application of an ecosystem services approach to the deep sea

ES are the contributions to human well-being from ecosystems. MA (2005) categorizes ES into four groups: provisioning, regulating, cultural, and supporting. Provisioning services are the outputs and products obtained from ecosystems; examples include fish and invertebrate catch, pharmaceuticals, and industrial agents (MA, 2005). There is some controversy over the inclusion of abiotic resources as provisioning services because their formation does not involve biotic processes and the timescale associated with their formation is extremely long. Our focus here is on the role of biotic ES in decision-making and planning, partly to identify areas where biotic ES losses can be minimized while still allowing extraction of abiotic resources. Regulating services are benefits from the regulation of environmental processes (MA, 2005). A deep-sea example would be promoting carbon sequestration through transport of carbon to the seabed for burial via the biological pump and diurnal vertical migrations. Another example includes biological regulation, which here will refer to the biological control of populations and pests (Armstrong et al., 2012). Cultural services are non-material benefits that include educational opportunities, aesthetic considerations (e.g. inspiration for the arts), the utility obtained simply from knowing the resource exists, and that the public is being a good steward of the resource for both the current and future generations. The underlying motive for valuing ES is, in many instances, maintaining the option to use these ES at some point in the future. The concept of quasi-option value, where investments are made in scientific research to improve knowledge of the ES, is particularly relevant because knowledge concerning deep-sea ES is often quite limited (Carson et al., 1999). When extractive activities pose the threat of irreversible harm, this consideration can be particularly large. The MA also defines supporting services as those necessary for the production of all other ES, which includes primary and secondary production, and element and nutrient cycling (MA, 2005).

A number of alternative classification systems for ES exist (e.g. Böhnke-Henrichs, et al., 2013; Landers and Nahlik, 2013; Liquete et al., 2013). Two that are commonly used are The Economics of Ecosystems and Biodiversity (TEEB) and the Common International Classification of Ecosystem Services (CICES). TEEB defines function as a subset of ecological processes with the potential or capacity to provide a service. Services are then defined as the realization of the function that provides a benefit to human well-being (de Groot et al., 2010). CICES defines final ES as contributions to human well-being while ecosystem goods and benefits are created or derived from final ES (Haines-Young and Potschin, 2013). Unlike the MA, both TEEB and CICES exclude supporting services from their classification, although both systems acknowledge their importance. What TEEB and CICES define as

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