Ecosystem-based ESIA approaches in deep-sea mining

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Abstract

A new paradigm in Environmental and Social Impact Assessment is required for permitting of deep-sea mining. The lack of precedent, vocal opposition, scientific uncertainty and untested legislation are some of the factors that dictate the need for novel approaches. The uncertainty dimension has placed a focus on marine scientific research elements of ESIA. While fundamental research is required, this focus creates the potential for atomised research topics and within the timelines of a mining proposal, potentially leads to a body of research that is difficult to integrate into an ESIA. Ecosystem-based approaches are needed by contractors and regulatory agencies as a framework for assessment that connects ESIA studies to indicators of serious harm and connects baseline studies with monitoring requirements. Ecosystem-based approaches are required to give contractors confidence that environmental studies are nested within an integrated ESIA structure and that study findings inform options in mine planning and link to monitoring and adaptive management scenarios. For regulators and other stakeholders, ecosystem-based approaches are required to ensure that environmental and societal values are addressed, that static environmental study 'completeness' tests do not override information requirements, and that data from individual projects can evolve into knowledge at the regional scale. We present practical examples of ecosystem-based approaches to deep-sea mining that provide a socio-ecological framework for ESIA and a tool for decision-making support and best practice.

Introduction

Deep-sea mining (DSM) is predicted to become increasingly important in a world transitioning from fossil fuels to alternative energy sources. DSM will have some level of impact on the deep-sea environment [1] and understanding the significance of these impacts is critical to the regulatory and societal acceptance of this practice. The International Seabed Authority (ISA), which regulates minerals activities in international waters has developed environmental regulations and recommendations. However, ultimately the onus is on the mining development proponent to produce not only a compliant Environmental Impact Assessment (EIA), but also the evidence that there will be no serious harm and the mitigation, monitoring and management plans that will be put in place as safeguards if unexpected impacts are detected. Given the lack of precedent, and scientific uncertainty as to ecological responses, the Precautionary Principle is installed in the deep-sea mining development process. Environmental baseline studies, equipment tests and trial mining are part of the evidence-building process. However, a methodology is required to pull these data into an Ecosystem Based Management framework.

Polymetallic nodules are valuable sources of manganese, copper, nickel and cobalt and cover large areas of the abyssal seabed [2]. Nodules represent a hard substrate in an otherwise unconsolidated seafloor environment, representing potential colonisation substrates for sessile invertebrates. Furthermore, nodules have surface structures that, in combination with the chemical environment, support community compositions that differ from non-nodule sediment beds. Nodule types, densities, distribution along the broad longitudinal gradient of the CCZ, in addition to Abyssal Hill topography and depth regimes are among the drivers of biological distributions.

The delivery of particulate organic matter from sunlit layers of the water column to the benthic environment is one of the major processes connecting the pelagic and benthic ecosystems [3]. Active biological interactions, such as the feeding of demersal fishes on epibenthos and infauna, also connect the pelagic and benthic ecosystems.

Polymetallic nodule mining will interact with benthic and pelagic ecosystems via the direct removal of nodules, reworking of sediments, the generation of near-bottom and midwater plumes and the generation of subsea and surface noise, among other potential pressures [4]. The approval of a nodule mining operation is contingent on a contractor demonstrating that there will be no serious harm [5], which requires detailed baseline investigations and an Environmental Impact Assessment (EIA) process.

Scientific studies in the water depths of the Clarion-Clipperton Zone (CCZ) (>4,000 m) are technically challenging and expensive. Studies necessarily involve several disciplines although the service providers of these studies are often narrowly focussed to particular subject matter expertise. Indeed, early regulatory advice from the ISA was focussed strongly on the need for taxonomic studies of benthic infauna and identifying the required studies and parameters for atomised baseline studies. As such, despite decades of research activity [6-8], significant unknowns remain in the area of integrated ecology and ecosystem function.

The ISA recommends adopting an ecosystem-based management (EBM) approach to manage and monitor mining operations [9]. However, ecosystem-based management must also be installed at the front end of program design to ensure that specific studies can assemble up to integrated assessments. Traditionally, EBM approaches focused on the impact of human activities on ecosystem interactions, such as trophic relationships. Recently, mixed approaches have been developed that incorporate ecosystem dynamics with social and economic perspectives and the drivers of human generated pressures. Mixed approaches have been effective in other large area management regimens and multi-stakeholder environments [10-12].

Here we demonstrate an EBM-DPSER model (D drivers, P pressures, S status indicators, E ecosystem services, R responses) (Figure 1) and the utility of this type of model to support decision-making in DSM. We develop a model that relates to spatially-explicit habitats and represents the interactions between DSM and deep-sea ecosystems and investigate the derivation of pressures from drivers. We investigate ecosystem components and identify monitoring indicators that link to multiple parts of the model, from the pressure components to the ecosystem components. We apply network analysis to examine the derived ecosystem models and develop hypotheses about which compartment or deep-sea community might be more vulnerable to deep-sea mining, what pressures will have the largest impact on the ecosystem and propose targeted monitoring responses. We describe how models of this kind can link to adaptive management strategies.

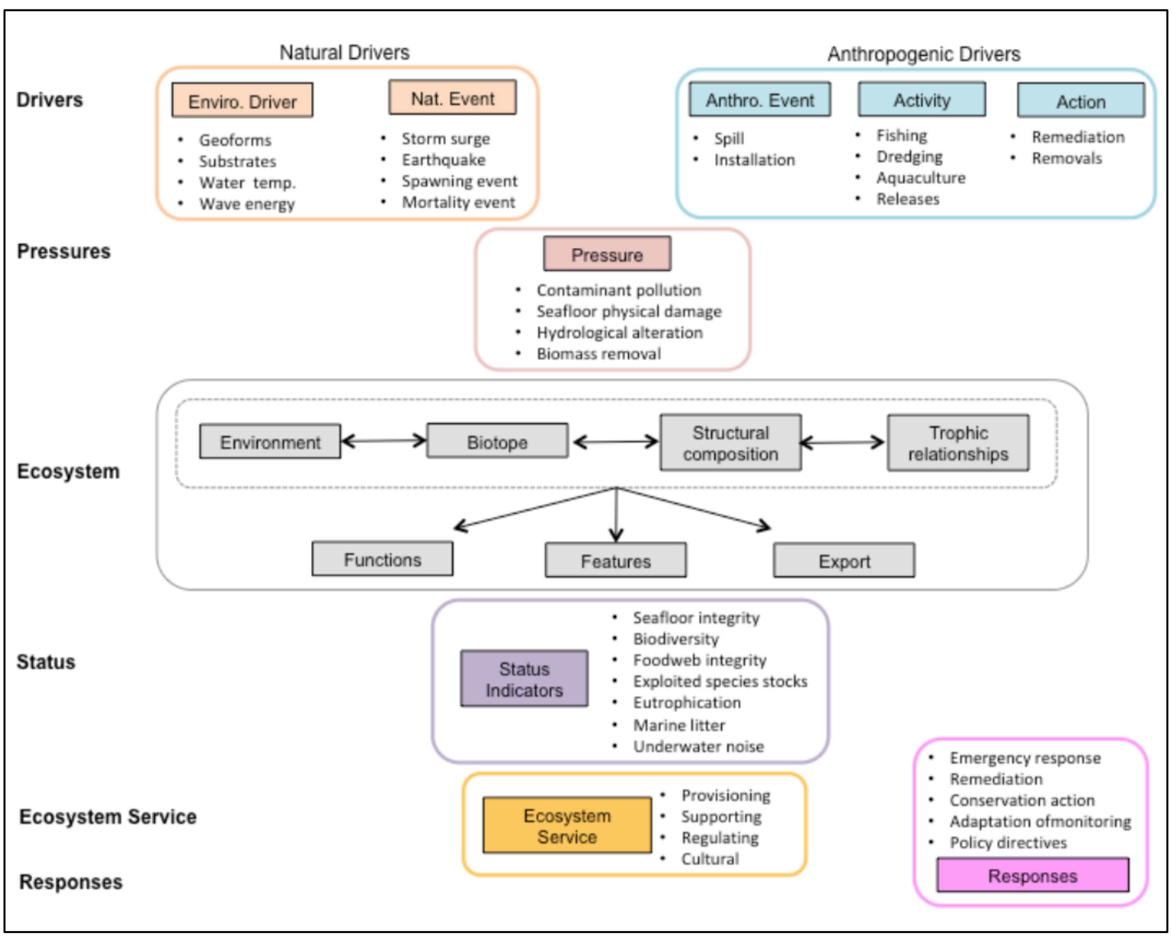

Figure 1: DPSER chain structure. Modified from Kelble et al. 2013.

Methods

A DPSER model was developed to represent the NORI-D Area, a polymetallic nodule exploration contract area region located in the Clarion-Clipperton Zone (CCZ) (Figure 2). The DPSER model creation used the so-called EcoNet model, a tool of an environmental database system known as qCore. The database is an integrated system that links individual sample data and records through classification structures to facilitate EBM. The qCore system combines the premises of the JNCC biotope classification scheme [12] and the CMECS abiotic classification scheme [13], and the concepts of the Scottish Feature-Activity-Sensitivity Tool (FeAST) (www.marine.scotland.gov.uk/feast/) and the European Union's Good Environment Status (GES) [14, 15]. GES concepts were used to frame the connection of status indicators in the ecosystem model. The model was constructed on the basis of contractor data, evidence from the literature and technical reports, describing CCZ habitats, geomorphology, marine species and ocean dynamics and features.

The ecosystem compartments included in the model are shown in Figure 3. Habitats are nested within these ecosystem compartments. EcoNet uses functional guilds in the model components that relate to trophic interactions. Fauna and indeed all components of the EcoNet model are described using a 6-level hierarchical approach. As such, models can be constructed at exploratory levels as planning tool in the absence of detailed information and progressively improved as information is produced. Here we present models at level 4 of the hierarchical scheme.

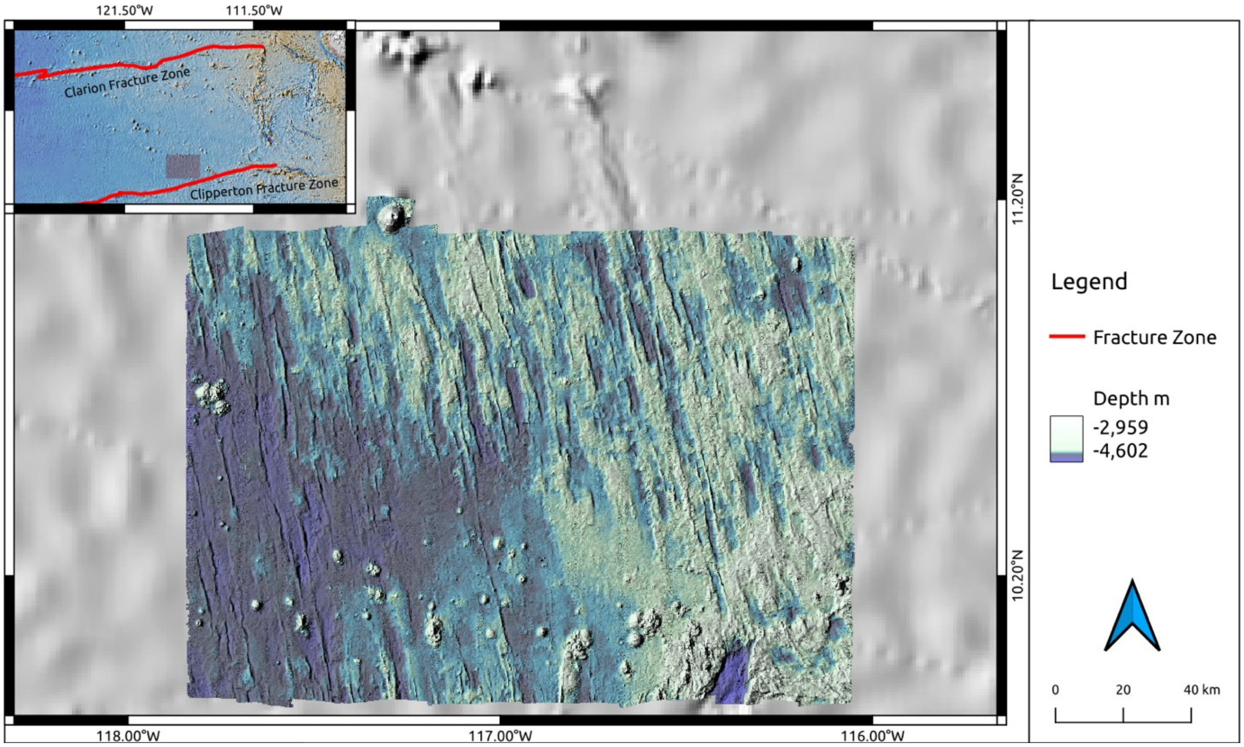

Figure 2: Map of study area.

The model was visualised as a network of nodes and links. Networks were analysed taking advantage of graph theory, which allows to rank network nodes and calculate several network level metrics to describe the graph properties. We calculated node degree, quantifying the number of links connected to a node, to rank node importance. We estimated network modularity, a metric used to detect the community structure, and edge density, often used in ecology to quantify the stability and vulnerability of an ecological network to perturbations [16].

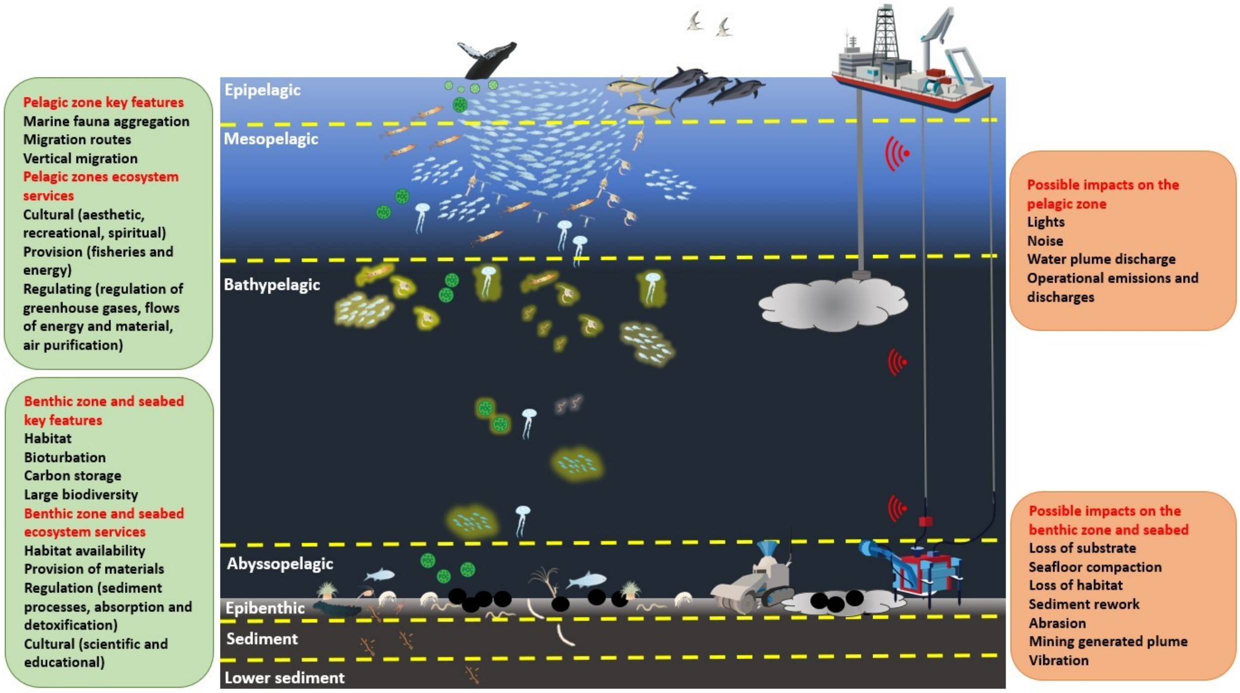

Figure 3: Schematic showing the processes involved in deep-sea mining for the water column and seabed. The figure also shows the ecological characteristics of the fauna inhabiting the pelagic and benthic zones. Pressures, key features, and ecosystem services are listed in the text boxes.

Results

We generated an EcoNet network for DSM linking all the DPSER nodes identified for all the ecological compartments of the water column and seabed. EcoNet subnetworks were grouped according to compartments (Figure 4).

Nodes degree was calculated as a proxy for node 'importance' in the model (Table 1).

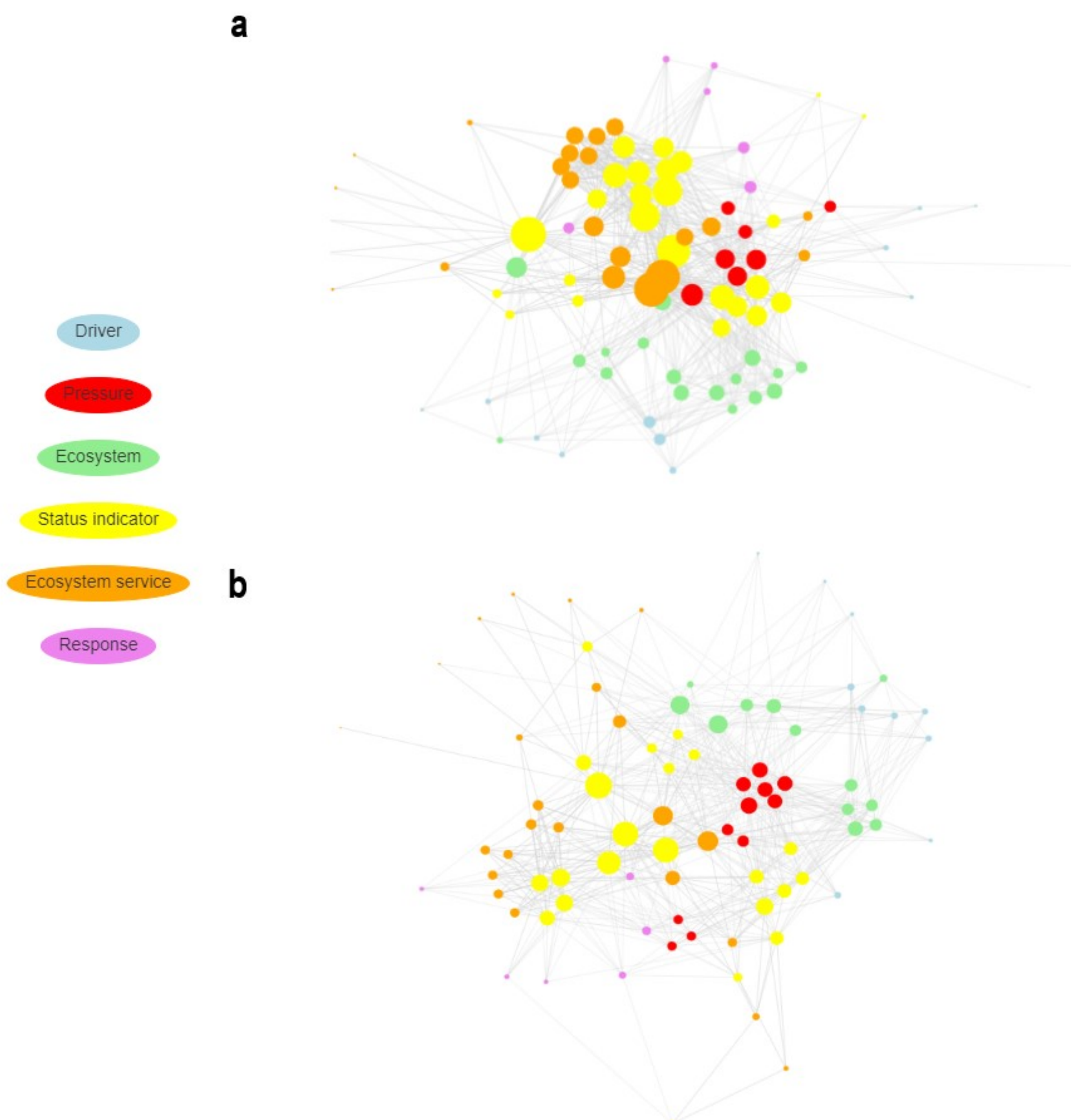

Figure 4: DSM EcoNet network at Level 4 for the epipelagic (a) and epibenthic zone (b). Node colours represent the DPSER group and node size varies according to node degree.

Table 1: Node degree of the top 5 most important nodes of the EcoNet model for the epibenthic and epipelagic compartments. Nodes are classified by their DPSER group. Calculations were completed using R [17] and the package 'igraph' [18].

Node name	Compartment	DPSER group	Node degree
Physical, hydrological and chemical conditions	Epibenthic	Status indicator	49
Condition of the typical species and communities	Epibenthic	Status indicator	47
Composition of the ecosystem components (habitats and species)	Epibenthic	Status indicator	47
Relative abundance and/or biomass	Epibenthic	Status indicator	43
Animal-based source of energy provision	Epibenthic	Ecosystem service	37
Physical, hydrological and chemical conditions	Epipelagic	Status indicator	53
Animal-based source of energy provision	Epipelagic	Ecosystem service	52
Trophic processes regulation	Epipelagic	Ecosystem service	52
Composition of the ecosystem components (habitats and species)	Epipelagic	Status indicator	50
Condition of the typical species and communities	Epipelagic	Status indicator	45

At the whole network level, the epipelagic network had 0.08 modularity and 0.11 edge density, while for the epibenthic zone we estimated 0.22 modularity and similarly a value of 0.11 for edge density.

The pressures associated with DSM were characterised for each model compartment to investigate the relative contribution and ranking of pressures (Figure 5). To further investigate the epibenthic compartment, the node degree per model component was calculated (Figure 6).

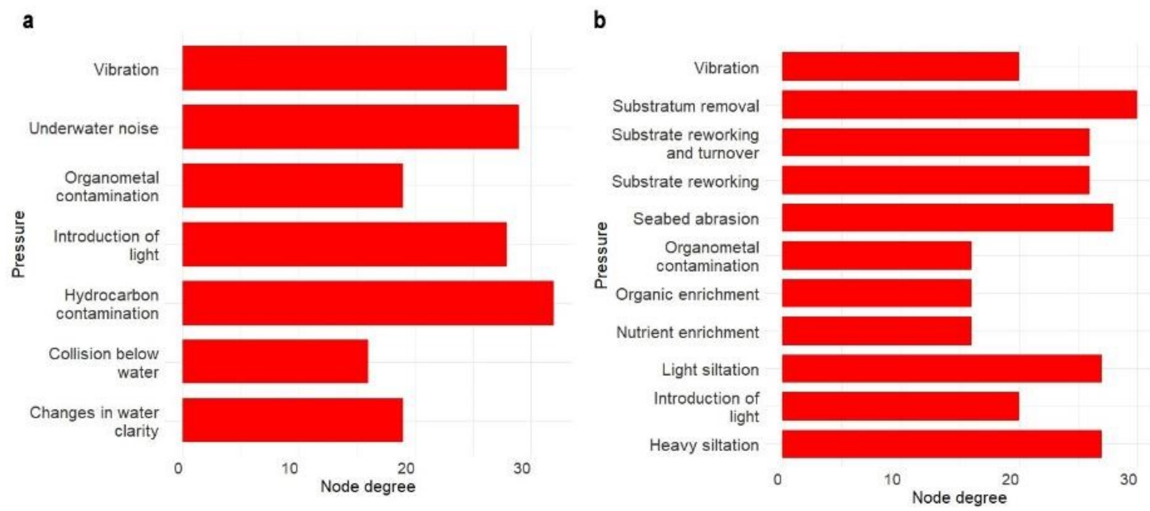

Figure 5: Node degree of the Pressure nodes for the epipelagic (a) and epibenthic (b) zone.

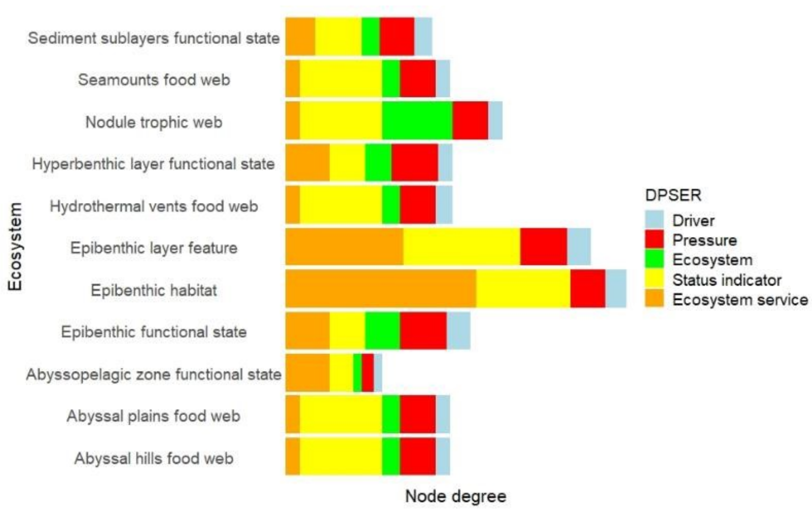

Figure 6: Ecosystem nodes degree for the epibenthic subnetwork, divided by DPSER groups.

Discussion

Developing a DPSER model requires careful consideration of the specific connections between activities and pressures, and where those pressures connect in the ecosystem. Comprehensive literature review is required and in the EcoNet system, consideration needs to be given the hierarchical structure. Therefore, during the early stages of a DSM project, the modelling process uncovers the main areas of model importance, information gaps, key linkages and ecosystem services of main concern which can be used to inform study design and ESIA structure. The models are spatially explicit, grounded by habitats and biotopes, nested in regions, as the major spatial units of management. The models can be used to examine the connection between a regulated or recommended baseline data requirement and its role in the ecosystem, thereby providing an effective decision support and stakeholder engagement tool.

Several metrics exist to interrogate different aspects of a DPSER network or compare networks (e.g. pre- and post-disturbance). In our model, ecosystem services had a high node degree, reflecting the large number of links to this component and indicating the importance of connecting status indicators to these nodes. Network-level metrics elucidate which subnetwork is more resilient to perturbations compared to others. In our example, despite the epipelagic subnetwork being linked to fewer pressures, it was characterised by lower modularity than the epibenthic subnetwork, potentially suggesting that this compartment has high interconnectedness and therefore impacts to one element in this compartment can potentially spread throughout the compartment.

DPSER Models have been implemented in a number of whole-of-ecosystem management programs and when linked with suitable indicators of environment status (which the models themselves help to determine), the models can provide a common suite of evaluation metrics. The hierarchical structure and the emphasis on biological responses and functions and services supports the detection of emergent ecosystem properties that may be missed by atomised studies, an important consideration given the uncertainties of impact processes in the deep-sea.

The structure of EcoNet style DPSER models encourage unification of studies under a common ecological structure which could allow more effective collaboration and integration of EBM at contract and regional level. DPSER style socio-ecological models can be one tool to help define serious harm and to provide a basis of evidence-based decision making for adaptive management.

References

1. Niner HJ, Ardron JA, Escobar EG, Gianni M, Jaeckel A, Jones DOB, et al. Deep-Sea Mining With No Net Loss of Biodiversity—An Impossible Aim. Frontiers in Marine Science. 2018;5(53).
2. Hein JR, Koschinsky A, Kuhn T. Deep-ocean polymetallic nodules as a resource for critical materials. Nature Reviews Earth & Environment. 2020;1(3):158-69.
3. Drazen JC, Sutton TT. Dining in the deep: the feeding ecology of deep-sea fishes. Annual review of marine science. 2017;9:337-66.
4. Drazen JC, Smith CR, Gjerde KM, Haddock SH, Carter GS, Choy CA, et al. Opinion: Midwater ecosystems must be considered when evaluating environmental risks of deep-sea mining. Proceedings of the National Academy of Sciences. 2020;117(30):17455-60.
5. Levin LA, Mengerink K, Gjerde KM, Rowden AA, Van Dover CL, Clark MR, et al. Defining "serious harm" to the marine environment in the context of deep-seabed mining. Marine Policy. 2016;74:245-59.
6. Simon-Lledó E, Bett BJ, Huvenne VAI, Schoening T, Benoist NMA, Jones DOB. Ecology of a polymetallic nodule occurrence gradient: Implications for deep-sea mining. Limnology and Oceanography. 2019;64(5):1883-94.
7. Stratmann T, Soetaert K, Kersken D, van Oevelen D. Polymetallic nodules are essential for food-web integrity of a prospective deep-seabed mining area in Pacific abyssal plains. bioRxiv. 2021.
8. Vanreusel A, Hilario A, Ribeiro PA, Menot L, Arbizu PM. Threatened by mining, polymetallic nodules are required to preserve abyssal epifauna. Scientific Reports. 2016;6(1):26808.
9. Guilhon M, Montserrat F, Turra A. Recognition of ecosystem-based management principles in key documents of the seabed mining regime: implications and further recommendations. ICES Journal of Marine Science. 2020.
10. Yee S. ReefLink Database: A decision support tool for Linking Coral Reefs and Society Through Systems Thinking. Guanica Bay Watershed Update2012. p. 9.
11. Net Gain. Final Recommendations. Submission to Natural England and JNCC. The North Sea Marine Conservation Zones Project. The Deep Business Centre. Tower Street Hull, HU1 4BG; 2011.
12. Connor DW, Allen JH, Golding N, Howell KL, Lieberknecht LM, Northen KO, et al. The Marine Habitat Classification for Britain and Ireland. Version 04.05 Infralittoral Rock Section. 2004.
13. FGDC. Coastal and Marine Ecological Classification Standard. US Federal Geographic Data Committee, Washington.; 2012.
14. Directive 2008/56/EC of the European Parliament and of the Council of 17 June 2008 establishing a framework for community action in the field of marine environmental policy (Marine Strategy Framework Directive), (2008).
15. Commission Decision (EU) 2017/848 of 17 May 2017. Laying down criteria and methodological standards on good environmental status of marine waters and specification and standardised methods for monitoring and assessment, and repealing Decision 2010/477/EU, (2017).
16. Tylianakis JM, Laliberté E, Nielsen A, Bascompte J. Conservation of species interaction networks. Biological Conservation. 2010;143(10):2270-9.
17. R Core Team. R: A language and environment for statistical computing. Vienna, Austria2019.
18. Csardi G, Nepusz T. The igraph software package for complex network research. InterJournal, Complex Systems. 2006;1695(5):1-9.