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Special Series

# Deep seabed mining and communities: A transdisciplinary approach to ecological risk assessment in the South Pacific

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## EDITOR'S NOTE:

This article is part of the special series entitled: "Implications of Deep-sea Mining on Marine Ecosystems." The series comprises the current state of the science regarding deep-sea ocean ecosystems and the likely ecological footprints, risks, and consequences of deep-sea mining. There is a focus on: impact assessment, policy solutions, and practices to aid in the implementation of industry guidance prepared by the International Seabed Authority and other authorities, new monitoring and assessment methods, best management practices, and emerging scientific research related to deep-sea ecosystems.

## Abstract

Deep-sea mineral extraction is a fledgling industry whose guiding principles, legislation, protocols, and regulations are still evolving. Responsible management of the industry is difficult when it is not clearly understood what biological and environmental diversity or ecosystem services may be at risk. But the industry's infancy provides an opportunity to address this challenge by stakeholder-led development and implementation of a multidisciplinary risk assessment framework. This article aims to present the findings of a workshop held in New Zealand that hosted stakeholders from a broad range of interests and regions in the South Pacific associated with the deep-sea mineral activity. The outputs provide stakeholder-informed ecological risk assessment approaches for deep-sea mining activities, identifying tools and techniques to improve the relevance of risk assessment of deep seabed mining projects to communities in the South Pacific. Discussions highlighted the importance of trust or respect among stakeholders, valuing the "life force" of the ocean, the importance of scientific data, and the complications associated with defining acceptable change. This research highlighted the need for a holistic transdisciplinary approach that connects science, management, industry, and community, an approach most likely to provide a "social license" to operate. There is also a need to revise traditional risk assessment methods to make them more relevant to stakeholders. The development of ecotoxicological tools and approaches is an example of how existing practices could be improved to better support deep-sea mineral management. A case study is provided that highlights the current challenges within the legislative framework of New Zealand. *Integr Environ Assess Manag* 2022;18:664–673. © 2021 SETAC

**KEYWORDS:** Ecosystems services, Ecotoxicological tools, Indigenous knowledge, Seabed biodiversity, Social license

## THE DEEP SEABED

The deep sea includes the whole ocean area beyond the continental shelf break, with depths ranging between ~150 and 11 000 m. It represents the largest and least explored environment on Earth (Ramirez-Llodra et al., 2010; Tyler, 2003). Less than 20% of the deep ocean floor has been mapped (seabed2030.org) and only a small fraction of it has been studied to assess its environmental, economic, and social values. Studies are ongoing and new benthic and pelagic species and habitats are continuously being discovered. Deep seabed areas contain a considerable spatial and temporal variation of environmental conditions that define a variety of habitats and ecosystems (e.g., Barbier et al., 2014; Grassle & Maciolek, 1992; Hessler & Sanders, 1967; Levin et al., 2001).

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These include topographic features, such as canyons, mid-ocean ridges, faults and hadal trenches, and thousands of seamounts, knolls, and hills. High pressure, low temperature, darkness, and food limitation characterize the deep seabed environment (Tyler, 2003).

Despite these conditions, deep seabed areas can harbor high diversity, similar to that observed in tropical rainforests (Grassle & Maciolek, 1992; McClain & Schlacher, 2015). This diversity comprises distinct spatial patterns and/or gradients likely to be linked to interdependent environmental, ecological, and evolutionary factors and processes (Danovaro et al., 2014; Levin et al., 2001). Ocean-wide trends of a decrease of abundance, biomass, and body size with increasing depth have been observed, primarily associated with energy constraints (Rex et al., 2006; Tittensor et al., 2011), although other factors, such as biotic interactions, may also be relevant (Levin et al., 2001; Ramirez-Llodra et al., 2010). A linkage between diversity and food availability has also been observed (Rex & Etter, 2010; Woolley et al., 2016), with diversity peaking at mid-slope depth in some areas (Rex & Etter, 2010, and citations therein). Latitudinal trends of a poleward decline in diversity, corresponding to that observed in shallow waters, are observed in North Atlantic deep seabed patterns, and are associated with factors, such as lower evolutionary rates at low temperatures, seasonality of food supply, and geographic range shifts (Jablonski et al., 2013; Rex et al., 1993; Tittensor et al., 2010). However, a similar trend has not been identified for southern hemispheric deep seabed biodiversity patterns, perhaps because the area is less well studied (Brandt et al., 2007; Rex & Etter, 2010).

Increasing pressures from resource exploitation, pollution, and the effects of climate change are now reaching great ocean depths, posing threats to the integrity of the deep seafloor (Gollner et al., 2017; Markus et al., 2015; Ramirez-Llodra et al., 2011). Impacts from seabed mining may include the removal and compaction of the substrate and generation of large sediment plumes, possibly containing toxic elements released from the sediments (Hauton et al., 2017; Washburn et al., 2019). The ecotoxicological effects could be severe for mid-water and benthic communities exposed to environmental changes such as these but they are generally not well understood (Drazen et al., 2020; Mestre et al., 2017; Washburn et al., 2019). Some information exists on the specialized biological communities and functioning of deep seabed ecosystems, but it is insufficient to properly assess the impacts of these pressures on them or on the services they may potentially provide for the well-being of humans (van den Hove & Moreau, 2007). The understanding of these ecosystem services, including the economic and social value derived from the naturally inherent value of biodiversity, is still in its infancy. Increased understanding of ecosystem services and biodiversity value provided by the deep sea and the dissemination of this knowledge is required for decision makers, stakeholders, and the general public (Jobstvogt et al., 2014).

## BACKGROUND TO THE WORKSHOP

The South Pacific region covers an area of about 33 million km$^2$ and is an area of high biodiversity, strategic importance, and anthropological significance. The region also has considerable mineral deposits, many of them within the Exclusive Economic Zone (EEZ) of Pacific Island states, including cobalt-rich ferromanganese crusts usually found on seamounts, seafloor massive sulfides associated with active and inactive hydrothermal vents, polymetallic or manganese nodules formed on abyssal plains, and phosphorite deposits formed on continental margins (Levin et al., 2016 and citations therein). The estimated extent of these resources ranges from 38 million km$^2$ for ferromanganese nodules to 3.2 million km$^2$ for massive sulfides and 1.7 million km$^2$ for polymetallic crusts on seamounts (Petersen et al., 2016). Similarly, the extent and nature of mining activities will vary by resource and will impact associated biota in different ways.

Many countries in the South Pacific do not have the financial or human resources to manage large development projects such as deep seabed mining and are thus dependent upon partnerships to develop these resources (Sun, 2017). Because the industry is in its infancy, deep seabed mining offers an opportunity to develop assessment and management practices that provide consideration and inclusion of environmental concerns raised by communities along with other community concerns at all stages of development, practices that can be adopted by any country.

The Deep-Sea Minerals Project, a collaboration between the Pacific Community and the European Union, was initiated in 2011. This project aimed to help Pacific Island countries to improve the governance and management of their deep seabed mineral resources in accordance with international law, with particular attention to the protection of the marine environment and securing equitable financial arrangements for Pacific Island countries and their people (e.g., Swaddling, 2016).

In 2014, the authors and contributors to the Deep-Sea Minerals Project participated in a follow-up workshop on "Reconciling mining and the sustainable development in the Pacific countries." The workshop was organized by the Centre for Technological Research (CNRT, New Caledonia) and was supported by the Pacific-Europe Network for Science Technology and Innovation (Pace-Net Plus Programme). One of the focus groups considered deep marine mineral resources, highlighting new issues and challenges and suggesting innovative ways to harmoniously foster development while ensuring an equitable consideration of the environment, social costs, and economic benefits. Following this meeting, funding was awarded to the authors to run a multidisciplinary workshop in 2016 to develop stakeholder-informed ecological risk assessment approaches for deep-sea mining activities, identifying tools and techniques to improve the relevance of risk assessment of deep seabed mining projects to communities in the South Pacific.

The workshop outputs described herein enable the expansion of multidisciplinary conversations highlighted in the Deep-Sea Minerals Project. New Zealand, which is not one of the member countries of the Deep-Sea Mineral Project, has begun to consider seabed mining projects and some of those results are considered. This paper provides new insights into what ecological risk assessment frameworks need to consider in order to engage in meaningful conversations with stakeholder communities.

## WORKSHOP FOCUS AND OUTPUTS

The objectives of the workshop, held in Wellington, New Zealand, on 4 March 2016 were to:

1. contribute to identifying values of deep seabed ecosystems important to South Pacific communities;
2. identify the concepts needed to develop a draft framework for ecological risk assessment for deep-sea mineral activities; and
3. identify tools and approaches for community-engaged risk assessment.

Figure 1 provides a synthesis of the workshop discussions highlighting the priority target approaches to risk assessment and risk minimization. The workshop participants agreed that the current lack of knowledge about the deep seabed increased the risk of unacceptable consequences arising from decisions about its development. It was also generally agreed that the ecosystem services identified in the EcoDEEP Project (EcoDeep-SIP Workshop, 2015) complemented the values that should be protected. Beyond this, there was a strong feeling that the perceived intangible value of the "life force" of the ocean needed to be included among the factors guiding decisions affecting deep seabed mining activities and could be reason enough for rejecting marine resource extraction. This value is closely linked to the precautionary approach that may be used in instances of high uncertainty, where there is a lack of scientific understanding of deep seabed biodiversity and ecosystem services. It highlights the collective view that responsible decision-making in a dearth of knowledge is challenging (Kung et al., 2021), and therefore requires a dynamic approach to responsible monitoring and adaptive management practices (Gluckman, 2016).

The focus of the concepts developed through the workshop (Figure 1) are primarily ecological and social, highlighting the importance of the environment in culture. Workshop participants also indicated that the understanding of ecosystem values can be improved through data sharing between sources of indigenous and "Western" scientific knowledge. For example, indigenous stories and harvest/collection times may provide information about the spawning or aggregations times of a species. A shared and open database that is regularly updated and consists of information and data relating to deep-sea ecosystems, resources, and values would enhance and share an understanding of biodiversity, ecosystem interactions, natural life cycle patterns, and adaptive management options. Such a database was identified as a key tool needed to support informed decision making and would be of further benefit if data from measured impacts of approved activities were also shared. It would help all stakeholders to understand the magnitude of the impact zone as compared to those predicted by models. It would also facilitate trust and respect

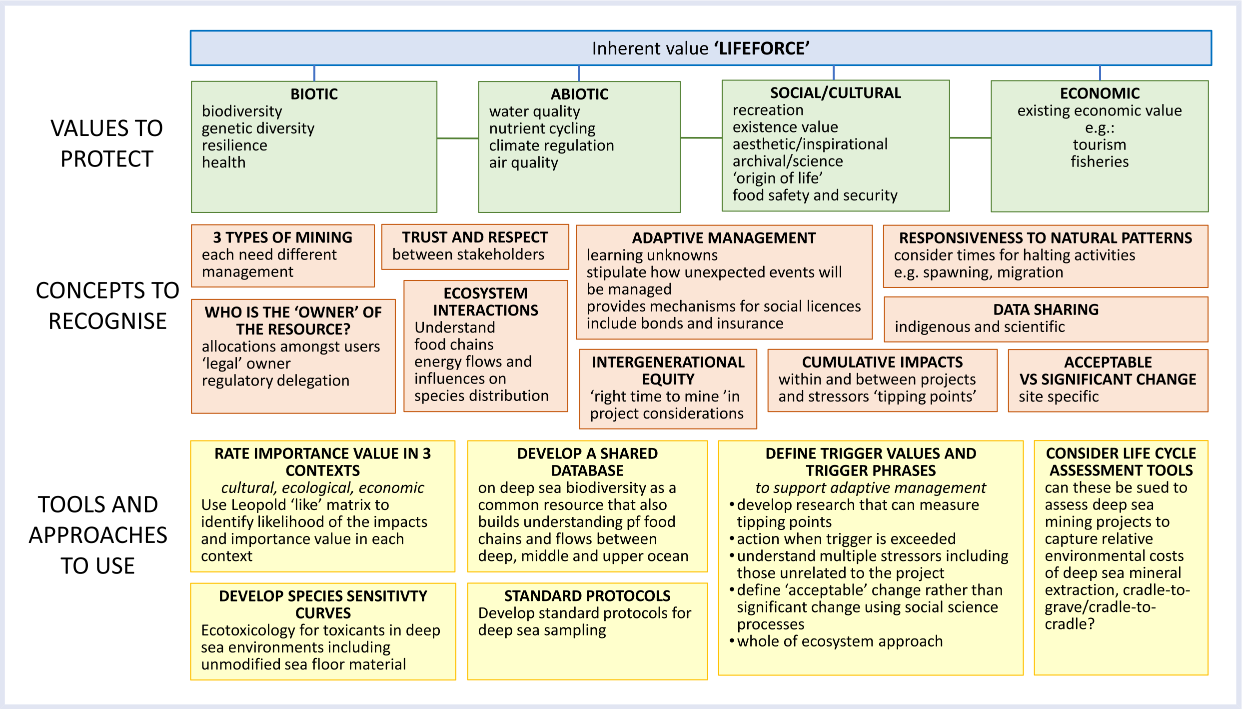

FIGURE 1 Synthesis of the factors identified during the community engagement workshop to help integrate community interests and improve integration between the social, environmental, and economic factors in risk assessment for deep seabed mining

among key stakeholders. Shared databases such as the one proposed have been used in multiple other environmental management frameworks (e.g., Aswani & Lauer, 2006; Calamia, 1999; Close & Hall, 2006; Hall et al., 2009; Lazrus & Sepez, 2005).

The responsible management of the deep seabed requires clarity about who the "legal" owner of the resource is and the relevant regulatory framework. Those located within the EEZ of countries are within national jurisdictions that extend up to 200 nautical miles from the coast. Beyond the EEZ international waters (or "the Area") fall under international regulatory arrangements that are the responsibility of the United Nations International Seabed Authority (ISA). The social interests and concerns of the South Pacific Islands extend beyond their EEZ's. Several of these States adjoin deposits identified in international waters and several (e.g., Tonga, Cook Islands, Nauru) have licenses in designated mining areas beyond national jurisdiction (Tilot et al., 2021, and citations therein). The social aspects of deep seabed mining are as complex as the legal and political aspects. This is in part because it is difficult to identify the local community and in part due to the different cultural backgrounds of the Pacific states (Filer & Gabriel, 2018). Therefore, there is no common social basis guiding decisions related to mining operations.

Measures of "significant change" or "serious harm" can be useful tools to gain an understanding of the consequences of factors affecting the deep seabed (e.g., Jones et al., 2017), but they can be hard to quantify and may have different interpretations when different perspectives are considered. They also may be difficult for the layperson to understand and may not address specific concerns of communities. Workshop discussions highlighted the difference between a "significant change" determined according to procedures and protocols and the determination of whether this change is acceptable (or not) to society. Clearly defined trigger values and/or trigger phrases and responses (i.e., adaptive management) based on scientific understanding and agreed to by stakeholders convey a similar message but may be easier to understand and provide more confidence in risk management.

Life Cycle Assessment (LCA) tools could help inform management decisions related to the deep seabed by providing information about the benefits and costs of resource extraction from the deep seabed with those from alternative sources. Tools for environmental impact assessment, such as the Leopold matrix (Leopold et al., 1971), which consider the likelihood of the impact with the severity of the consequence would help decision makers understand the magnitude of the risks of deep seabed projects. The power of both of these tools increases as the scientific understanding of the ecosystems and their processes improves. They may also be used to set environmental goals and objectives through strategic planning for deep seabed mining as described in Tunnicliffe et al. (2020).

## EVOLVING TOOLS AND APPROACHES TO INTEGRATE VALUES AND CONCEPTS

### *Addressing the "life force" of the deep sea*

The evaluation of how society (directly or indirectly) benefits from and depends on deep seabed systems comprises the sum of their provisioning, regulating, supporting, and cultural services (Millennium Ecosystem Assessment [MEA], 2005). Without deep-sea life, all life on Earth would cease because of the essential role the deep sea plays in biogeochemical cycles (Armstrong et al., 2012; Cochonat et al., 2007). Ecosystem function includes the flux of materials such as shown in biogeochemical cycles along with stocks of energy and materials, fluxes of energy, and the stability of rates and stock over time (van den Hove & Moreau, 2007) and this function has been exponentially related to benthic biodiversity (Danovaro et al., 2008) The deep sea also has a considerable scientific, esthetic and spiritual value; and it is inherently important to people (Koschinsky et al., 2018; Thurber et al., 2014). This value is evidenced by the common, though unquantifiable, interest in deep seabed habitats and their biota in spite of their remoteness and lack of publicity (Jobstvogt et al., 2014; Thurber et al., 2014). Understanding the value of the deep sea will expand further if new knowledge is shared, particularly without sensationalizing it (Jamieson et al., 2021).

Examples from Pacific jurisdictions, such as Hawai'i and New Zealand, underscore the importance of respecting cultural values and of a holistic view of nature and its services (Pascua et al., 2017). For example, the Mauri model, originally developed in the New Zealand context but widely used throughout the Pacific, quantifies the impact of actions on Mauri (i.e., the life force of all living things). It considers four equally weighted dimensions: economic, social, cultural, and environmental well-being (Faaui, 2018; Pascua et al., 2017). Recently, Tilot et al. (2021) provided a thorough consideration of these traditional dimensions in the context of deep seabed mining in the Pacific and linked these to legal frameworks. Further to this, in a more general but relevant framework, the Declaration on the Rights of Indigenous Peoples (UN General Assembly, 2007) specifically recognizes "the urgent need to respect and promote the inherent rights of indigenous peoples which derive from their political, economic and social structures and from their cultures, spiritual traditions, histories and philosophies, especially their rights to their lands, territories and resources."

More work needs to be done to uncover patterns and processes that modulate the diversity of the deep sea and enable the refinement of ecosystem services. Data and knowledge sharing among industry, governments, and the concerned public would help provide a better understanding of deep seabed environments and support tools and approaches highlighted in the workshop. Greater involvement of indigenous communities and their cultural values and knowledge in decision-making processes would improve the environmental management of the deep sea and sustainable use of its resources that lie within the limits of national jurisdiction. However, there are challenges in the international seabed area where mining could be carried out or sponsored by a member state of the ISA but community involvement is potentially excluded due to the limits of the ISA's decision-making structure and the member state being guided by what its national laws and policies state (Kim, 2017). At this point, it is noteworthy that indigenous knowledge has not yet been incorporated into the draft of the so-called Mining Code, which is currently being developed by the ISA to determine rules, recommendations, and procedures for the mining of deep-sea minerals in the Area (Jaeckel, 2017).

### *Focusing on knowledge gaps to better understand the risk*

An adequate assessment of the ecological risks of deep-sea mining activities is made difficult by the lack of basic information about the biological communities and the extent and mode of the effects of mining on them. In particular, the lack of information on impacts for biota is viewed as one of the major gaps in predicting the risk of mineral extractions in the deep sea (Jones et al., 2017; Mestre et al., 2017; Santos et al., 2018). This is particularly noteworthy as toxicity, the burial of organisms, and changes in seawater chemistry from plumes created during mining or tailings have been identified as the greatest ecological risks associated with deep-sea mining (Washburn et al., 2019).

Against this background, the development of relevant ecotoxicological instruments and approaches with social relevance was highlighted as a research focus during the workshop. This paper sets out a plan to utilize known links among biological traits, sensitivity to specific stressors, and ecosystem function to improve ecotoxicological tools used in ecological risk assessment; for example, feeding behavior and nutritional source, mobility, and life history could guide the species selection rather than just the traditional focus on taxonomic groups. Further examples of trait-based categorization can be found in A. S. A. Chapman et al. (2019).

### *Present methods and understanding*

Current ecotoxicity tests focus on the dose-response of few standard species. These species are selected for their known and measurable sensitivity to stressors through the assessment of sublethal endpoints in dose-response experiments, suitability to laboratory conditions, and their likelihood of accumulating contaminants. Standard tests are particularly useful in allowing comparison between locations and transference of toxicity guidelines. Problems with the use of standard species are that they may not be present in the specific location, making it difficult to explain how their response may predict that of the environments in question and their relevance to local communities and their food safety and security. The limitation of the standard test species approach is a general problem of ecotoxicology and results in uncertainty in risk assessment for biodiversity protection and ecosystem services (Artigas et al., 2012) although it does enable comparative assessment.

Unfortunately, there are currently few alternatives to test species that can be used as surrogates for deep-sea taxa. Little is known about trace metal concentrations in deep seabed organisms or their responses to changes in environmental conditions (Koschinsky et al., 2003). Bioaccumulation of terrestrially derived organic compounds measured in deep-sea species (e.g., Mormede & Davies, 2003; Storelli et al., 2007; Unger et al., 2008) highlights pathways of their distribution and uptake. Laboratory-based studies of impacts of metals on deep-sea biota and their shallow-water surrogates are difficult and limited (e.g., Auguste et al., 2016; Black et al., 2015; Brown et al., 2017; Hauton et al., 2017; Mestre et al., 2019) also because little is known about the effects of extreme deep-sea conditions (e.g., low temperatures; hydrostatic pressure) on the toxicity of pollutants (Brown et al., 2017; Mestre et al., 2014). In addition, impacts on ecosystem structure and function have not been considered. These limitations mean that even global studies of geographic differences in metal toxicity fail to take account of deep-sea environments (e.g., P. M. Chapman et al., 2006). Furthermore, bioaccumulation studies of deep-sea organisms are hampered by factors affecting most research in the deep sea (e.g., costs, logistics, and resources) and specific factors arising from limited taxonomic information and understanding of the relevance of various uptake pathways.

Field-based Species Sensitivity Distributions (f-SSD developed by Leung et al., 2005) determine species sensitives along gradients of chemicals. This sampling "in place" incorporates the use of local species and allows for assessment in circumstances where mining produces multiple contaminants. As they require sampling in place they may be hard to implement in deep-sea locations. However, f-SSDs are particularly useful for understanding cumulative impacts and therefore the likelihood of tipping points (Hewitt et al., 2009).

### *Future approaches and opportunities*

Given the limitations of using standard approaches in deep-sea ecotoxicology, it would be constructive and timely to invest resources in developing a new approach to ecotoxicological understanding that supports the rationale identified in the workshop. Indeed Santos et al. (2018) highlight many additional tools and approaches for deep-sea risk assessment in general. The new approach presented here focuses on the selection of nonstandard species that represent levels of organization and types of species (e.g., bioturbators, habitat structure) to be used for ecotoxicological understanding (the "what") (Figure 2). These decisions also can focus selection of the type of ecotoxicology methods that can be undertaken ("how" and "where"). For example, the approach could consider whether species can be brought to laboratories for testing or hyperbaric laboratories be developed (e.g., Pinheiro et al., 2021; Santos et al., 2018). Consideration could also be given to the appropriateness of field-based environmental DNA studies (e.g., Birrer et al., 2018; Chariton et al., 2016; Gammon et al., 2018). The

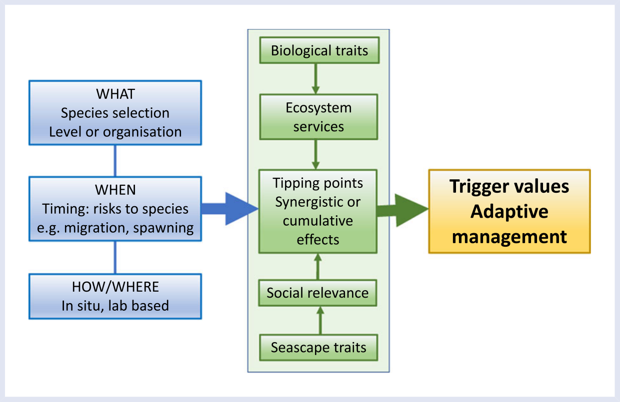

FIGURE 2 Considerations for developing new approaches to ecotoxicology

selection of "what," particularly if a species is chosen, often leads to the timing of the tests ("when"), which, in turn, may lead to constraints on when mining could occur. Use of both biological traits and landscape-based traits (relative dominance, patchiness, dispersal corridors) can also highlight the likelihood of synergistic cumulative impacts and the potential for tipping points that can be explored via ecosystem network models or spatially explicit planning tools (e.g., Zonation; Van Teeffelen et al., 2006) to help identify trigger values that support adaptive management (e.g., Gladstone-Gallagher et al., 2019, 2021; Hewitt et al., 2018).

We propose ongoing research linking traits through ecological function to ecosystem services and social values (e.g., Artigas et al., 2012; Siwicka & Thrush, 2020) and, in particular, a decision-making process that engages stakeholders in the selection of ecologically and socially relevant species for developing ecotoxicity test methods for deep-water environments (Figure 2). This is an area of research presently being undertaken in many marine systems, allowing the lessons learned in places where sampling is easier to be adapted for use in deeper areas, for example, ecosystem services research (Jobstvogt et al., 2014).

Another challenge is the management of expectations of local communities. This requires an appreciation of what can realistically be achieved by ecotoxicology studies, what they would miss, and what the implications of the missing pieces are. Workshops bringing together ecologists, ecotoxicologists, industry, and local communities to share understandings are, at this stage, the most fruitful way forward.

The workshop highlighted the value of the integration of indigenous and "Western" scientific knowledge and approaches. Indigenous knowledge and values are likely to reveal concerns about specific types of species. Expert scientific studies may focus attention on biological traits that predispose particular levels of organization (or types of species) to harm (whether directly or indirectly; Hewitt et al., 2018 [including dispersal problems]) or on keystone species that are of particular importance to maintaining biodiversity, ecosystem services, and function or ecosystem interactions (Siwicka & Thrush, 2020). The selection of species and/or levels of the organization would underpin tools and approaches recommended in the workshop.

### *Integrating indigenous and scientific knowledge through legislation—An example in practice*

There are currently a few ways in which South Pacific countries could manage the environmental risks of deep seabed mining through effective integration of indigenous and scientific knowledge. An example we highlight here comes from the Exclusive Economic Zone and Continental Shelf (Environmental Effects) Act 2012 (EEZ Act) of New Zealand (Anton & Kim, 2015) which "continues or enables the implementation of New Zealand's obligations under … the United Nations Convention on the Law of the Sea 1982" (EEZ Act, section 11). Under this *Act*, all seabed mining applications within national jurisdiction must satisfy the sustainable management purpose, which supports concepts highlighted in the workshop and is defined as (EEZ Act, section 10):

> *"managing the use, development, and protection of natural resources in a way, or at a rate, that enables people to provide for their economic wellbeing while—(a) sustaining the potential of natural resources (excluding minerals) to meet the reasonably foreseeable needs of future generations; and (b) safeguarding the life-supporting capacity of the environment; and (c) avoiding, remedying, or mitigating any adverse effects of activities on the environment."*

To achieve this purpose the *Act* pays due consideration to the principles of the Treaty of Waitangi. It establishes a Māori Advisory Committee, which advises marine consent authorities so that decisions made under this *Act* may be informed by a Māori perspective (EEZ Act, section 18). The *Act* requires the responsible minister to establish and use a process that gives iwi (Māori people) adequate time and opportunity to comment on the subject matter of proposed regulations (EEZ Act, section 32). The *Act* requires the Environmental Protection Authority to notify iwi authorities, customary marine title groups, and protected customary rights groups directly of consent applications that may affect them (EEZ Act, section 46).

In addition, the *Act* establishes adequate principles for dealing with scientific knowledge and uncertainties. The so-called "information principles"—as set out in the *Act*—require the consenting authority to base its decisions on the "best available information," defined as "the best information that, in the particular circumstances, is available without unreasonable cost, effort, or time" (EEZ Act, sections 34 and 61). If information is uncertain or inadequate then the authority is required to "favour caution and environmental protection" (EEZ Act, sections 34 and 61). The authority is required to consider whether taking an adaptive management approach would allow the activity to

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be undertaken by sufficiently reducing uncertainty and adequately managing any remaining risk.

In addition, the decision-making criteria in the *Act* provide guidance on how the abovementioned purpose is to be achieved in a socially, culturally, economically, and ecologically sustainable manner. For example, the *Act* contains an extensive list of relevant matters, including “the effects on the environment or existing interests of other activities undertaken in the area covered by the application or in its vicinity”; “the effects on human health that may arise from effects on the environment”; “the importance of protecting the biological diversity and integrity of marine species, ecosystems, and processes”; and “the economic benefit to New Zealand of allowing the application” (EEZ Act, section 59).

It should be emphasized that the term “effect,” which appears in the decision-making criteria as well as in the statutory purpose, is defined very broadly to include any positive, adverse, temporary, permanent, past, present, future, cumulative, and highly probable effect, as well as an effect of the low probability that has a high potential impact (EEZ Act, section 6(1)). These matters outline the factors that must be considered to decide whether the environmental risks of the project are acceptable or not. Understanding the impact in terms of acceptability would address one of the concepts developed in the workshop (Figure 1). This *Act* provides a framework for considering deep-sea mining and the case study described below provides an example of how this *Act* is being applied.

A commitment to growing an accessible database of relevant information would provide greater confidence in the evaluation of environmental risks and assist with the identification of adaptive management strategies. An adaptive management approach, as defined in the *Act*, includes “allowing an activity to commence on a small scale or for a short period so that its effects on the environment and existing interests can be monitored.” The *Act* empowers the consenting authority to “impose conditions under section 63 that authorize the activity to be undertaken in stages, with a requirement for regular monitoring and reporting before the next stage of the activity may be undertaken or the activity continued for the next period.”

## CASE STUDY: CHATHAM ROCK PHOSPHATE, NEW ZEALAND

In New Zealand, a company must get a mining permit and environmental consent to develop an offshore natural resource. Granting of a mining permit is based on the assessment of the technical, financial, health, and safety capabilities of the company and whether the development of the resource is aligned with the purpose of legislative objectives. Granting of environmental consent is based on the assessment of a plan for the sustainable management of the development of natural resources. Chatham Rock Phosphate Ltd. (CRP) was granted a mining permit covering 820 km$^2$ of the phosphate resource on the Chatham Rise in 2013. CRP's application for environmental consent was declined in 2015.

Consideration of the environmental consent application was complicated by the occurrence of a protected species of stony coral, the dynamic oceanographic conditions on the crest of the Chatham Rise, and overlap of the resource with a benthic protection area established to prohibit bottom trawling by the fishing industry. There were some gaps in the environmental data presented to the decision-making committee, for example, less than a year's measurements of baseline turbidity, and statistical rather than complete observations of the extent of coral communities. CRP argued that the data were sufficient to evaluate the fundamental environmental risks of mining operations and proposed conditions that would fill these gaps before mining commenced and guide adaptive management of its operations to address the refined analysis of the risks and adverse environmental effects, if they occurred.

Interested parties objected to the project on the grounds that it would adversely affect fishing, seabirds, marine mammals, and primary productivity. Experts representing all of the interested parties analyzed these issues and decided that it was unlikely that there would be any significant impacts on them. The phosphate on the Chatham Rise has a number of environmental benefits (e.g., extremely low cadmium, low runoff into waterways, reduced $CO_2$ emissions from transport) but there was almost no vocal support for the project from the agricultural or environmental sectors.

Ultimately the decision-making committee declined the application because they did not consider the environmental risks were sufficiently well understood, did not believe the proposed conditions or adaptive management could address possible adverse environmental effects, and thought the benefits of the project were not sufficient to outweigh these uncertainties.

CRP has since identified the work required to fill the data gaps to support another environmental consent application. It is awaiting the outcome of court appeals arising from a marine mining project closer to shore that will clarify the interpretation of the governing legislation before starting its reapplication process.

The uncertainties associated with offshore mining projects are perhaps greater than many other projects because of the difficulties of making remote observations and measurements in a marine environment. Knowledge of the resource or the environment will never be complete. However, unless lifestyle expectations change or there is a significant change in the use or recycling of minerals then mining will become increasingly important to society. If this is the case then it is likely that offshore mining will be needed to help meet the demand for resources. The legislation and regulations that govern offshore mining must accept that if uncertainties are understood and managed through informed conditions and adaptive management practices then the industry can progress in an environmentally responsible way.

## CONCLUSIONS

Deep-sea mining poses significant risks to the environment and it impacts the social and cultural values of local communities and their "life force." If these risks and impacts are not mitigated collectively then the social license to operate can be withdrawn and create economic uncertainty for the mining industry. Because there is little experience in deep-sea mineral mining there are large uncertainties about its effects, and progress requires a considered balance between the needs of society for mineral resources, the protection of ecosystems that are poorly understood, and the confidence that local communities will not bear the social costs of poor or misunderstood implementation and management. This is a challenge for all stakeholders. Some social and cultural considerations are connected with understanding environmental impacts and it is important that they be incorporated into ecological risk assessment, which can be achieved, for example, through the participation and consultation of community representatives and accompanying platforms for knowledge and data exchange between the actors from industry, regulatory authorities, and science and civil society. The combination of these factors results in the need to adapt standard ecotoxicity tests using a few standard species and develop tests that assess risks to ecosystem structure and function using species that are valued by local communities in the South Pacific, and at locations of proposed deep seabed mining. Deep-sea mining will need risk assessments that meet these requirements while being robust, reliable, and relevant. By involving local communities and their knowledge in the choice of "risk to what," the social license can be gained along with a better appreciation of how to offset social and cultural risks. This paper highlights some elements to be considered to holistically address risk assessment strategies and tools that address community uncertainties. Stakeholders must establish trusted relationships, develop agreeable trigger values and trigger thresholds and adaptive management processes, and commit to them.

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## CONFLICT OF INTEREST

The authors declare Ray Wood's workplace is involved in the development of the Chatham Rise phosphate mining project.

## DATA AVAILABILITY STATEMENT

This manuscript does not contain numerical data. Workshop material and photographs of activity outputs are available from corresponding author Amanda Reichelt-Brushett (amanda.reichelt-brushett@scu.edu.au).

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