Closing the liability gap: A review of liability alternatives in environmental regulation for the emerging seafloor mineral extraction industry

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Abstract

The potential for vast mineral wealth on the seafloor has led to the emergence of commercial interest in recent decades. A critical barrier to seafloor mineral development has been the lack of regulatory regime for commercial exploitation, which would address how mining entities are to monitor or be monitored, manage or be managed, and compensate for potential adverse environmental impacts. Seafloor minerals that occur in the area beyond national jurisdiction (the Area) are governed by the International Seabed Authority (ISA). The ISA and stakeholders recognize that unknown impacts and even unknown consequences of foreseen impacts to the seabed and pelagic ecosystems may present an environmental liability gap, which may unnecessarily increase environmental risk exposure to the ISA. This paper presents an analysis in an effort to support the ISA in its work to minimize the potential for a liability gap in seafloor mineral exploitation in the Area. It develops a structured review of regulatory alternatives, bonds and insurance, that have been implemented in established industries that exhibit similar operational and liability characteristics to seafloor mineral extraction, and offers a decision pathway to support ISA efforts to reduce environmental risk exposure.

Introduction

The potential for tremendous mineral wealth from the seafloor has led to the emergence of commercial interest in recent decades. Seafloor minerals occur within and beyond national jurisdictions, the latter being a region defined by the United Nations as "The Area" or "the common heritage of mankind" (1833 UNTS 3; 21 ILM 1261 1982). The Area is governed by the International Seabed Authority (ISA), which, at the time of this writing, manages 23 exploration contracts between private entities and signatories of the United Nations Convention on the Law of the Sea. A large concentration of exploration activity – 14 licenses – occurs in one region of the Pacific Ocean known as the Clarion Clipperton Zone (CCZ), which is comprised of 6 million square kilometers of abyssal plain at 4,000 to 6,000 meter depths. The mineral resources in the CCZ are found in so-called manganese nodules, and include nickel, manganese, iron, copper, cobalt, and other metals and rare earth elements (ISA brochure). All current contracts are for exploration only and thus there is currently no commercial extraction of seafloor minerals in the CCZ.

Interest in mining seabed manganese nodules has waxed and waned over several decades. Commercial interest in seabed minerals has been renewed due to increasing worldwide consumption of minerals (Statista 2016a, Statista 2016b) and improvements in undersea technology (Wedding et al. 2015, Mengerink et al. 2014, Wedding et al. 2013, Ramirez-Llodra et al. 2011). A critical barrier to seafloor mineral development in the CCZ and elsewhere remains the lack of a regulatory regime that covers commercial exploitation. Such a regime would arguably address how entities (contractors), who in the future may conduct commercial extraction, are to monitor or be monitored, manage or be managed, and compensate for potential adverse environmental impacts. We use the CCZ as a context through which to discuss alternatives for regulating environmental liability in this emerging industry; these alternatives could apply to other ecosystems and jurisdictions also preparing for commercial-scale seafloor mineral extraction.

While the anticipated environmental impacts of seafloor mineral extraction are expected to be accounted for in the final Environmental Impact Statement (EIS) within a contractor's mining permit, the ISA and stakeholders – including academic experts, environmental managers, industry, and regulators – recognize that unknown impacts and even unknown consequences of foreseen impacts to the seabed and pelagic ecosystems represent an environmental liability gap (M. Lodge Personal Communication October 2015). This is an important issue that the ISA will address in their forthcoming exploitation regulations (International Tribunal on the Law of the Sea Seabed Disputes Chamber paragraph 203, M. Lodge Personal Communication October 2015, Anton et al. 2011). Such an environmental liability gap is not unique to seafloor minerals. Indeed, other industries have attempted to bridge this liability gap by implementing insurance mandates, environmental bond mechanisms and the precautionary principle. Such previous activities could provide insight for the seafloor mineral extraction industry. Understanding how unknown environmental impacts—as opposed to known impacts with measurable financial consequences—are regulated in comparable industries may inform the ISA's development of exploitation regulations.

This paper presents a structured review of two overarching regulatory alternatives that have been implemented in similar industries in an effort to support the ISA in its work to minimize the potential for a liability gap in seafloor mineral exploitation in the Area. First, the environmental bond alternative uses a strict liability rule that involves organizing and managing a bond payment scheme, with *ex-ante* payments from contractors conducting commercial extraction of mineral resources. Second, the insurance alternative uses a negligence-based liability rule, for which the ISA would provide guidance on or regulate insurance, with *ex-post* payouts for unanticipated or unpermitted environmental damages. A subset of the insurance alternative, Protection and Indemnity (P&I) Clubs, are mutual insurance organizations that may be particularly applicable to the ISA's efforts.

Two industries, terrestrial mining and maritime shipping, have similar liability characteristics to those of seafloor mineral extraction, and may inform the ISA in its deliberations on which regulatory mechanism, bonds or insurance, may be appropriate to apply. From the terrestrial mining industry, one

can look to approaches to managing environmental liability where the activity has a life span of several decades. The maritime shipping industry manages similar environmental liability issues to seabed mining in areas beyond national jurisdiction with transboundary forces at play. Terrestrial mining and maritime shipping use environmental bonds and insurance, including P&I Clubs as a subset of insurance, insight from which could apply to seafloor mineral extraction. Other industries, such as shallow-water mining (diamond, phosphate, sand) and offshore oil and gas, could also provide insight on bonds and insurance, but are outside the scope of this work.

This analysis does not deliver a detailed and thorough legal or historical review of strict (bonds) or negligence-based (insurance) liability rules. Rather, it presents a broad analysis of potential solutions to an environmental liability gap issue that relates to seafloor mineral extraction and offers a possible decision pathway for the ISA in support of efforts to reduce environmental risk exposure from potential unknown or unanticipated environmental impacts. A more careful and inclusive study is needed prior to implementing one or more regulatory instruments, and suggestions for how this might be executed are provided.

1) Introduction. A discussion of (a) environmental impacts from a regulatory point of view and (b) how environmental bonds and insurance may serve as regulatory instruments to cover unanticipated environmental impacts.
2) A discussion of alternatives. An analysis of how the terrestrial mining and maritime shipping industries have implemented bonds and insurance.
3) Strengths-Weaknesses-Threats-Opportunities (SWOT). A SWOT analysis for each regulatory alternative and discussion of application of these alternatives to seafloor mineral extraction.
4) Discussion. Suggestions for future work and limitations of this research

PART 1: Introduction. A discussion of (a) environmental impacts from a regulatory perspective and (b) how bonds and insurance may serve as regulatory instruments to cover unanticipated environmental impacts

This section presents a general, industry-agnostic characterization of environmental impacts that presents an environmental liability gap from a regulatory perspective. It also introduces the concept of bonds and insurance as they relate to environmental regulation. These pieces together develop an important foundation for Part 2, which reviews how terrestrial mining and maritime shipping have implemented environmental bonds and insurance in efforts to reduce the potential for an environmental liability gap.

Breaking down environmental impacts: An approach for regulators

It is useful to normalize environmental impacts into broad categories in order to draw parallels on how industries with similar characteristics to seafloor mineral extraction have regulated uncertain and accidental environmental impacts. These categories are: (1) known impacts with known consequences; (2) known impacts with unknown consequences; and (3) unknown impacts with unknown consequences (L. Pendleton, Personal Communication 17 March 2016). Impacts that fall in the first category can be managed by imposing an up-front fee or tax because the impacts are known and can be financially quantified. For example, greenhouse gas emissions from a seafloor mineral extraction vessel or a shipping vessel can be handled *ex-ante* to allow for a certain amount of emissions, and supplemental payment schemes could be instituted should the contractor exceed agreed-upon emissions levels (Idelhakkar and Hamza 2010).

The second two categories of environmental impacts are more difficult to regulate given the embedded uncertainty in an impact's ecological magnitude, financial cost, and probability of occurrence (MERAG fact sheet 2007, L Pendleton Personal Communication 17 March 2016). Known environmental impacts with unknown consequences include light and sound pollution, which may or may not have a significant impact on the environment (Global Ocean Commission 2013, L Pendleton Personal

Communication 17 March 2016). That these impacts are known implies they can be monitored, and hence the costs associated with mitigation or remediation can be assessed and agreed upon between the regulator and contractor. Large scale disasters, for which there is little or no precedent, fall in the category of unknown impact with unknown cost or consequence. These impacts are harder to monitor because, by their nature, they cannot easily be foreseen. Furthermore, an environmental baseline from which to measure impact may not exist because the nature of the impact was unknown prior to the start of a commercial activity. For both categories of known and unknown impacts with unknown costs or consequences, *ex-ante* environmental charges cannot be easily assessed because the economic costs of the damage cannot be estimated in advance. This issue may lead to a gap in coverage and the regulator may be left with the burden of the financial consequences associated with the impact. Both bonds and insurance may be used to provide assurances to regulators that impacts not otherwise accounted for in an environmental permit will be covered *post facto*.

In recognizing that the latter two categories of environmental impact with embedded uncertainty exist, we also recognize that failure to account for the complete range of potential environmental impacts in such uncertain situations risks providing decision-makers with unrealistic assumptions of possible outcomes (Uusalito et al. 2015, Burgman 2005, Power and McCarty 2006). Such assumptions may increase the risk exposure of the regulator and could lead to a liability gap between the responsibilities of the contractor and those of the regulator. Anton et al. (2011) describe three situations in which a gap in coverage could arise: (1) a firm takes all necessary and appropriate measures required by the law to prevent the impact, however the blameless actions of the contractor nevertheless cause environmental harm; (2) a firm takes all necessary and appropriate measures required by the law to prevent the impact, however is found blameworthy and is insolvent or its assets are inadequate; or (3) a firm fails to take all necessary and appropriate measures required by the law to prevent the impact, and there is environmental harm, but with no causal link to the contractor's failure to comply.

Estimation of the financial cost associated with an environmental impact is an important variable in determining whether there is a liability gap; however, environmental liabilities are extremely difficult

to estimate (Sullivan 2005, Dobler et al. 2014, Cuddihy 2000, Uusitalo et al. 2015). The challenge of assigning cost to uncertain events is exacerbated by the fact that regulating potential liabilities from unknown environmental impacts may reveal conflicting incentives on the part of regulators and industry. While there is increasing recognition of the importance of environmental responsibility, and indeed "there have been… major advances in voluntary actions by industry" (United Nations ST/TCD/20, p. i), private sector incentives in general are often to minimize risk at the least cost, while regulator incentives may be to incur the least cost to society by implementing policies that may add unfavorably high costs to industry (Finnie et al. 2009). Estimating uncertainty is critical to estimating environmental risk in any natural resource extractive industry, and yet it is challenging to know the probability of impacts and to place a value on economic and societal costs of environmental damage (Rogers and Atkins 2015, Sullivan 2005, Dobler et al. 2014, Cuddihy 2000, Uusitalo et al. 2015). These unknowns, combined with the current lack of standardized metrics of environmental performance, make it difficult to assess potential and incurred environmental costs (Finnie et al. 2009). Bennet (2000) and Groenveld (1995) argue that strong and consistent regulations can help to provide the right incentives to industry and support sufficient regulatory mechanisms, such as bonds and/or insurance, to close a potential environmental liability gap.

Financial assurances signal to regulators that a firm has the financial ability to meet its environmental obligations, thus reducing environmental risk exposure of regulators should the firm default or go bankrupt. The International Council on Mining and Metals (ICMM), the World Bank, academic experts (Boyer and Porrini 2008, Boyd 2002) and others distinguish bonds from insurance as two types of financial assurances (guarantees) for meeting environmental obligations. Financial assurances can take many forms, and may include letters of credit, third party guarantee from a bank, or other financial organization, trust funds, cash, company guarantees, unit levies, insurance, sinking funds, pledges of assets, fund pools, and transfers of liability (ICMM, SASSOON 2008). Financial assurances are perhaps so varied because of different industry and company characteristics. For instance, where one firm may not have the capital to submit to an environmental bond with cash, a regulator may deem a third party or asset-backed guarantee an equally acceptable form of assurance (ICMM, SASSOON 2008). The

scope of this research on environmental bonds and insurance was decided through conversations with the ISA as well as research on environmental liability coverage in maritime industries that suggest P&I Clubs (i.e., mutual insurance organizations) may be worthwhile to study for its potential applications to the emerging seafloor mineral extraction industry.

Definitions

Environmental bonds: An ex-ante *assurance mechanism*

In the case of strict liability, the regulator would not need to prove the company liable for damages (Bennett 2000). Strict liability can be less expensive because it eliminates the expense of a legal proceeding (Cohen 1998); however, "even strict liability [could be] evaded if it is larger than the assets of the firm as a firm can simply declare itself bankrupt" (Bennett 2000, p. 884). Environmental bonds are aligned with a strict liability framework and are often used in environmental management (Innes et al. 2015). Environmental bonds are consistent with the "polluter pays principle", which is defined by the Organization for Economic Co-Operation and Development (OECD) as:

> "A principle to be used for allocating the costs of pollution prevention and control… to encourage rational use of scarce environmental resources… and means that the polluter should bear the expenses of carrying out the pollution prevention control measures… to ensure the environment is in an acceptable state" (OECD, Recommendation of the Council concerning the application of the polluter-pays principle to accidental pollution C(89)88/FINAL).

The full or partial cost of potential environmental damage or remediation is delivered upfront by a developer for an environmental remediation activity that is certain to happen, such as during mine closure in terrestrial settings (Innes 2015, SASSOON 2008). The environmental costs associated with a mine closure may be uncertain. In many cases, the upfront payment (the environmental bond), or a portion of it, is returned to the firm if the firm meets agreed-upon environmental standards (SASOON 2008). Cash is not the only method of payment; other *ex-ante* instruments, such as letters of credit or corporate guarantees (i.e., from a parent company), that demonstrate sufficient financing to cover certain environmental obligations *before* operational activities begin can be deemed acceptable by a regulator (Innes et al. 2015, Boyer and Porrini 2008, ICMM 2005, Boyd 2002). Such assurances that

environmental obligations will be met can vary greatly among industries and regulatory environments. Indeed, the "optimum [solution that serves the mutual interest of the government and the company] is likely to be attained by constructive, well-informed and transparent negotiations between the parties" (ICMM 2005, p. 29). Often, environmental, or performance, bonds are issued by an insurance company (UN ST/TCD/20, p. 13).

According to a report by the United Nations Social and Economic Commission for Asia and the Pacific (2002), there are six decision factors in structuring an environmental bond: (1) constructing a bonding system; (2) delineating how bonds are posted; (3) defining terms of payment; (4) specifying bond return requirements; (5) determining appropriate organizational structure; and (6) establishing an auditing system. A bond system may vary in the price of the bond by an entity's proposed operations and environmental management practices, as well as predicted environmental impacts. The posting of bonds requires specifying how the upfront payment is to be received, whether it be in the form of cash or another guarantee from a company, a bank, or liquid assets. The report clarifies that the decision of which financial assurances are acceptable could expose "imperfections in the capital market" (UN 2002, p. 62) that favor entities with deeper pockets, thus pricing some potential entities out of the industry. Such perversion could be presented in an environmental liability regime in which a firm with greater financial resources and perhaps lower environmental standards is granted a permit and a firm with fewer financial resources but higher environmental standards is not granted a permit. In this instance, it is also possible that the potential for an adverse environmental impact could be greater due to heavier weight placed on financial surety rather than quality of environmental management.

Full payment is not always required before mining begins, which eases the financial burden on the firm. The UN (2002) report describes three types of term payment structures – (1) fixed percentage, (2) staged, and (3) incrementally phased – as potential solutions to make the bonding system more affordable while ensuring effective incentives are in place for appropriate environmental management (p. 62). Each approach has different requirements of payment at varying stages of a project's life cycle, and each aligns with different economic realities. For instance, a staged payment scheme may require

payments at different project stages that correspond to different probabilities of certain environmental impacts, whereas a phased scheme can be prorated such that the contractor pays a small percentage of the total bond that relates to a project's operational phases (i.e., in the startup phase and more in later phases). Table 1 briefly summarizes the payment process for each category as characterized by the UN (2002).

Table 1: Summary of bond term payment categories (source: UN report 2002)	
Fixed percentage	A greater proportion of the bond is posted prior to industrial activities and a fixed percentage of total payment is due each year following the start of the activity. Each payment should include interest on the amount of the bond that remains to be paid (p. 62). This process is simple and transparent, however may not be a realistic reflection of cost related to an environmental impact.
Staged	Payments are made in proportion to the environmental costs estimated to probabilistically occur during different phases of a project's life. If, for example, environmental costs are expected to be less during the first phase of an exploitation license, the payment due at the beginning of the project would be less relative to payments due at later stages. This alternative could theoretically ease the financial burden on contractors at the startup phase and would allow for the project to generate revenues that support future bond payments (p. 62). A staged approach may potentially reduce the high environmental cost barrier to entry.
Incremental and phase	Incremental bonding requires payment upon completion of individual activities within a permit. Phase bonding requires payment upon completion of a group of activities, and can be prorated such that the contractor pays a small percentage of the total bond in the startup phase and more in later phases. This is similar to the staged approach in that it allows for the readjustment of bond costs as the project progresses, but also poses a risk to the regulator that could be left with the financial and operational burden of environmental remediation should the contractor go bankrupt and no longer be able to meet its environmental obligations (p. 63).

Bond return requirements also vary between project characteristics and regulatory jurisdictions. The UN (2002) report states that, in many cases, bond payments can be returned to the contractor during the life of a terrestrial mine if the contractor meets agreed-upon environmental obligations. It is usual for up to 25% of the full bond amount to be withheld and returned to the firm "once the area is in stable condition" (UN 2002, p. 63). The definition of "stable condition" is qualitative, subjective, and not clearly defined or agreed upon (UN 2002 p. 57). Organizational structure and auditing systems need to be in place to ensure the financial terms of the bond deal are adhered to and that the bonding activity meets the

objectives of environmental management. Such activities would include establishing an impartial authority responsible for deciding the value of the bond and term structure described above, managing compliance and auditing, and determining whether a contractor has successfully met environmental obligations at each required stage set up by the bond system and term structure (United Nations 2002, p. 63 – 64).

The *ex-ante* payment mechanism "creates the incentive for firms to research the future environmental costs of their activities" (Innes et al. 2015, p. 6), supporting a mutually beneficial and perhaps more economically realistic level of the bond as set by the regulator (Costanza and Perrings 1990). Innes et al. (2015) cite several ways in which bonding mechanisms have been used in marine environments. In the United States, offshore renewable energy projects implement environmental bonds to ensure financing is available for decommissioning of pipelines, cables, and other structures (Innes et al. 2015, p. 6; Hill 2011; Kaiser and Snyder 2012). Seafloor mineral extraction will be conducted on much larger scales than this renewable energy project, and thus may have different needs in constructing *ex-ante* payment mechanisms. In Australia, cash bonds or guarantees have been used to manage development activities in the Great Barrier Reef Marine Park (Innes et al. 2015, p. 6; Great Barrier Marine Park Authority 2010). Seafloor mineral extraction again differs from the Australian example in that the regions in the Area, such as the CCZ, are slated for development rather than as a protected area. While these examples are not a perfect parallel to seafloor mineral extraction, each nonetheless illustrates how regulators have set up *ex-ante* funds to incentivize proactive environmental management of marine ecosystems.

Insurance: An ex-post *mechanism*

Under an *ex-post* mechanism, the ISA would need to prove that a contractor is liable for damages in order to obtain remediation funds (Bennett 2000). Environmental insurance schemes are founded on a negligence-based system, in which "contracts determine the allocation of risk" (Schäfer and Müller-Langer 2008, p. 23) and insurance companies are required to pay damages if a firm is found responsible

for environmental harm outside the boundaries of permitted activities (Freeman and Kunreuther 2003, M. Lodge Personal Communication October 2015). Freeman and Kunreuther (2003) further state that insurance companies are only obligated to compensate for risks that have been included in policy coverage. While insurance is an *ex-post* measure of remediation and negligence must be proven following an unanticipated (which may include accidental) environmental impact event, Boyer and Porrini (2008) argue that these measures, including *ex-ante* premium payments and the monitoring required on the part of insurance companies, may likely stimulate upfront investment from the firm to minimize environmental impact and avoid having to pay *ex-post*. Insurance companies that underwrite environmental insurance and thus assume environmental liability are also incentivized to monitor the firm to ensure compliance. To that end, Boyer and Porrini (2008) define the role of insurance companies as "internalizing environmental damage in the context of assignment of liability" (p. 338). Brown (1991) states that insurable risks must meet the following criteria:

(1) covered losses must be definite in time, place and amount;
(2) covered losses must be accidental in nature;
(3) covered losses should not have catastrophic potential for the insurer;
(4) there should be a large number of homogenous but independent exposure units;
(5) the price of insurance should be economically feasible (p. 20).

Estimation of insurance premiums and losses associated with environmental liabilities are hard to measure and further complicate the provision of environmental insurance, ambiguity from which has often led to substantially higher premiums than for more predictable impacts (Boyer and Porrini 2008, Freeman and Kenreuther 1997). Indeed, insurance schemes could be subject to an adverse selection phenomenon as a result of information asymmetry, where firms know more about a particular risk than the insurer, thus insurers raise premiums and monitoring requirements as a result of such asymmetry (Boyer and Porrini 2008, Laffont and Martimort 2001, Freeman and Kenreuther 1997). Insurers must be able to pay for potential losses should a risk materialize prior to underwriting a project. To do so, insurers pool particular types of risk and measure the impact of one project on the stability of the insurance firm by calculating a loss ratio, defined in Freeman and Kenreuther (1997) as "paid losses versus written premiums" (Freeman and Kenreuther 1997, p. 42). In other words, the losses cannot exceed the premium

payments and, to diversify this risk, insurance companies underwrite multiple projects in the same risk category.

Insurance provides a system by which multiple actors bear responsibility for risk: regulators to monitor firms, firms to manage operational activities, and insurers to provide financial surety to regulators and firms (Boyer and Porrini 2008). Further, experts argue that insurance mechanisms are most "suitable where adverse outcomes may involve high costs which individuals were unlikely to be able to meet, but the likelihood and consequences of these outcomes were highly uncertain" (Innes et al. 2015, p. 6). Others argue that there is no guarantee that environmental liability insurance will meet the intended goals of mitigating liabilities (Bennett 2000, Rose-Ackerman 1995). Bennett (2000) asserts: "Especially when the risks are large, but rare and unpredictable, liability may have little meaning" (p. 883).

Part 2: A discussion of alternatives. A review of how the terrestrial mining and maritime shipping industries have implemented bonds and insurance

This section reviews how established industries, terrestrial mining and maritime shipping, have implemented environmental bonds and insurance in efforts to reduce the potential for an environmental liability gap. Terrestrial mining has largely relied on environmental bonds tied to mine closure to spread environmental liability risk between the firm (mining entity) and regulator. Maritime Shipping has implemented mutual insurance, known as Protection and Indemnity Clubs (or, P&I Clubs) as a form of co-managed, or mutual, insurance to protect shipowners from unknown environmental liabilities.

Terrestrial mining

Environmental Bonds

The *polluter pays* principle (environmental bonds) is prominent in the terrestrial mining industry and is implemented most often in mine closure regulations (White et al. 2012, ICMM 2005, SASSOON 2008). For terrestrial mines, bankruptcy is generally the unanticipated event, rather than environmental damage; however, there remains uncertainty in estimating the true financial cost of environmental remediation of mine sites because damage is often difficult to monitor, and mining operations and environmental conditions vary greatly between sites (ICMM 2005). Financial planning for mine closure is dependent on several factors, including geopolitics, environmental and social conditions, geographic extent, the firm's environmental performance history, corporate governance policies, financial solvency, and liquidity tests (ICMM 2005). Acceptable planning "can differ dramatically between countries and [thus] should only be established on a country-by-country and site-by-site basis" (SASSOON 2008, p. 1). ICMM guidance on implementation of environmental bonds for terrestrial mining emphasizes the need for flexibility, as indicated by instrument characteristics of different countries. For example, Ghana employs a bond instrument that is paid for partially upfront, and the remaining assurance of funds may be

provided by a bank guarantee, trust fund, private insurance, or other options that are approved on a case-by-case basis (ICMM 2005, p. 62).

Kempton et al. (2010) discuss financing of environmental impacts from mining beyond site closure. They argue that the perpetual management of closed mine sites may bring clarity to investors and mining companies for what constitutes appropriate funding over what time period, and present a case study in Canada's Saskatchewan province, in which the government implemented an Institutional Control Program (ICP) that generates funds from contractors and are managed by the municipality. The long-term returns from the investments of these funds are meant to sustain environmental remediation costs (Saskatchewan 2008). Contractors are obligated to apply for this program, which must include a mine closure and rehabilitation plan and an estimate of costs associated with a major failure event. For the purposes of this paper, a major failure event could be described as a "very serious failure" of a tailings storage facility, which Bowker and Chambers (2015) define as a release of greater than one million cubic meters and/or a release that traveled at least 20 kilometers, and/or a release in which there were multiple deaths (p. 1). The ICP benefits the mining company by providing clarity over post-closure environmental liability, and institutes funding mechanisms to ensure the government can manage the long-term monitoring and management and cover unforeseen events.

Canadian Diavik and Ekati diamond mines, both operated by Dominion Diamond Corporation, a wholly owned subsidiary of Rio Tinto in Canada, also demonstrate how environmental bonds have been applied to minimize the gap between risk of unfavorable environmental impacts and sufficient coverage for remediation. Environmental surety covers a water license and environmental agreement, and is held by the Government of Northwest Territories in Canada in the form of surety bonds or letters of credit (Dominion Diamond Corporation 2015 Annual Report, p. 37). The Independent Environmental Monitoring Agency (IEMA) is the neutral organization in charge of monitoring compliance. Pembina, a clean energy think tank organization in Canada, has raised the issue that a general lack of "legal requirements for the federal government to collect full security bonds" (Pembina Institute 2013, p. 30) weakens the regulatory power of environmental bonds, increasing regulators' exposure to risk of

unanticipated environmental impacts. The World Bank and the International Finance Corporation, on the other hand, praises Canada and other countries with a strong mining industry presence that are trending "toward stricter environmental regulations and better environmental performance" (International Finance Corporation 2002, p. 12). The focus on these tools, the organizations argue, is on environmental remediation and mine closure, supported by environmental funds and independent monitoring. Regardless of stakeholder opinion on these regulatory regimes, both sides seem to agree on three critical components of environmental bonds: (1) the process must be transparent; (2) companies, government, scientists, and civil society must cooperate; and (3) regulations must be clear.

Australia also has a long history with terrestrial mining, where the implementation of bonds has developed largely because other liabilities (e.g., unpaid tax and unemployment payments) have historically taken priority over environmental liabilities and proper environmental management was not implemented (White et al. 2012). To shield against a mining entity's incentive to intentionally declare bankruptcy and avoid paying remediation charges, the Australian government requires bonds to be unconditionally guaranteed by a bank (ICMM 2005). Bonds are posted upfront payments by the state regulator in Australia and subsequently guaranteed by a bank; the funds raised are only called upon when the uncertain event (bankruptcy) occurs (Kabir et al. 2015, White et al. 2012).

These examples demonstrate the importance of transparency and multi-stakeholder cooperation with regulators, scientists, and civil society in the implementation of environmental bonds to close the environmental liability gap. They also follow a structure similar to what was described above in the UN (2002) report to estimate the charge of the bond, develop an organized structure for collecting and managing funds, and introduce a monitoring system to ensure compliance. In the review provide by Kempton et al. (2010), general characteristics for the adaptive management of mine closure also incorporate uncertainty in costs associated with long-term remediation, a situation that may also apply to the expected long time scales for mining projects in the CCZ.

Insurance

Insurance for terrestrial mining is more difficult to apply to environmental liabilities than to other types of liability, such as loss of equipment or worker safety liability, largely because economic values are harder to estimate and agree upon (SASSOON 2008, Kempton et al. 2010, Dechar JLT Mining 2014). Environmental liabilities are amplified in marine environments, where "the unknown nature of [the industry and its impacts] will attract few underwriters willing to write it" (Dechar JLT Mining 2014). Herrmann (2003) delineates between two environmental insurance mechanisms for the mining industry: reclamation liability insurance and pollution liability insurance. First, reclamation liability insurance is mostly used for known impacts that must be remedied upon closure of a mine. Examples of mine closure costs include building decommissioning, environmental restoration of areas where there was damage during mine operations, maintenance, and care post-closure (van Niekerk 2014). While these costs can be significant for a terrestrial mine, ranging between USD $1 million and more than USD $50 million (SASSOON 2008, p. 1), the certainty of reclamation and the estimation of costs fall in the first category of environmental risk mentioned in Part I: known impacts with known consequences. Second, pollution liability insurance addresses environmental impacts with a defined probability of occurring, and covers impacts that are known with unknown consequences and that have a probability of occurrence based on historical data (Willis Group Holdings plc, Marsh Insurance Brokers).

Maritime Shipping

Environmental Bonds

There is little public information on how the maritime shipping industry uses environmental bonds. The International Maritime Organization (IMO) is interested in instituting a tool similar to the concept of environmental bonds aligned with the *polluter pays principle*, in which sufficient funding is raised from the shipping industry to support the clean-up of hazardous substance pollution spilled into the ocean: 1.56 million cubic meters between 1998 and 2013, of the more than 200 million tons of chemicals traded annually by tankers (MarEx February 8 2016 online). These *ex-ante* funds would be raised from a

levy on minimum quantities of cargo of hazardous substances to cover unanticipated spills, thus ensuring financial resources are available when needed by maritime partners. While it is not an environmental bond *per* se, the IMO has identified this need because there exists "no uniform and comprehensive international regime currently in force to provide compensation for cost, including clean-up and restoring the environment" (IMO Brochure accessed 22 February 2016). While the IMO made an attempt in 2010 to adopt the program, an insufficient number of Member States have signed the protocol and thus the program has not been entered into force (International Oil Pollution Compensation Funds Presentation 2013, slide 18). In theory, the program would provide a liquid financing option that is in the control of the regulator to respond to pollution accidents. Such characteristics align with those of an environmental bond described in Part I in that they require upfront payment by a firm and provide some liquidity and financial control over a regulatory authority's environmental liability risk.

Insurance and Protection & Indemnity Clubs

One type of insurance that dominates liability coverage for the maritime shipping industry is a form of mutual insurance known as Protection and Indemnity (P&I) clubs. Indeed, "90% of the world's merchant fleet by tonnage is bound to [a P&I Club]" (Bennett 2001, p. 13). Bennett (2001) describes P&I Clubs as a form of co-management that arose from a choice by industry to commit to a cooperative solution. These mutual insurance groups have historically been the only entities willing to cover unknown environmental impacts (Kite-Powell 2001, Ronneberg 1991). P&I Clubs differ from private insurance in that they are mutually insured; one vessel or shipowner contributes to an organization that insures the entire member group against a host of liabilities and is organized by a set of rules by which each member must abide (Ronneberg 1991). This scheme differs from regulation-led schemes, such as the IMO program mentioned above because P&I Clubs funnel funding into a mutual party of private sector actors rather than a regulatory body, which is the proposal of the IMO to cover hazardous substance spills.

While the co-management framework of P&I Clubs may work toward an alignment of incentives for shipowners and regulators by forming a cost-effective and self-monitoring mechanism to ensure environmental compliance, there is also the risk of introducing moral hazard and adverse selection that could threaten the care shipowners take in minimizing environmental impact (Bennett 2001). A moral hazard could arise from a situation in which a shipowner, once a member of a P&I Club, may be less incentivized to take precautionary measures because they know damages will be covered by the co-managed fund (Bennet 2001). Adverse selection could arise from information asymmetry, where a shipowner could withhold its true riskiness and pay a lower rate (Bennett 2001). To combat these threats, P&I Clubs conduct thorough due diligence on potential new members and base future premiums on past performance (Bennett 2001).

The International Group (IG) functions as a coordinating body for a collective of 13 independent P&I Clubs (International Group of Protection & Indemnity Clubs website accessed 22 February 2016). Willis Marine Protection & Insurance reports that the IG market overall exhibited a strong performance in 2014-2015, despite the volatility in the number of major claims and a fragile investment market (Willis Marine Protection & Indemnity website).[1] Future risks to P&I Clubs include: (1) investment income volatility of financial asset management of collected funds; and (2) increases in claim amounts that threaten Club performance as calculated by the Net Combined Ratio (net incurred claims and operational expenses divided by the difference between premium and insurance costs; a combined ratio of 1 is the break-even position, a ratio > 1 would be a loss, expenses > income; a ratio < 1 would be a surplus, expenses < income).

[1] See http://www.willis.com/pandipublications/individual-club-underwriting-results.html for latest ranking of individual P&I Clubs.

Part 3. Strengths-Weaknesses-Threats-Opportunities (SWOT). A SWOT analysis for each regulatory alternative and discussion of application of these alternatives to seafloor mineral extraction.

This section builds on existing publicly available information, advice, and feedback from industries similar to the seafloor mineral extraction industry and examines how each alternative could be integrated in the final draft of ISA exploitation regulations. SWOT analysis is a useful framework to compare environmental bonds and insurance. This is preceded with a brief discussion of how each alternative could apply to the ISA and seafloor mineral extraction in the Area. A separate and explicit inclusion of a SWOT analysis on P&I Clubs is also merited given their influential role in the maritime shipping industry and their potential applicability to seafloor mineral extraction. The analysis below pays particular attention to how the ISA regulations will affect mining in the CCZ; there are other ecosystems and other regions within and beyond national jurisdiction considered for mining that are not included here.

Bonds

In general, regulators may favor this approach because it would embed processes for making withdrawals quickly if needed. The high liquidity of this option may lower the financial risk on behalf of the regulator. The ISA may also favor environmental bonds because of greater alignment with the precautionary principle and a 'set-aside' approach, which is part of the ISA's mandate to protect seabed and pelagic ecosystems (Smith et al. 2008). In particular, the ISA's existing strategic environmental management plans for exploration licenses adopt a precautionary approach in the designating of areas of particular environmental interest (APEIs) that set-aside (unavailable for mining) approximately 25% of the CCZ (Lodge et al. 2014).

Bonds also provide an element of certainty around the potential costs to known environmental impacts with unknown consequences or unknown impacts with unknown consequences, which may give more confidence to industry that they can meet their environmental responsibilities during and after

mining. To some contractors, this certainty may be worth a potentially higher upfront fee that could be associated with a bond, while a high upfront fee may price other contractors out of the market. While insurance may seem like the only option with minimal costs *ex-ante*, environmental bonds can also provide time- and capital-sensitive support to developers through a phased or staged payment structure. Hence, the issue of upfront payments could be solved under either regulatory alternative.

Currently, the ISA has not publicly defined a process for estimating of the value of potential environmental consequences nor does a plan exist for spending funds should the contractor fail to meet agreed-upon environmental obligations. Implementing an environmental bond in exploitation regulations could thus place a significant weight on a potentially poorly estimated value of the environmental consequences, which could lead to higher costs to the regulator and hence to society *post facto*. However, there is currently a lack of agreement or guidelines on what the environmental obligations will be and how success or failure will be measured regarding environmental management. The SWOT analysis below summarizes these trade-offs.

ENVIRONMENTAL BONDS	
Strengths: o A portion or all of the funds are delivered upfront, favorable to regulators o Uniform standards improve regulatory certainty o Simple o Liquid: Theoretically, funding is available to regulator if needed, assuming appropriate withdrawal mechanisms o Cost certainty for contractor o Aligned with precautionary principle (set-aside APEIs, set-aside financing)	**Weaknesses**: o Potentially not aligned with industry incentives: smaller firms may not be able to afford high upfront fees o Contractors cannot invest fee dollars in environmental management or other profit-driving activities of the firm; could negatively impact environmental activities otherwise planned by the contractor o High management costs for the regulator
Opportunities: o Interest-bearing accounts can be invested and grown over time, potentially increasing the amount of funding available for recovering unknown/unforeseen environmental damages o Potential to reconcile regulatory and contractor incentives by accepting non-cash forms of guarantee	**Threats:** o Large up-front costs may "tip the scale" and be cost prohibitive for smaller exploration contractors looking to enter into exploitation phase; potentially inequitable to contractors o Investment returns are subject to market volatility o Funding might not be enough if cost estimates are wrong

○ Environmental bonds could be designed to be time- and capital-sensitive to support contractors through a phased or staged payment structure	

Insurance

Because there is minimal public information on private insurance plans in the terrestrial mining and maritime shipping industries, details of coverage for both known environmental impacts with unknown consequences and unknown impacts with unknown consequences (e.g., information on premium payments, liability caps, and payout history) are unavailable. Seafloor mineral developers may prefer seeking private insurance for such uncertain impacts because of the minimal upfront financial burden; public insurance may not be practical for firms with limited access to capital during their early stages. The ISA may see private insurance as a way to spread the burden of environmental monitoring, which must cover the 6 million square kilometers of the CCZ region, a daunting task for a single entity.

Market-based mechanisms, such as private insurance, could work to close a potential environmental liability gap by aligning incentives. The ISA may also see an opportunity to leverage private insurance as a market-driven alternative that more efficiently manages and monitors environmental performance and drives innovation for practical and effective environmental management and monitoring processes. A trade-off to this market-based mechanism, however, lies in its negligence-based characteristics. Implementing this regulatory mechanism may lead to the development of complex systems, and hence impose a greater burden on ISA resources to prove negligence should an impact occur that is outside the scope of a contractor's environmental permit.

The requirement to prove negligence may not only produce substantial legal costs on behalf of the developer and/or the ISA, but also may restrict the ISA's access to capital following an unanticipated event to remediate damage. Another issue presented in the private insurance mechanism is that insurance companies generally prefer diversification of risk in the same industry. Recent insight from JLT Mining, an insurance company that deals with mining projects, suggests that it may be difficult for insurers to

initially provide coverage due to limited data, and that, apart from incorporating conservative estimates of impact, "private insurance may not be suited for insuring the significant uncertainties of environmental impacts" (Dechar JLT Mining 2014) of seafloor mineral extraction. While sediment plume modeling and environmental impact studies are conscious of building-in conservative estimates, uncertainty is still high (EPA document online 2014, Oebius et al. 2001). JLT Mining argues, then, that an insurance market may begin to develop as the industry grows and as information on environmental impacts becomes increasingly available, providing more certainty for insurance providers.

INSURANCE	
Strengths: ○ Contractors may prefer this option with lower upfront payments, especially if the firm does not have access to capital at early stages of mining ○ Some of the regulator's and developer's burden of monitoring may be relieved by a third party insurer	**Weaknesses**: ○ Many environmental insurance products are poorly regulated and are new/uncertain ○ Information asymmetries where the firm has more information than the insurer may be too high, reducing transparency, possibly deterring the development of an insurance market and perhaps negatively affecting regulatory power ○ Negligence-based liability may lead to more complex systems and impose greater burden on the regulator to prove negligence (i.e., high legal fees)
Opportunities: ○ A market driven scheme, in which the private sector equilibrates a price of insurance as more players come onto the market, could potentially be more efficient ○ Reduced upfront expense may lead to greater investment in innovative environmental monitoring and mitigation practices (i.e., because funds are freed up)	**Threats**: ○ Restricted access to capital if the regulator needs cash quickly following for an environmental event due to the probable need to prove negligence before unlocking funds from insurer

Mutual insurance or P&I clubs

A P&I Club may align the incentives of both contractors and the ISA to reduce environmental risk exposure. Specifically, contractors may find the individual financial contribution more affordable under a collective funding (i.e., cost-sharing) scheme. The ISA may prefer the liquidity of a P&I Club as opposed to private insurance, in that P&I Clubs could distribute funds to remediate environmental

damage in the event of an unanticipated impact. This assumes that the environmental regulations fully define what an unanticipated impact may be, how it will be discovered, and how costs will be determined. Non-governmental organizations may prefer this option as well because collective funding may encourage more environmentally responsible practices through peer checks and balances. While mutual insurance in the form of a P&I Club offers the opportunity to build alignment between the different actors, information asymmetry issues could persist, which would reduce transparency and perhaps weaken the ISA's ability to oversee environmental monitoring and management.

Another consideration is that P&I Clubs may require a certain volume of contractors to make the membership payment affordable for individual entities. Without such scale, payments to a P&I Club fund slated to cover uncertain environmental impacts may be too high for contractors with limited financial resources at the beginning stages of mining. P&I Clubs may be organized in various ways, including by region (i.e., collect membership fees and cover impacts for only those contractors operating in the CCZ), by resource type (i.e., manganese nodules, seafloor massive sulfides, cobalt crusts), or as a single organization that covers the entire Area. Greater transparency may require more coordination in developing the organization and management architecture of a P&I Club for seafloor mineral extraction. A strong process for making these decisions may achieve collective stakeholder acceptance of the final decision that is laid out in the final exploitation regulation regime.

PROTECTION AND INDEMNITY (P&I) CLUBS	
Strengths: o Incentives are more closely aligned between regulators and industry to reduce environmental risk exposure at least cost to individual firms o Collective funding may reduce individual contributions, thus lowering the upfront cost to close liability gap o Compared to third party private insurance, P&I Clubs are more willing to cover uncertain environmental risks o High liquidity, assuming withdrawal processes are defined to allow this	**Weaknesses**: o Information asymmetry issues in which the firm has more information than the P&I Club or regulator could lead to lower transparency and thus weaker regulatory power and oversight o Requires large market to pool resources o High management costs o May still require firms to have private insurance

Opportunities:	**Threats**:
○ Peer checks and balances through a co-management approach may encourage more environmentally responsible practices ○ Sound investment management could boost returns, lower premiums and encourage firms to invest in responsible development	○ In the long run, it may be likely that a higher number of claims made in a year could unexpectedly diminish Club funds ○ Market volatility could hurt investment returns

PART 4: Discussion. Suggestions for future work and limitations of this research

This section places the research above in the context of the ISA's decision of which environmental regulation alternative—environmental bonds or insurance—may be most appropriate for the seafloor mineral extraction industry to minimize the potential for an environmental liability gap. The discussion centers around a draft exploitation regulation framework published by the ISA in 2015 (ISA 2015a) and recommends more work to define foundational concepts that bring forward the discussion of regulation alternatives as the ISA deliberates and finalizes exploitation regulations.

Addressing challenges specific to the ISA

This review offers a definition of and presents trade-offs associated with environmental bonds and insurance, including P&I Clubs as a form of mutual insurance. More work is needed with targeted stakeholder input and deeper analyses prior to selecting a regulatory alternative for this issue and bringing greater certainty to, and agreement on, the environmental regulatory regime for the Area. It is useful to look at existing ISA documentation to understand what work specifically may be needed to make this decision. The ISA collected stakeholder advice and opinions through a 2014 survey have been synthesized in a 2015 draft framework of exploitation regulations for the Area (ISA 2015a). The stakeholder group, defined by the ISA, consists of: contractors, international organization, non-government organizations, scientific institutions and universities, private entities, and individuals (ISA 2015a, p. 2). The ISA highlighted several issues from this stakeholder survey responses, two of which relate to this review: (1) there needs to be a process for risk assessment, evaluation and management; and

(2) the ISA should implement effective protection for the marine environment from harmful effects (ISA 2015a, p. 42-43).

(1) There needs to be a process for risk assessment, evaluation, and management

With regard to the first issue of risk assessment, evaluation, and management, stakeholders reported that the process must contribute to the "orderly development of [mining] in the Area" (ISA 2015a, p. 42), which depends on developing risk assessment and management systems. Moreover, stakeholders on the whole noted that established industries could provide useful guidance in setting up such programs (ISA 2015a). This paper should be viewed as an attempt to bring lessons and ideas from similar and established industries to inform the ISA's development of environmental risk assessment, evaluation and management systems specific to the seafloor mineral extraction industry.

A review of additional alternatives used in industries not reviewed here may reveal other options that the ISA could consider. Other industries with similar characteristics to the operations and environmental liability of seafloor mineral extraction include shallow water mining and dredging, offshore oil and gas, and potentially offshore wind and hydraulic fracturing. While shallow water mining and dredging industries may present the ISA with more in-depth comparable information on the operational vicissitudes of insurance or bonds in a variety of established extractive industries, offshore oil and gas and hydraulic fracturing give insight into how environmental risk from new industries in the ocean can be built into regulatory regimes. Further research may include, for example, a deeper analysis of how Naylor and Dybdahl's (2007) categorization of four building blocks of environmental liability insurance – pollution, storage tank, contractors' pollution, and cleanup cost cap – have formed a foundation for many individualized insurance plans for specific oil and gas projects. Such additional levels of insight will undoubtedly provide the ISA with more information that may be useful in developing a regulation mechanism fit for the purpose of creating a process for assessing, evaluating and managing unknown environmental liabilities that may results from seafloor mineral extraction in the CCZ and in the Area.

(2) The ISA should implement effective protection for the marine environment from harmful effects

With regard to the second stakeholder issue of what constitutes effective protection of the marine environment, stakeholders emphasized the need to define terms such as "significant adverse change" (ISA 2015a, p. 43) that can inform the development of best regulation and environmental management practices. This feedback speaks to the underlying set of processes and beliefs that may be important for the ISA to establish as part of its informed environmental liability regulation decision. The ISA may wish to consider how it will define boundaries of acceptable environmental impacts, the process by which an impact is identified as a "significant adverse change," and what the associated economic values may be for such an impact. The ISA could also use this definition to determine when an impact with such "significant" changes triggers liability coverage, either from an environmental bond or insurance scheme.

While these definitions have not yet been finalized, the ISA has laid important groundwork to establish effective and precautionary environmental protection mechanisms through the environmental management plan (EMP) for the CCZ. The spatially-oriented plan is considered best practice environmental management guidelines for seafloor mineral production and was developed from a collaborative strategic environmental assessment that leveraged expert scientific guidance, such as from Hannides and Smith (2003) and Wedding et al. (2013) and resulted from a number of workshops (Lodge et al. 2014, ISBA/17/LTC/WP.1). Perhaps more in-person collaboration through the form of a workshop would bring the ISA to the next level of decision-making, which may involve defining such things as "significant adverse change" to abyssal seafloor communities that will support the decision of which regulation alternative will most effectively cover unknown environmental liabilities.

Recommendations for a way forward

At the time of writing, the most appropriate approach for managing environmental liability of the seafloor minerals sector is still being considered. The ISA may benefit from deeper consideration of regulatory alternatives to account for a potential environmental liability gap. Such alternatives may not

be limited to environmental bonds and insurance, including P&I clubs as a subset of insurance. While this review does outline some of the trade-offs associated with implementing each alternative, two other insights were gained particularly from understanding how industry and regulators in the terrestrial mining and maritime shipping sectors manage both known and unknown environmental impacts with unknown consequences: (1) there needs to be agreed-upon methods for estimating the probabilistic financial consequences associated with potential environmental impacts that ultimately decide how much impact an environmental bond or insurance scheme should cover; and (2) regulators can support an industry (emergent or otherwise) by setting clear, consistent, and practical boundaries regarding environmental obligations upon which contractors can rely.

The ISA is interested in developing an environmental liability regime for seafloor mineral extraction in the Area, which must arguably rest on clear and practical boundaries regarding environmental obligations. A roadmap for how this might be done is comprised of three foundational components: (1) further stakeholder consultation; (2) leveraging decision modeling as a process to estimate economic values and suggest regulation alternative; and (3) a workshop with broad stakeholder cooperation to decide on a regulation alternative. Details for component (2) are provided in the appendix, and an overview of each component is presented below.

(1) Further stakeholder consultation

Further consultation with stakeholders related to the seafloor minerals industry and with comparable industries, such as terrestrial mining, maritime shipping, shallow-water mining and dredging, offshore diamond mining, and offshore oil and gas, as well as input from maritime insurance experts, could be achieved through a strategic and proactive interview or survey activity.

(2) Leverage decision modeling as a process to estimate the economic values and suggest a regulation alternative

a. Estimating financial cost: Probabilistic modeling combines "the probability of occurrence of an event and its consequences or impact" (Dobler et al. 2014, p. 2), where averages are not sufficient (O'Hagan 2012). Such an exercise may help to define the upper and lower ceiling of financing needs and inform the most appropriate instrument to raise such funds (MERAG uncertainty analysis 2007, p. 3). A simple valuation model using Monte Carlo simulation may facilitate the comparison of cumulative probabilities of environmental impacts to the financial consequences of that event and inform the ISA in developing an adaptive management approach (ISA 2015a, Part IV p. 35).

b. Multi-Criteria Decision Analysis (MCDA): MCDA is "an umbrella term to describe a collection of formal approaches that seek to take explicit account of multiple criteria in helping individuals or groups explore decisions that matter" (Belton and Stewart 2002, p. 2) and is widely used in a variety of industries. The purpose of MCDA tools is to inform a decision and identify trade-offs and key value drivers, rather than make the "correct" decision. MCDA involves using a matrix to rank each alternative based on key decision criteria and their relative importance. By using this tool, the ISA may expose differing assumptions or incentives and encourage a constructive conversation toward a mutually agreeable solution of which regulation alternative, environmental bonds or insurance, is most appropriate for closing a potential environmental liability gap (Belton and Steward 2002). Resources on the details of implementing MCDA are offered in the appendix.

(3) Workshop to decide on a regulation alternative

The ISA could convene a workshop with stakeholders on completion of the stakeholder survey and modeling efforts (components 1 and 2 of the recommended roadmap). The goals of the workshop would be to review the results of the survey and modeling, achieve consensus on cost-estimate tools and decision frameworks and to develop the rationale for an environmental liability regime for seafloor mineral extraction. One stakeholder group that has not evidently been included in

discussions of environmental liability regulations in seafloor mineral extraction is the third-party insurance industry, a group that would offer critical input in terms of the most practical solution.

Key limitations of this study

This analysis did not have the expertise nor the resources to identify the most appropriate use of funds for environmental remediation or offset activities in the event of an unknown environmental impact with "significant adverse change", which is clearly stated as a concern among the stakeholder community in the survey summary of the 2015 ISA report. The scope of this review was limited to discussion of two environmental regulation alternatives the ISA is considering implementing in the final exploitation regulations. Limited resources also constrained the depth and scope of the review of each alternative, namely environmental bonds and insurance (including P&I Clubs). More information and discussion is needed prior to selecting a regulatory mechanism to attempt to close the potential liability gap of known and unknown environmental impacts with unknown consequences. The costs of obtaining more information, however, may increase disproportionately to the usefulness of that information in making a decision. A workshop may ensure stakeholders and relevant expertise are adequately represented, which may bring tremendous value to the ISA in its decision-making processes. To ensure inclusion, supplemental additional activities may also be necessary, such as phone and in-person consultations. The ISA may need to conduct its own cost benefit analysis to understand its limitations toward a reaching a resolution of which regulatory mechanism to employ, and also to understand which mechanism has the greatest benefit for and least cost to the many actors involved in this decision.

This paper is meant to start a deeper discussion of potential regulatory mechanisms that might close a potential liability gap in environmental risk for a new industry such as seafloor mineral extraction. It does not speculate as to the definitions of environmental events, nor does it assign probabilities and financial costs associated with an event. This exercise must be done with careful input from a wide range of experts in science, economics, environmental management, industry, regulation, insurance, and perhaps financial management. Such an expert group must agree on assumptions and methodologies for

incorporating lower and upper limits of costs, as well as characteristics of environmental values and costs. Indeed, while insights from similar industries may develop a critical foundational understanding of the ISA's task at hand, "detailed study is necessary of the institution(s) concerned in order to assess how regulation will work in practice" (Bennett 2000, p. 876) and follows from Coase (1964) who warned that "there was little we could learn about how to change or modify regulation from the consideration of theoretically optimal system" (Bennett 2000, p. 876). Expert input is thus a critical element to understanding how bonds or insurance (or P&I Clubs) may apply to the specific characteristics of the seafloor mineral extraction industry to build practical solutions.

Conclusion

The commercialization of seafloor minerals has not yet occurred and thus, like any new industry, there remains uncertainty in terms of how the industry will perform technically, financially, and environmentally. By recognizing the existence of uncertainty, a practical discussion is possible to develop regulatory instruments that reduce the potential environmental liability gap. This analysis attempts to build on existing internal conversations with the ISA and its stakeholders. Its primary goal was to analyze alternatives to regulating unknown environmental impacts that may most practically and effectively close the potential for an environmental liability gap that comes with the uncertainty of seafloor mineral extraction.

Bonds may align with the precautionary principle and provide liquidity for regulators should an environmental event occur; however, the upfront payments – if they were required – in this instrument may be less desirable for contractors who may not have the funds or would rather invest in other environmentally responsible activities. Environmental bonds could be structured to meet the needs of capital-constrained contractors, and such customized alternatives may be considered worthwhile for the added efforts and resources required by the ISA. Insurance, on the other hand, may be preferred in some instances with contractors in terms of the perception of lower up-front costs, however this alternative may not be widely available from third parties given the potentially material financial consequences of environmental impacts. One alternative to insurance is mutual, self-insured P&I Clubs, which have worked well within the maritime shipping industry. While this option is an alternative the ISA may consider moving forward, a limitation exists in that P&I Clubs require a certain volume of members to subsidize membership fees, and the number of contractors in the Area may not provide such a subsidy. The regulatory mechanism that is established in the final regulatory regime could have significant effects on the development of this emerging industry. This analysis appreciates the weight of the decision in front of the ISA and recommends implementing a thorough and inclusive process to ensure stakeholder incentives are aligned and the ISA has a defensible way forward.

Appendix. Second component of recommended roadmap forward for the ISA: Cost estimation with decision modeling

It may help the ISA to develop a probabilistic cost estimate model of potential environmental liabilities and a decision model to inform a structured discussion with stakeholders and within the ISA as it finalizes its environmental liability regulations. The first model would be most useful if it was based on assumptions and data collected from stakeholder consultation. Multi-Attribute Utility Theory (MAUT) and multi-criteria decision analysis (MCDA) are two concepts that may guide the ISA and stakeholders through a simple and informative process to understand the trade-offs between and value drivers of various alternatives, including but not limited to bonds and insurance, with insurance including consideration of the P&I Club option.

Estimating financial cost

To provide adequate financial resources in case of an accident, one must estimate the damage (Boyer and Porrini 2008). Probabilistic modeling is a sophisticated way to capture multiple outcomes (Sullivan 2005, Uusitalo et al. 2015). This kind of modeling combines "the probability of occurrence of an event and its consequences or impact" (Dobler et al. 2013, p. 2), where averages are not sufficient (O'Hagan 2012). Such an exercise may help to define the upper and lower ceiling of financing needed, and inform the most appropriate instrument to raise such funds (MERAG uncertainty analysis 2007, p. 3). Several questions arise when considering how a probabilistic analysis would be implemented for estimating potential environmental damages to the seabed as a result of seafloor mineral extraction and are thus suggested as questions to include in the consultation phase of the project (see Figure 1). Answers to such questions should elucidate the probability of particular incidents (e.g., sediment plumes, noise impacts) occurring, how to assign characteristics or boundaries of costs associated with certain ecosystem functioning in CCZ seabed and pelagic ecosystems, who should be responsible for monitoring or remediation, or what constitutes an acceptable environmental offset for impacts to the seabed and pelagic

environments? Answers are subject to a range of stakeholder points of view: while one stakeholder group may consider environmental monitoring to be the financial responsibility of the contractor, another group may consider it a potential for moral hazard. This could be mitigating by using reputable scientific expertise.

It may be useful to start the process by thinking of a simple valuation model that leverages Monte Carlo simulation to compare the cumulative probability of an event to the financial consequence of that event. Table 1 presents a method to assess distributions of the range of probabilities an event will occur and of the range of financial costs the liable party may assume. The sum product of these two variables less the investment put into avoiding that event is equal to the value of the risk.

Table 1

Risk	Probability (P)	Financial cost (F)	Annual mitigation investment (I)	Valuation (V)
1)…	[min, max]	[$min, $max]	[$min, $max]	$V = - I + (\Delta P * \Delta F)$
n)…	…	…	…	…

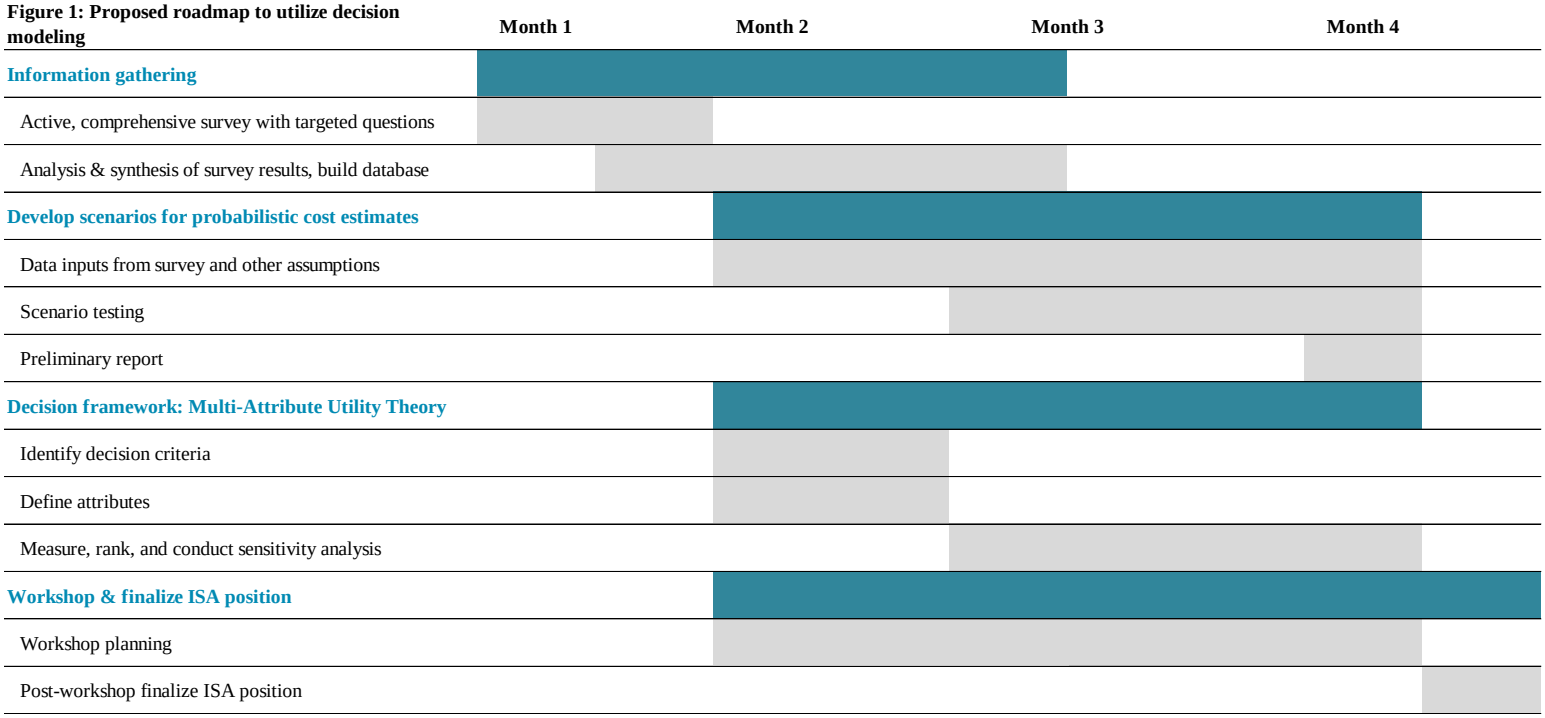
The first column, risk, can be categorized as environmental impacts. Probability can be estimated by incorporating a range of expert opinions, such as from scientific, economics, regulatory, industry, and other experts, on the expected frequency of a particular risk. Cost may be estimated as a function of ecological impacts and ecosystem service value studies, such as Mangi et al. (2010) or Armstrong et al. (2012). The model may be premature to complete at the moment (i.e., prior to the start of commercial-scale mining), but incorporating a model in the process of addressing environmental liabilities and allowing for new information to be built into the model may align well with the ISA's adaptive management approach. For example, the investment variable will need to be derived from industry data on the operational expenditures related to maintaining strong environmental performance/minimizing environmental risk exposure. These costs may come from a firm's financial statements, financial stress tests, or otherwise reported cost accounting. Much of this data is not currently available, and establishing this model and process upfront may allow the ISA to collect such information from contractors and other stakeholders as this industry progresses.

Multi-Criteria Decision Analysis

MCDA is "an umbrella term to describe a collection of formal approaches that seek to take explicit account of multiple criteria in helping individuals or groups explore decisions that matter" (Belton and Stewart 2002, p. 2). MCDA can be used to focus a discussion of complex problems, such as natural resource management and regulatory decisions, through a structured process where decision-makers explicitly rationalize and justify a decision (Belton and Stewart 2002, Mendoza and Martins 2006). The purpose of MCDA tools is to inform a decision and call out the trade-offs and key value drivers, rather than make the "correct" decision. While MCDA is a subjective exercise, it may expose differing assumptions or incentives and encourage a constructive conversation toward a mutually agreeable solution (Belton and Stewart 2002).

The process of conducting an MCDA is described in detail in Belton and Stewart (2002). In brief, MCDA involves using a matrix to rank each alternative based on key decision criteria and their relative importance. It begins with defining what success means to the decision maker(s) using a list of decision criteria that are mutually exclusive and collectively exhaustive. Decision criteria have a metric (qualitative or quantitative) assigned to them and are ranked in order of importance. Then, all possible alternatives or, in this case, environmental regulation alternatives, are listed and described in terms of each decision criterion. The next step involves attributing values to each alternative based on how they meet the decision criteria (i.e. they are ranked). Following the assignment of ranking, a sum product of the relative ranking is applied to each criterion of each alternative to assign the final score for all alternatives. Sensitivity analyses are critical in understanding the levers that drive value for each alternative.

Figure 1: Proposed roadmap to utilize decision modeling



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