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Good governance of deep-seabed mining:
transparency and the monitoring of environmental harm

by

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Thesis for the degree of Doctor of Philosophy

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University of Southampton

<u>Abstract</u>

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This thesis considers the good environmental governance of deep-seabed mining (**DSM**), with a focus on the seabed 'Area' beyond national jurisdiction (**ABNJ**). DSM in ABNJ has not yet begun, due in part to a lack of internationally agreed upon regulations. Shortly after this thesis research began, however, the International Seabed Authority (**ISA**) began consultations and drafting of its exploitation regulations, making this research particularly timely. Herein, two themes run throughout: i) *transparency* and ii) *statistically robust monitoring of environmental impacts*. For each of these themes, the research presented here suggests that there is considerable room for the ISA to improve its practices. For example, it is currently much less transparent than bodies managing international fisheries (Chapter 2). Furthermore, its practices largely do not meet the expectations contained in recognised standards for terrestrial mining and other related sectors (Chapter 3). Regarding the monitoring of environmental impacts, the ISA calls for statistical robustness. However, it currently lacks guidance on how such robustness should be assessed and reported upon. Mortality modelling conducted here (Chapter 4), using data from the Clarion-Clipperton Zone, suggests that impacts on benthic megafauna from neighbouring polymetallic nodule mining operations could be difficult to detect until it is 'too late'; i.e. only after serious harm has already occurred. To be able to detect early warnings of possible serious environmental harm, monitoring design will need to take into account increased statistical power from the outset, which will require large sample areas (containing 500-750 individuals) and adequate replication (≥5 sites) in order to be able to rule out 'false negatives'; i.e. type II errors. The thesis contains 45 recommendations, which if implemented by the ISA would improve the likelihood of statistically robust environmental monitoring and informed decision making. Additionally, in Chapter 5 (Epilogue), three simply stated, overarching good practices are put forward, not only for the ISA, but for DSM contractors and researchers alike: i) ensure DSM environmental data are readily available; ii) establish robust statistical practices in the analysis of environmental data; and iii) be inclusive when considering the results of environmental data analyses.

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Research Thesis: Declaration of Authorship

Name:	Jeffrey Allan Ardron
Title of thesis:	Good governance of deep-seabed mining: transparency and the monitoring of environmental harm

I declare that this thesis and the work presented in it are my own and has been generated by me as the result of my own original research.

I confirm that:

1. This work was done wholly or mainly while in candidature for a research degree at this University;
2. Where any part of this thesis has previously been submitted for a degree or any other qualification at this University or any other institution, this has been clearly stated;
3. Where I have consulted the published work of others, this is always clearly attributed;
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   Chapter 2: Ardron, J. A. 2018. (Online 2016.) Transparency in the operations of the International Seabed Authority: an initial assessment. Marine Policy 95:324-331.

   Chapter 3: Ardron, J. A., Ruhl, H. A., & Jones, D. O. 2018 Incorporating transparency into the governance of deep-seabed mining in the Area beyond national jurisdiction. Marine policy 89:58-66.

   Chapter 4: Ardron, J. A., Simon-Lledó, E., Jones, D. O., & Ruhl, H. A. 2019. Detecting the effects of deep-seabed mining before serious harm occurs. Frontiers in Marine Science 5:604.

   Appendix A: Jones, D.O., Ardron, J.A., Colaço, A. and Durden, J.M. 2020. (Online 2018.) Environmental considerations for impact and preservation reference zones for deep-sea polymetallic nodule mining. Marine Policy 118.

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Appendix A: This work has arisen out of discussions in several international workshops including: ISA workshop on the design of impact reference zones (IRZ) and preservation reference zones (PRZ) in the Area, Berlin, Germany; ISA workshop on an Environmental Management Strategy for the Area, Berlin, Germany; Griffith Law School and the ISA workshop on environmental assessment and management for exploitation of minerals in the Area, Surfers Paradise, Queensland, Australia; Managing Impacts of Deep-seA reSource exploitation (MIDAS) Annual Meeting, Sintra, Portugal; MIDAS workshop on environmental management of deep-sea mining, Southampton, UK; and the EcoDeep-SIP Workshop on the crafting of seabed mining ecosystem-based management, Tokyo, Japan. This work has received funding from the European Union Seventh Framework Programme (FP7/2007-2013) under the MIDAS project, grant agreement 603418. This study also had the support of Fundação para a Ciência e a Tecnologia (FCT), through the strategic project UID/MAR/04292/2013 granted to MARE. AC is supported by Program Investigador (IF/00029/2014/CP1230/CT0002) from FCT.

Definitions and Abbreviations

ABNJ	areas beyond national jurisdiction
CAD	Canadian dollars
CHM	common heritage of mankind / humankind
COP	conference of parties
CCZ	Clarion-Clipperton Zone / Clarion-Clipperton Fracture Zone
DSM	deep-seabed mining / deep-sea mining
EIA	environmental impact assessment
ISA	International Seabed Authority
JVA	joint venture agreement
m	metres
LTC	Legal and Technical Commission (of the ISA)
MEA	multilateral environmental agreement
MPA	marine protected area
mspp	morphospecies (plural; singular: msp)
PNG	Papua New Guinea
RFMO	regional fisheries management organisation
SMS	seafloor massive sulphides, also known as polymetallic sulphides
UK	United Kingdom
UN	United Nations
UNCLOS	United Nations Convention on the Law of the Sea (or, Law of the Sea Convention, LOSC, not used here)
UNGA	United Nations General Assembly
US	United States
USD	US dollars

Chapter 1 Introduction

1.1 Abstract

This introductory chapter covers the main legal, policy, and institutional considerations of deep-seabed mining in areas beyond national jurisdictions. A brief history is provided of deep-seabed mining interest, the United Nations Convention on the Law of the Sea, and the International Seabed Authority. In seeking possibly analogous lessons to be learned, the literature of natural resource governance within national jurisdictions is also briefly considered. The recent case of deep-sea mining bankruptcy in Papua New Guinea is presented, illustrating possible governance pitfalls to be avoided in the future.

The intertwined themes of good governance and protection of the environment, in traduced here, are discussed throughout this thesis, with the assertion that neither are likely without transparency (e.g. the details of contractual performance) and access to reliable scientific (environmental monitoring) data, respectively. The thesis research question is introduced and qualified, with key terms defined. The other thesis chapters are outlined, highlighting their original contributions to the field of research.

1.2 Brief context

Although discussed for more than fifty years, commercial scale deep-seabed mining (**DSM**) has not yet begun. Deep-seabed metal and mineral resources (excluding hydrocarbons) of current commercial interest fall into three distinct categories and depth ranges: manganese nodules (henceforth, *nodules*) –potato-sized and found on the seafloor surface at abyssal depths (mainly 4000 – 6500 metres; Glasby, 1972;); cobalt-rich ferromanganese crusts (*crusts*) –found on ridges and seamounts generally at bathyal depths (mainly 800 – 2500 m; Hein et al., 2000), and seafloor massive sulphides (**SMS**, and related resources[1]) associated with hydrothermal vents found along the intersections of tectonic plates in a wide range of depths from 500 to 5000 metres (Hannington et al., 2011). It is estimated that 81% of nodules lie in the legal 'Area' beyond national jurisdictions (**ABNJ**); 58% of SMS; and 46% of crusts (Petersen et al., 2016).

[1] In this category are included metal-bearing hot brines and muds first reported in 1965, in a series of deep basins along the central rift valley beneath the Red Sea, the largest of which is named Atlantis II (McKelvey, 1980). Sometimes this category is further broadened to include all *chemosynthetic ecosystems*, sensu Van Dover et al. (2012).

The possible commercial exploitation of each of these deep-seabed resource types come with their own sets of environmental concerns (e.g. Van Dover, 2011a, 2011b; Jones et al., 2018, 2020), though many of the recommended regulatory and management actions to limit harm are shared in common (Jones et al., 2019); mainly, conducting environmental impact assessments and refining methods and technology accordingly (**EIA**s; Collins et al., 2013; Durden et al., 2018), adaptive management (Jaeckel, 2016a; Jones et al., 2018; Craik, 2020), and the establishment of marine protected areas with other area-based management (**MPA**s; Van Dover et al., 2012; Miller et al., 2018). As shall be posited throughout this thesis, these (and other) management actions rely upon reliable scientific baseline surveys, ongoing monitoring of impacts and changes over time, and access to these data allowing for review and consideration by a broad range of experts and stakeholders. However, because of the remoteness of the resources, and in the case of nodules, the patchy low-density distributions of the deep-sea benthos (see Chapter 4), the data are difficult and expensive to acquire and process, underlining their scientific and monetary value, which can impede sharing.

Some of the international institutional structures to regulate commercial DSM in ABNJ are now in place, and the rules and regulations concerning *exploitation* (as opposed to exploration) have been under consideration by the International Seabed Authority (**ISA**) for about the same time period as this thesis research –from 2014 to present.[2]

Identified as the *common heritage of mankind* by the United Nations Convention on the law of the Sea (**UNCLOS**, 1982, art. 136; henceforth undated), this unique legal status of DSM resources adds governance complications unique to DSM in ABNJ. A result of ten years of intense negotiations, 1973 through to 1982,[3] the DSM provisions of UNCLOS (Part XI) concerning royalties, technology transfer and benefit sharing were at the time of signing still unacceptable to some developed nations interested in pursuing DSM, particularly the United States.[4] With the desired universality of UNCLOS under threat (Brown, 1995), revisions –mainly through rescinding text– were made to Part XI (Part XI Agreement, 1994). As a result, “the development of the common heritage for the benefit of mankind as a whole” (UNCLOS, art. 150(i)) is perhaps less concrete

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[2] International Seabed Authority website: https://www.isa.org.jm/legal-instruments/ongoing-development-regulations-exploitation-mineral-resources-area [Accessed Dec. 2019.]

[3] At the time of the third UNCLOS negotiation, only nodules were considered economically viable. Hydrothermal vents were discovered mid-way into the negotiation period (1977) but were only of scientific interest at the time.

[4] The US has signed but still not ratified UNCLOS. However, even before the Part IX Agreement was negotiated, in 1989 the US position was that the Convention, “…generally constitute[s] international law and practice” (quoted in Roach, 2014). Other states interested in pursuing DSM that held back UNCLOS ratification until Part XI was revised include the United Kingdom, Germany, Japan, and the Russian Federation (then USSR).

today than when it was first discussed in the 1970s, and key benefit-sharing issues remain largely unresolved (Jaeckel et al., 2016).

Meanwhile, international norms and expectations more generally have continued to evolve. For example, the phrase *social licence,* now commonly associated with mining on land, did not exist at the time UNCLOS was negotiated and remains problematic for DSM (Filer and Gabriel, 2018). Also, deep-sea scientists are increasingly seeing themselves as stakeholders with responsibilities to tread lightly in the environments they study, which has led to improved scientific practices (Godet et al., 2011), and a recognised role in ISA and DSM discussions, but also carries the risk of scientists outside of the ISA's Legal and Technical Commission (**LTC**) being treated like any other stakeholder group (Godet et al., 2011), rather than trusted external advisers.[5]

Salient lessons can be drawn from other issues of broad societal and environmental concern, particularly climate change, which is to some extent directing deep-sea research (Ruhl et al., 2011), and wherein the role of science and scientists, previously seen as detached and purely objective, has become more nuanced with greater societal interpretation and engagement (Jasanoff, 2006, 2011, 2013). However, perceived hidden agendas has also diminished some of the public's trust in climate science (Leiserowitz et al., 2013), in turn driving climate scientists to be more transparent in their methods than previously (Voosen, 2016).[6]

To what degree the International Seabed Authority is aware of, and overcoming, these modern challenges is an underlying theme that runs throughout this thesis –especially concerning transparency. Of particular concern is the hitherto insular nature of the Authority, which has arguably impeded an inclusive approach to science and policy making that could help bridge the unique historical, scientific, social and cultural difficulties posed by the governance of DSM.

1.3 A brief history of deep-seabed mining interest

Interest in DSM first arose in the mid-1960s and focussed on nodules, some of which contain sufficient concentrations of manganese, nickel, copper, molybdenum, and cobalt to be of commercial interest. Nodules had been discovered a century earlier, in 1868 during the Swedish Nordenskold expedition in the Kara Sea. At the time, the discovery was deemed unimportant,

[5] The Deep Ocean Stewardship Initiative (DOSI), a network of over 650 experts from 50 different countries, is an official observer at ISA meetings, alongside industry and environmental groups. https://www.dosi-project.org/topics/minerals/ [Accessed Feb. 2020.]

[6] While increased transparency in science is generally regarded as a positive trend, transparency recently has also been 'weaponised' by climate change deniers to stymie government regulators when they are unable to fully document and share all information used to make their regulatory decisions (Levy & Johns, 2016).

went unpublished and therefore largely unknown (Baturin, 1999). As a result, Murray and Renard of the much better-known Challenger Expedition were for several decades (and frequently still are[7]) given credit for their (re-) discovery five years later, in 1873 (e.g. Bonatti and Nayudu, 1965; McKelvey, 1980).

Although nodules initially generated little interest outside of geological circles, the publication of John Mero's *The Mineral Resources of the Sea* (Mero, 1965)[8] is widely credited with helping bring them onto the international stage, when in November 1967 it was quoted extensively in the United Nations General Assembly (**UNGA**). In what is now recognised as a seminal moment in the development of the international legal regime for DSM, Ambassador Arvid Pardo of Malta delivered a 14-page 2 ½ hour address to the First Committee of the UNGA, consuming the entire morning sessions, with the expressed purpose of providing a 'brief explanation' of why he disagreed that there was no rush to develop a new legal agreement regarding seabed resources (UNGA, 1967a). Pardo referred to Mero's book extensively, reciting its 'astounding' results. For example, amongst many other enormous numbers, he quotes that nodules could yield, "…5.2 billion tons of cobalt equivalent to reserves for 200,000 years as compared to land reserves for 40 years only" (ibid.). Subsequently, such numbers have been found to be overly optimistic, sometimes by orders of magnitude (Glasby, 1976, 1986, 2000; McKelvey, 1980). However, at the time they captivated the UNGA audience and had the intended galvanising effect.

The discovery of nodules and their subsequent over-valuation is thought to have triggered a series of events leading to reinvigorated UNCLOS negotiations, which had hitherto foundered (Rona, 2003). Six weeks after Pardo's speech, an ad hoc UN committee was struck (UNGA, 1967b), which became a formal committee the following year (UNGA, 1968), which led to the 1969 General Assembly to request the Secretary General to, "…ascertain the views of Member States on the desirability of convening at an early date a conference on the law of the sea..." (UNGA, 1969). The following year, three years after Pardo's speech, the UNGA declared that "The seabed and ocean floor, and the subsoil thereof, beyond the limits of national jurisdiction […], as well as the resources of the area, are the common heritage of mankind" (UNGA, 1970), setting the mould for UNCLOS, where much of that 1970 declaration's language is preserved.

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[7] E.g. The Geological Society website page on nodules, opens, "Deep-sea manganese nodules were first recovered in 1873 during the voyage of HMS Challenger. Yet their exploitation - until now - has remained uneconomic." https://www.geolsoc.org.uk/Geoscientist/Archive/May-2013/Treasures-from-the-abyss [Accessed Dec. 2019.]

[8] More than one-third of that wide-ranging book is devoted to the economic promise of nodules, providing initial estimates of gigantic volumes (>1.5 trillion tons; p 278). However, Mero was hardly a disinterested party and had created his own company to exploit marine minerals, Ocean Resources Inc., of La Jolla, California (no longer in existence).

Although hopes in the UNGA may have run high, in reality the deep sea was, and remains, a difficult and expensive environment in which to prospect for minerals and pilot new technologies. Between 1974 and 1982 a consortium of mining companies spent USD 650 million (over USD 2.5 billion in current dollars[9]) in an ultimately failed attempt to bring nodule mining to commercial readiness (Glasby, 2000). High extraction costs combined with several other factors,[10] including inflated valuations of the mineral resource, political interference, and collapsing metal prices, were attributed to contributing to its failure (Scott, 2001).

Today, similar arguments to those made in the 1960s, 70s and 80s continue to shape DSM discussions, though with an added 'green' component suggesting these deep-sea minerals are *needed* for renewable energy technologies. They originate generally from industry and related media stories, suggesting: i) mineral resources on land are running out; ii) deep seabed mineral wealth is enormous;[11] and iii) the deep seabed should be developed for the greater benefit of humanity.[12] Because these arguments are not being made in the peer-reviewed literature, presented without supporting evidence, they are difficult to evaluate on those terms.

The only peer-reviewed paper found on the topic suggests in passing that "The mineral resources required to sustain that growth and to support green- and emerging-technologies can no longer be supplied solely from land-based sources" (Hein et al., 2013). However, the two references they provide (Nature Geoscience editorial, 2011; Ragnarsdóttir, 2008)) are from an editorial and a comment (also in Nature Geoscience); i.e. not peer-reviewed assessments, but expert opinions on the possible future directions of mining, presented in a respected journal, that both focus on demand rather than supply. Hein et al. (2013) continue, "The grades of land-based mines are continually decreasing. For example, average Cu ore in 1900 contained 4% Cu, whereas now it is close to 0.5% Cu, with some mines as low as 0.25% Cu." The reference provided (Mudd, 2009) is

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[9] Estimate done as follows: the mid-point of the expenditures (1978) was put into a converter calibrated for US inflation (http://www.usinflationcalculator.com/). Because most of the investment was indeed US-based, and that it tended to taper off towards the end of this period, these are reasonable simplifications. The calculator's exact result is: $2 547 640 000.

[10]Growing interest in DSM was used as cover story for a top secret 1974 CIA effort to raise a sunken Soviet nuclear submarine. A massive purpose-built ship, the Glomar Explorer, was commissioned by the CIA under the pretence of deep-sea nodule mining (US National Security Archive, 1985). The eccentric but very successful industrialist Howard Hughes agreed to build the ship. Hughes' involvement may have further perpetuated the belief that nodule mining was commercially viable (Glasby, 2000; The Economist, 2015).

[11] For example, the Deep Green Resources website: "The [Deep Green] Contract Area alone is potentially big enough to supply battery metals for 140 million electric vehicles." https://deep.green/nodules/ [Accessed Jan. 2020.]

[12] E.g. BBC News, 2019. *Electric car future may depend on deep sea mining*. https://www.bbc.co.uk/news/science-environment-49759626 [Accessed Dec. 2019.]; The Guardian, 2017. *Is deep sea mining vital for a greener future – even if it destroys ecosystems?* https://www.theguardian.com/environment/2017/jun/04/is-deep-sea-mining-vital-for-greener-future-even-if-it-means-destroying-precious-ecosystems [Accessed Dec. 2019.]

not from the peer-reviewed literature, but rather a grey literature report regarding Australia only. Nevertheless, this latter supply-side argument at first glance appears compelling. However, in a peer-reviewed paper looking at land reserves only (i.e., not considering DSM), Crowson (2012)[13] responds to such assessments, warning against jumping to premature conclusions based on ore grades. He presents data to illustrate that decreasing ore grades is a normal part of the lifecycle of mines (i.e., that companies inevitably mine the best seams first), and that recent copper discoveries continue to present higher-than-average grades, similar to historic finds. In a grey-literature report, Teske et al. (2016) perform various scenario analyses that suggest there are indeed sufficient reserves on land to meet the growing demands of transitioning to renewal energy technologies for more than one hundred years.

Therefore, the need to mine the deep seabed in this century is far from settled. This distinction is of more than academic interest, however, since the perception of necessity can colour the environmental trade-offs seen as either unpleasant but necessary, or not, when drafting DSM regulations, and later, regulating the activity.

Regardless of necessity, should it prove to be economically feasible, DSM will be attractive to some investors and governments as a new source of (potential) income. For example, UK Seabed Resources, a wholly owned subsidiary of the US-based Lockheed Martin Corporation, in 2013 applied to the ISA for a nodule exploration contract, sponsored by the United Kingdom (**UK**).[14] Then British Prime Minister David Cameron pledged to put Britain at the forefront of seabed mining, which he claimed could be worth £40bn to the country's economy over the next 30 years.[15] The calculations and sources for this claim, published widely in the media, were not revealed; neither were the terms of the agreement with the new mining company. Without transparency as to where such information originated, and what the country stands to gain in its new contractual partnership, the appropriateness of such statements is impossible to assess.

1.4 United Nations Convention on the Law of the Sea

Here, a brief overview of the UNCLOS negotiations regarding DSM is provided. More information can be found in Miles (1997) and Anderson (2008), among others. There were three sets of

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[13] Prof. Philip Crowson was a director of several Rio Tinto subsidiaries, past president of the Mining Association of the United Kingdom, and an Invited Director of the London Metal Exchange for a maximum possible twelve-year term. (https://www.dundee.ac.uk/people/phillip-crowson [Accessed Dec. 2019.)

[14] Because the US is not a party to UNCLOS, US companies must look to foreign governments that have ratified UNCLOS for DSM sponsorship.

[15] E.g.: The Guardian, 2013. *David Cameron says seabed mining could be worth £40bn to Britain*. http://www.theguardian.com/business/2013/mar/14/david-cameron-seabed-mining-worth-40bn [Accessed Dec. 2019.]

negotiations, but seabed mining was not a topic of discussion until third and final round, which was also the longest, from 1973 to 1982, propelled by Pardo's speech and subsequent UNGA decisions, where DSM played a dominant role (Nandan et al., 2002). Although there was general agreement that the seabed resources should remain the 'common heritage of mankind' (i.e. the legacy of all human beings; McKelvey, 1980)[16], much debate was nevertheless spent seeking the right balance of private (corporate) revenues with global benefit-sharing.[17] As noted above, the debate continued after UNCLOS was adopted in 1982, with the Part XI Implementing Agreement (Part XI Agreement, 1994) finally allowing for UNCLOS to be signed by all the dissenting industrialised nations, and ratified by all save one.[18] Critically, the Agreement provided UNCLOS with (near-) universality, but it came at a steep price; most of the benefit-sharing details contained in the original Part XI were rescinded, leaving them to be developed by the ISA sometime in the future.

1.5 The International Seabed Authority

The management of mineral resources in ABNJ falls exclusively under the ISA. Mandated by UNCLOS, the ISA is the autonomous international organisation through which States Parties must organise and control DSM in the Area (UNCLOS, art. 157(1)).

1.5.1 The legally dormant years: 1982-1994

As outlined above, although UNCLOS was adopted in 1982, it did not come into force until 1994, and with it the ISA. (Two years later, in 1996, the Part XI Agreement came into force.) During the ISA's dormant period, from 1982 to 1994,[19] the idea of *sustainable development* took root globally, as reflected in the 'Brundtland report' (World Commission on Environment and Development, 1987; Schubert and Láng, 2005) and Agenda 21 (UN, 1992; Spangenberg, 2002). The development of international multilateral environmental agreements (**MEA**s) also gathered apace, with 95 new MEAs signed during this period –though not necessarily coming into force

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[16] In 1966 (i.e. the year before Pardo's now famous speech), US President Johnson had already expressed this sentiment: "We must ensure that the deep seas and ocean bottoms are and remain the legacy of all human beings" (quoted in McKelvey, 1980).
[17] DOALOS (UN Division for Ocean Affairs and the Law of the Sea). *The United Nations Convention on the Law of the Sea - a historical perspective*. Website: http://www.un.org/Depts/los/convention_agreements/convention_historical_perspective.htm [Accessed Dec. 2019.]
[18] The USA signed, but has not ratified the agreement, unable to date to achieve the two-thirds supermajority necessary in its Senate.
[19] Although the ISA was dormant, a Preparatory Commission met, drafting, *inter alia*, ISA operational rules and procedures. Its final report consisted of 13 volumes (ISA, 1995).

during this time (UNEP, 2005). In 1992 at the first Earth Summit in Rio de Janeiro, two treaties that would prove to be particularly influential were opened for signature: the United Nations Framework Convention on Climate Change (UNFCCC**,** 1992; in force 1994), and the Convention on Biological Diversity (CBD, 1992; in force 1993).[20] Thus in 1994, when the ISA emerged from its twelve-year legal hiatus and its Assembly first met in 1995, it was into a world with significantly changed views on sustainability,[21] natural resource development, protection of the environment, and the role of society in natural resources decision-making. Indeed, even the ISA's bricks and mortar secretariat in Kingston Jamaica was an anachronism, in a world where contemporary MEAs followed the more economical *Conference of the Parties* (**COP**) approach, wherein parties to the agreements met in conference halls hosted by different member governments each cycle (Churchill and Ulfstein, 2000). Institutional rules once considered fit for purpose had perhaps already become aged, focussing mainly on confidentiality rather than transparency, with little to say regarding environmental protection (ISA, 2012a).[22] However, as discussed below, there was early recognition by ISA members and the first Secretary-General of these shortcomings.

1.5.2 ISA operations

The ISA Assembly (i.e. members of the ISA) first met in 1995. The President of the Assembly noted preliminary discussions on the question of its priorities:

> "It was suggested that two themes be considered by the Assembly, one being the <u>issue of transparency</u> in the relationship between the Council and the wider membership of the Assembly, and the other being the development of principles regarding <u>environmental protection</u> […]" (ISA, 1995, para 12, underlining added).

These two original priorities still resonate today, and underpin this thesis' research. While the issue of transparency is arguably broader today than formulated in 1994, the parallels with present day are noteworthy. As will be elaborated upon here in subsequent chapters, ISA transparency remains an ongoing issue (Chapters 2 & 3), and principles to guide the rules and regulations for environmental protection are still under discussion.

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[20] Also in Rio de Janeiro, negotiations began on the Convention to Combat Desertification (CCD), which was opened for signature in 1994 and entered into force in 1996.

[21] The word 'sustainable' only occurs twice in UNCLOS, in both instances with regard to fishing at 'maximum sustainable yield.' It does not appear at all in the Part XI Agreement concerning DSM.

[22] In the ISA's combined rules (ISA, 2012a), the aim of transparency is not mentioned at all, but confidentiality is mentioned 26 times; protection of the environment is mentioned three times, but protection of the ISA's name and its premises is mentioned 10 times, and legal protection of staff, representatives and diplomats four times. The ISA's preoccupation with confidentiality continues to present day (ISA, 2017d).

The ISA's first Council (i.e. its executive organ) was established and met the following year in 1996, marking the first year that the ISA was seen to be *fully functional* (ISA, 1996).[23] In the Secretary-General's report to the Assembly, it highlights the need for more work to be done on the question of protecting and preserving the marine environment, the value of new scientific information, and the linkages between the establishment of threshold criteria for harm and monitoring -the central topic of Chapter 4 herein:

> "As a result of the review of the substantive functions of the Secretariat of the Authority, it became apparent that while a considerable amount of work has been undertaken in respect of the rules and regulations for the protection and preservation of the marine environment from activities in the Area, this work has not been completed and requires further review in the light of new information. In addition, the review reveals that a considerable amount of research work on this subject matter had, and continues to take place by national Bodies [sic], research institutions, pioneer investors and potential applicants. In order to complete this aspect of the draft seabed mining code, it will be useful to come to a common understanding in a number of areas, such as the <u>establishment of acceptance criteria (a kind of basic standard for protecting the environment against harmful effects)</u> and the linkages between, inter alia, the Authority's monitoring programme, the programme for oceanographic and baseline environmental studies and the assessment of the potential environmental impacts of proposed activities in a plan of work." (ISA, 1996, para 5, reiterated in para 113, underlining added.)

Again, the parallels to present day are considerable. It is noteworthy that the Secretary-General was suggesting 'a basic standard' for protecting the marine environment against harmful effects in general, rather than only *serious harm* –a distinction that is still debated today (ISA, 2019a, 2019b), and particularly relevant in the ISA's interpretation of how to implement the precautionary principle when protecting the environment (Jaeckel, 2017).

The ISA's first fifteen years were relatively quiet. International interest in DSM had waned, providing the ISA opportunity to slowly develop its *exploration* regulations for nodules, finalised in 2000 (ISA, 2000), which were the only resource of possible economic interest at the time. Ten years later, regulations were developed for SMS in 2010, in 2012 for crusts, and revised for nodules in 2013 (ISA, 2010b, 2012b, 2013a). Until 2011, there had been just eight exploration

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[23] The term used by the Secretary-General of the ISA was actually, 'full functional phase', reflected in the title of his report to the Assembly of 1996: FUNCTIONS OF THE INTERNATIONAL SEABED AUTHORITY IN THE FIRST YEAR OF ITS FULL FUNCTIONAL PHASE, INCLUDING MATTERS PENDING FROM THE WORK OF THE PREPARATORY COMMISSION FOR THE INTERNATIONAL SEABED AUTHORITY AND FOR THE INTERNATIONAL TRIBUNAL FOR THE LAW OF THE SEA (ISA, 1996, all-caps lettering retained).

contracts issued by the ISA to the so-called 'pioneer' contractors who had carried out work on nodules in the 1970s and 1980s. Around 2011, however, interest resurged, and 22 more exploration contracts have since been approved for all three resource types, bringing the total to 30. After peaking in 2013 (following record-high metal prices[24]), interest again tapered off sharply, with just one exploration application in 2015, another in 2017, and one more in 2019 (Figure 1).

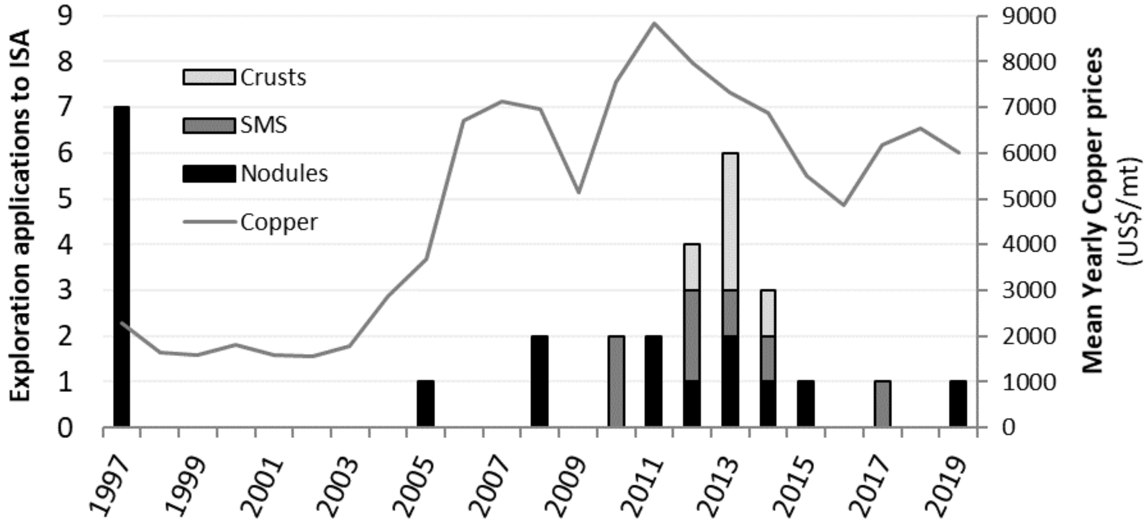

Figure 1-1: DSM exploration applications made to the ISA (as of Jan. 2020)

Shown is the year of application rather than when they were signed and came into effect – generally a year or two later. All thirty applications have been approved. The seven applications in 1997 were from historical activities beginning in the 1970s by 'pioneer' contractors. The two 2008 nodule applications (sponsored by Nauru and Tonga) were paused during the financial crisis (note the dip in 2009 copper price) while an advisory opinion was sought from the Seabed Disputes Chamber of the International Tribunal for the Law of the Sea on the responsibilities and liabilities of Sponsoring States. The applications were updated and resubmitted in 2011 (not shown, to avoid double-counting), before being approved that same year. In 2020, there has been one more, as yet unapproved, application for the exploration of nodules (not shown). Information on applications was compiled from the annual reports of the Secretary-General.[25] Copper data are from World Bank commodity prices, in nominal US dollars, uncorrected for inflation.[26]

[24] Commonly attributed to the Chinese construction boom, commodity prices have subsequently declined (e.g. World Economic Forum: https://www.weforum.org/agenda/2013/08/what-do-falling-commodity-prices-mean-for-the-economy [Accessed Dec. 2019].)
[25] ISA annual reports of the Secretary-General to the Assembly can be found here and in the related links: https://www.isa.org.jm/sessions/25th-session-2019 [Accessed Dec. 2019.]
[26] World Bank: https://www.worldbank.org/en/research/commodity-markets [Accessed Feb. 2019.]

Both the revival of interest in DSM, combined with the pending expiration of the original 15-year contracts issued in the early 2000s, spurred the ISA towards developing its *exploitation* regulations. These regulations will establish, *inter alia*, the fiscal regime, environmental impact assessment rules, liabilities, rules concerning the disclosure of information, and roles of third party experts, industry groups, and civil society organisations in the decision-making processes, as well as the possible development of new institutional structure(s) responsible for the regulation of commercial DSM. To date, there have been three drafts of partial regulations, eight workshop reports, and five discussion papers.[27] However, no complete set of regulations, including environmental standards and guidelines, has yet been produced, making it hitherto difficult to comment on the adequacy of the sections that have been released (see discussion below on *serious harm*). A fuller set of draft regulations, including standards and guidelines, is anticipated to be released incrementally in 2020 through to 2021.

1.6 Good governance of natural resources: lessons learned from national jurisdictions

This section introduces unexpected negative outcomes that have occurred within national jurisdictions during natural resource development, and looks at what can be learned with regard to the governance of DSM in ABNJ. As in ABNJ, DSM exploitation within national jurisdictions has not yet occurred. How many DSM exploration licenses have been granted within the national jurisdictions is unknown because they are usually treated as confidential (but for some known examples see Miller et al. (2018)). Here, key lessons learned from natural resource development on land are briefly outlined, followed by an overview of developing states that are currently sponsoring DSM, and finally the case of the Government of Papua New Guinea and Nautilus Minerals Inc. is presented, which until recently was widely expected to be the first commercial DSM operation.[28]

[27] ISA website tracking the ongoing development of regulations: https://www.isa.org.jm/legal-instruments/ongoing-development-regulations-exploitation-mineral-resources-area [Accessed Dec. 2019.]
[28] Though, with much less fanfare, development of SMS DSM within Japanese waters is proceeding apace (Narita et al., 2015).

1.6.1 Natural resource problems and good governance

The sudden influx of resource income[29] into a state's economy can be a mixed blessing, bringing with it environmental, social, and paradoxically, also economic problems, many of which are unexpected, or at first glance seem unrelated to the resources.[30]

In the late 1980s and 1990s, negative terms began to appear in various research publications. Gelb (1988: *Oil Windfalls: Blessing or Curse?*) examines the unexpectedly negative effects of windfall profits on petroleum-based economies of smaller countries. Auty (1993, 1994) applies the term *resource curse*, suggesting:

> "…a growing body of evidence suggests that a favourable natural resource endowment may be less beneficial to countries at low- and mid-income levels of development than the conventional wisdom might suppose. […] The new evidence suggests that not only may resource-rich countries fail to benefit from a favourable endowment, they may actually perform worse than less well-endowed countries. This counterintuitive outcome is the basis of the resource curse thesis." (Auty, 1993, p1., underlining added.)

The *resource curse* thesis was elaborated upon (and is often attributed to) Jeffrey Sachs and Andrew Warner, arising from a series of their papers (Sachs and Warner, 1995 (updated 1997), 1998, 2001). As noted above, there is a rich literature that preceded them, such that there were already serious questions and doubts about why resource riches did not inevitably lead to economic wealth (e.g. Attiga, 1981). Indeed, as early as 1859, it was recognised that the then recent gold discoveries in Australia had had negative economic effects on some other Australian industries (Corden, 1984). Sachs and Warner, however, moved from anecdotal case studies to applying global comparative statistics, and in doing so put forward the troubling notion that not only did the economies of exporting nations rich in natural resources (in these studies, agriculture, minerals, and petroleum) generally fail to live up to expectations, but paradoxically, their gross domestic product appeared to grow more slowly than those of their neighbours who had fewer such resources (Sachs and Warner 1995 (updated 1997)).

The resource curse thesis remains highly controversial. There have been a variety of explanations (Sachs and Warner, 2001) and counter-arguments (Torres et al., 2013) regarding why the economic aspects of the resource curse occur, including how it can be 'escaped' (Humphreys et al., 2007), countered by disagreement on whether it in fact does occur –focussed mostly on

[29] Technically, mineral resources are not 'income,' but rather converted capital, from natural to financial capital.
[30] E.g. Ross (2013) argues that petroleum wealth has played a role in the subjugation of women's rights.

statistical arguments (Brunnschweiler and Bulte, 2007; Davis, 2011, 2013). However, there is no disagreement that low- and mid-income states reliant on natural resource exports usually do not experience the grand improvements to their national wellbeing that they had anticipated, and do often instead experience unexpected and unwelcome economic impacts.

Governance considerations have in general had much less space in the comparative academic literature than economics, due to the difficulty in identifying, gathering and interpreting governance indicators, as opposed to economic indicators; nevertheless, the range of possible ill effects is very broad (Karl, 1997). One global study, for example, suggests that oil-rich countries are less democratic and less politically stable, with more frequent wars (Ross, 2013). In short, economic and environmental ill effects of resource wealth (Karl, 1999) are greatly exacerbated by weak institutions and governance,[31] which could indeed be the deciding factors (Lane and Tornell, 1996; Mehlum, Moene, and Torvik, 2006).

1.6.2 Developing states and DSM

While all states experience governance challenges, the good governance of new industries and associated environmental protection can be particularly difficult for small and medium-sized developing countries. The developing states engaged as *sponsoring states* for DSM in ABNJ are generally Pacific island countries, which have small land mass, populations and administrations.[32] For example, Tonga and Kiribati each have populations that just exceed one hundred thousand; the Cook Islands has a population of only about eleven thousand citizens; Nauru has less than ten thousand. Public consultation, publication of government policy, decisions and practices, and administrative and judicial oversight mechanisms have not been common practice in the Pacific. There have been past allegations and instances of corruption, poor financial management, or simply bad decision-making by senior officials, resulting in Pacific Island citizens failing to see improved economic development from natural resource extraction in their countries (Chene, 2010). Additionally, these states are vulnerable to natural disasters, political instability, 'clientelism',[33] poor IT capabilities and access to the internet, and often limited previous experience in mineral / natural resource management (Chene, 2010; Lily, 2016).

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[31] Sachs & Warner (1997), Table XI, present evidence that resource abundant countries have significantly poorer scores on a variety of measures of institutional quality. This result is successfully replicated by Davis (2013). However, neither paper explores this correlation further or attempts to control for it, focussing instead on the presence of natural resources. See also Torres et al. (2013).

[32] The exceptions are Singapore and China –both of which have sponsored ISA applications as self-declared 'developing countries.' In 2020, Jamaica sponsored an as-yet unapproved application as well.

[33] Clientelism is the exchange of goods and services for political support, often involving an implicit or explicit quid-pro-quo. (Stokes et al., 2003)

From 2011 to 2016, the EU-funded Pacific Deep Sea [sic] Minerals Project, run by the Secretariat of the Pacific Community, helped build some regulatory and governance capacity in 15 Pacific Island Countries,[34] though notable gaps still remain (Lily, 2016).[35] Even though the effort required from a (small or medium-sized state) government to properly prepare the governance structures for DSM is considerable, it is not insurmountable, as evidenced by the example of the Cook Islands, which has developed a bespoke authority, conducted stakeholder consultations, and is taking a holistic approach to managing its entire ocean space of approximately two million km^2 (Petterson & Tawake, 2019; cf. Waiti & Lorrenij, 2018). Conversely, the risks of not properly preparing for DSM are considerable, as illustrated below.

1.6.3 Nautilus Minerals Inc.: a case study

In 2011, Nautilus Minerals Inc. (henceforth, Nautilus) entered into a joint venture agreement (**JVA**) with the Government of Papua New Guinea (**PNG**) to mine two SMS sites within its territorial waters –as part of PNG granting the world's first DSM *exploitation* licence (Miller et al., 2018).[36] However, despite promising beginnings,[37] execution of the (confidential) agreement soon ran into difficulties and was sent to arbitration, which in 2013 was found in Nautilus' favour with PNG ordered to pay approximately USD 118 million owed, including interest.[38] About one year later, after further negotiations, USD 113m was paid by PNG to Nautilus as constituting a 15% JVA interest in the *Solwara 1* project up to first production.[39] However, the expected production date was pushed back several times, for various political, financial, and technical reasons.[40] (Although

[34] The Cook Islands, Federated States of Micronesia, Fiji, Kiribati, Marshall Islands, Nauru, Niue, Palau, Papua New Guinea, Samoa, Solomon Islands, Timor Leste, Tonga, Tuvalu and Vanuatu.
[35] The SPC- EU Deep Sea Minerals Project website: https://dsm.gsd.spc.int/ [Accessed Dec. 2019.]
[36] Atlantis II, initiated in the Red Sea in the 1970s, was apparently granted an exploitation license, though little information is available. Despite various announcements, it has not proceeded, apparently due to legal disputes (Miller et al., 2018).
[37] Nautilus press releases, 16 Dec. 2010: http://www.nautilusminerals.com/irm/PDF/993_0/NautilusMineralsIntersectsMoreHighGradesatDepth [Accessed Dec. 2019.] and 25 Nov. 2011: http://www.nautilusminerals.com/irm/PDF/1010_0/NAUTILUSINCREASESMINERALRESOURCES [Accessed Dec. 2019.]
[38] Nautilus press release, 03 Oct. 2013: http://www.nautilusminerals.com/irm/PDF/1136_0/NautilusMineralsAwardedFavourableArbitrationDecision [Accessed Dec. 2019.]
[39] Nautilus press release, 11 Dec. 2014: http://www.nautilusminerals.com/irm/PDF/1455_0/US113millionreleasedtoNautilusandSolwara1JVformed [Accessed Dec. 2019.]
[40] Various Nautilus press releases explaining progress and set-backs: http://www.nautilusminerals.com/IRM/ShowCategory.aspx?CategoryId=311&FilterStyle=B&archive=true&masterpage=31&year=2014&RID=291 [Accessed Dec. 2019.]

environmental concerns were being expressed by some civil society organisations, they do not appear to have been responsible for the delays.[41])

Similar to nodules, initial estimates of global SMS metal abundance from hydrothermal vents were very optimistic. Subsequently, however, estimates of deposits of potential commercial interest became much more conservative, and consequently less appealing to investors, with one peer-reviewed estimate putting the total global (unproven) resources of copper and zinc from vent sites worldwide to be only slightly more than the *one year's production* of these metals from land-based mines (Hannington et al., 2011). In PNG, the 1.54 mega-tonne inferred mineral resource ore estimate for Solwara 1 and 0.23 mega-tonnes for Solwara 12 (Golder Associates, 2012, Tables 1 & 2) would be enough for perhaps one or two years of commercial mining activity –unlikely to produce much if any profits to be shared with the Government of PNG, if the capital expenditures on the new DSM machines and the new ship (leased) were to be paid down first. Furthermore, in the years following the JVA, no other potentially commercial-sized SMS sites were announced by Nautilus –in PNG or elsewhere– leaving the long-term viability of the company itself open to conjecture.[42]

In 2019, after two years of struggling to secure additional financing, Nautilus filed for creditor protection.[43] Four of its five Directors resigned,[44] the company was delisted from the Toronto Stock Exchange, and a 'plan of compromise and arrangement' was approved.[45] Assets were liquidated, and in November 2019, Nautilus Minerals was declared bankrupt.[46] After settling with Nautilus' creditors, Deep Sea Mining Finance Ltd. (a company created in 2017 by the two largest shareholders of Nautilus: Russian mining company Metalloinvest and Omani conglomerate MB

[41] E.g. the Deep Sea Mining Campaign: http://www.deepseaminingoutofourdepth.org/nautilus-solwara-1-seabed-mine-is-an-experiment/ [Accessed Jan. 2020.]
[42] The Economist, 6 Dec. 2018: https://www.economist.com/business/2018/12/06/a-high-profile-deep-sea-mining-company-is-struggling [Accessed Dec. 2019.]
[43] Nautilus Minerals press release, 22 Feb. 2019: http://www.nautilusminerals.com/irm/PDF/2078_0/NautilusfilesforreliefundertheCCAAandreceivesadditionalloanundersecuredloanfacility [Accessed Dec. 2019.]
[44] Nautilus Minerals press release, 03 Apr. 2019: http://www.nautilusminerals.com/irm/PDF/2086_0/NautilusMineralschangeindirectorsandofficers [Accessed Dec. 2019.]
[45] http://www.nautilusminerals.com/irm/PDF/2096_0/Nautilusobtainscourtapprovalofplanofcompromiseandarrangement [Accessed Dec. 2019.]
[46] Price Waterhouse Cooper, in its capacity as Court-Appointed Monitor of the Petitioners, under Companies' Creditors Arrangement Act (Canada) regarding Nautilus Minerals, status as of 21 Nov. 2019: https://www.pwc.com/ca/en/services/insolvency-assignments/nautilus-minerals-inc.html [Accessed Dec. 2019.]

Holdings[47]) acquired the remaining Nautilus assets, but not its liabilities. The fate of the USD 113m invested by PNG into the now bankrupt joint venture remains unconfirmed, but newspaper accounts suggested it was lost completely. In a 2019 interview with PNG Prime Minister James Marape, he characterised the project as “a total failure.”[48]

In hindsight, there were governance shortcomings concerning the available laws, internal decision-making, lack of PNG government transparency,[49] and difficulties surrounding social engagement and buy-in. Under PNG’s Mining Act, which was applied holus-bolus to DSM, the Minister was free to enter into a financial agreement with the mining company (PNG, 1992, art. 17). However, this legislation designed for the much more mature terrestrial mining industry could not anticipate the riskier nature of DSM, and consequently had no internal or public review mechanism for this part of the decision-making process. Because all JVA and license arrangements were treated as confidential, neither local governments nor civil society were able to adequately access or assess the arrangements being made for this new industry in their neighbouring waters.[50] In 2017, legal proceedings were launched against the PNG Government by a civil society organisation on behalf of some of the coastal communities in an attempt to attain information on the approval and permitting process.[51] Meanwhile, attempts by Nautilus to gain ‘social license’ amongst these same local communities who were unfamiliar with, and often wary of, DSM ended up being seen by some as being an attempt to ‘manufacture’ this consent through the creation of a new advisory body that circumvented problematic actors (Filer and Gabriel, 2018).

When the JVA with PNG was being finalised, Nautilus share prices exceeded CAD 3.00. Eight years later, they were worth a Canadian nickel (CAD 0.05),[52] underlining that DSM remains a risky venture for investors and partnering countries alike, with success far from guaranteed.

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[47] BankTrack website investor alert, 25 Oct. 2017: https://www.banktrack.org/article/investor_alert_deep_sea_mining_project_in_lastditch_search_for_capital [Accessed Dec. 2019.].

[48] The Guardian newspaper 15 Sept. 2019: https://www.theguardian.com/world/2019/sep/16/collapse-of-png-deep-sea-mining-venture-sparks-calls-for-moratorium [Accessed Dec. 2019.] In May 2019, the previous Prime Minister Peter O’Neill had also taken pains to distance his government from the one that had signed, calling it “…a deal that should not have happened.” https://postcourier.com.pg/pm-labels-solwara-venture-wasted-investment/ [Accessed Jan. 2020.]

[49] Nautilus, as a publicly listed company on the Toronto Stock Exchange, appears to have abided by its reporting requirements, regularly issuing bulletins / press releases.

[50] The Solwara sites in the Bismarck Sea are bounded by New Ireland and New Britain (Golder Associates, 2012, Figure 2). Legally, the sites were beyond the 12 nautical mile territorial sea, and thus under the national government’s jurisdiction. However, local communities and governments were both concerned about possible impacts on fishing and expected to receive a share of the revenues (Filer and Gabriel, 2018).

[51] https://www.edonsw.org.au/deep_seabed_mining_png [Accessed Jan. 2020.] (There is no follow-up on the website regarding whether the attempt to access this information succeeded.)

[52] Share prices from: https://www.investing.com/equities/nautilus-minerals-inc.-historical-data [Accessed Dec. 2019.]

In the concluding paragraph of his 2000 *Science* article on DSM, G.P. Glasby penned words that were, unfortunately, prescient:

> "This brief history shows how false economic forecasts and poorly designed laws based on overoptimistic assessments ultimately led to much wasted effort and money in an attempt to mine deep-sea minerals [nodules]. Hopefully, the advent of a new phase of exploration for submarine hydrothermal deposits [SMS] will not result in the same mistakes in the future." (Glasby, 2000, p553)

1.7 Research question

The thesis seeks to identify, and elaborate upon, DSM policy-science factors critical to both good governance and the minimisation of harm to the marine environment. It presumes that the widely held goal of minimising harm to the environment cannot be achieved without good governance and the development of appropriate DSM rules and regulations. The intent behind the research question is not to produce a lengthy list of elements said to ensure good governance or good protection of the marine environment –such analyses already exist in abundance (e.g. Wilkinson, 2005; Jentoft, van Son & Bjørkan, 2007; Weiss, 2012; Rife et al., 2013; Edgar et al., 2014). Rather, it is to identify just a few key 'bridges' or 'leverage points' that while likely insufficient on their own, will nevertheless be critical in this particular situation.

<u>Research question</u>*: In the development of rules and regulations for deep-seabed mining in the Area beyond national jurisdictions, what policy and science elements will be amongst the most critical to ensure good governance that minimises harm to the marine environment, particularly serious harm?*

Definitions for terms used in the above question are described in the next section.

1.8 Key definitions and commentary

1.8.1 Deep-seabed mining

For the purposes of this research, DSM shall be defined as commercial exploitation of the seabed for solid minerals and metals (i.e. not petroleum or methane hydrates) in waters deeper than 500 m, within and beyond national jurisdictions. The 500 m cut-off, which is deeper than commonly used to describe the biological 'deep sea' (e.g. Gage & Tyler, 1991, who suggest 200 m), was chosen to distinguish the subject of this study from mining for aggregates, phosphorite, and diamonds on continental shelves (in places deeper than 200 m). Though many of the same good governance ingredients may also be applicable to these shallower-water operations, the deep sea is considered separately because: a) it constitutes different mineral resources and marine ecosystems than those found in shallower waters; b) there has been renewed international interest in this form of deeper mining; c) it spans both national jurisdictions and the legal *Area* beyond national jurisdictions, making it a distinct legal and policy research topic with global implications; and d) commercial DSM has not yet occurred, with exploitation regulations now being formulated.

1.8.2 Policy-science elements

These are policy considerations that have strong linkages to scientific practices and knowledge. Here, 'policy' is used broadly to encompass LTC *guidance* (which is treated by the ISA like *rules* (Bräger et al., 2020)) as well as elements of the ISA draft *regulations*, though the latter are, strictly speaking, legal elements.

1.8.3 Good governance

Governance is a broad term that encompasses those entities vested with authority, such as governments, corporations, societal organisations, and tribal groupings. The Institute on Governance suggests that most definitions of governance have the following common elements: "…who has power, who makes decisions, how other players make their voice heard and how account is rendered."[53] *Good governance*, although a fairly recent term, is not new conceptually. Western notions of good governance, particularly concerning the relationship of a ruling body with the populace can be found in the writings of John Locke (1632-1704) and Jean-Jacques Rousseau (1712-1778). Rousseau's views expressed in *On The Social Contract* continue to resonate today with regard to the tension between high seas 'freedoms' and obligations associated with shared seabed mineral resources (Rousseau, 2012 (orig. 1762)).[54] In Eastern

[53] https://iog.ca/what-is-governance/ [accessed Dec. 2019].
[54] Rousseau distinguishes between *possession* (what could be called 'finders keepers') from *property* (ownership recognised by society) −a distinction relevant to ABNJ and deep-sea mining. Throughout this work, he criticises the earlier views of Grotius (now best known for his treatise on the freedom of the seas – *Mare Liberum* (1609)) who viewed authority and possessions gained from strength as self-evident −a legal 'might is right' argument. Rousseau, however, took a different view: "What man loses by the social contract is his natural liberty and an unlimited right to everything he tries to get and succeeds in getting; what he gains is civil liberty and the proprietorship of all he possesses. If we are to avoid mistake in weighing one against the other, we must clearly distinguish natural liberty, which is bounded only by the strength of the individual, from civil liberty, which is limited by the general will; and possession, which is merely the effect of force or the right of the first occupier, from property, which can be founded only on a positive title." (pp 14-15) With regard to the high seas, the Grotian freedom of the sea argument still largely prevails (e.g. in fisheries); however, in ABNJ Rousseau's vision appears to have taken hold.

thought, good governance can be traced to at least 300 B.C. to a treatise on governance[55] known as the *Arthashastra*, which emphasises justice, ethics, and thoughtful decision-making (Olivelle, 2012). Firmly embedded in time and place, the ideal of *good governance,* continues to evolve, including at the level of the United Nations (Weiss, 2000). Elements now generally accepted, such as participatory decision-making, transparency, and accountability of governments, arose to prominence only in the latter twentieth century, and continue to pose challenges to earlier international governance structures created to manage shared natural resources such as fish and minerals in ABNJ (Ardron et al., 2014a; as well as the Chapters herein.) Furthermore, an adaptive management approach has also in recent years become part of the recommended good governance of DSM (e.g. Allen et al., 2011; Miller et al., 2018; Jones et al., 2018). Adaptive decision making relies upon reliable scientific monitoring data and results, as well as good experimental design (Walters, 1986). However, the limited legal and institutional tools available to the ISA will make adaptive management challenging, requiring forethought (Craik, 2020).

1.8.4 Serious harm

A legal term of art under UNCLOS, the ISA must take actions to prevent 'serious harm' to the marine environment, but which is limited to rejecting mining applications and suspending operations already underway (UNCLOS, art. 162(2)(w)(x), 165(2)(k)(l)). However, UNCLOS does not define this critical term.

The regulatory necessity of defining *serious harm* has been long recognised. The earliest definition can be found in the 1990 draft regulations, drafted by the Preparatory Commission before the ISA had even begun its operations:

> "*Serious harm to the marine environment* means any effect from activities in the Area on the living or non-living components of the marine environment and associated ecosystems beyond that which is negligible or which has been assessed and judged to be acceptable by the Authority pursuant to these regulations and the relevant rules and regulations adopted by the Authority and which represent:
>
> (a) significant adverse changes in the living and non-living components of the marine and atmospheric environment;
>
> (b) significant adverse changes in the ecosystem diversity, productivity and stability of the biological communities within the environment; or

[55] Attributed to a king, it may actually have had several authors (Olivelle, 2012).

(c) loss of scientific or economic values which is unreasonable in relation to the benefit derived from the activity in question."

(ISA Preparatory Commission, 1990, art. 2(2))

In this early definition, the sub-sections, particularly (a) and (b), would have naturally led to the monitoring of particular indicators of the ecosystem's health; i.e., abundance, diversity, productivity, and stability (variation over time), using a mix of appropriate metrics such as are considered in Chapter 4.

Thirty years later, the ISA definition, interpretation and regulation of *serious harm* is still under discussion, with a divergence of views still being expressed.[56] However, the definition currently under discussion lacks the specificity of the earlier one, relying instead on rules, regulations and procedures yet to be adopted by the ISA:

"*Serious Harm* means any effect from activities in the Area on the Marine Environment which represents a significant adverse change in the Marine Environment determined according to the rules, regulations and procedures adopted by the Authority on the basis of internationally recognized standards and practices informed by Best Available Scientific Evidence." (ISA, 2019a)

Though shorter than the 1990 version, this draft definition, if it stands, will be more difficult to operationalise due to the lack of readily interpreted measurables contained within its language. Here, *serious harm* is framed as 'a significant adverse change', but is not defined any further. The word *significant* is likely intended to mean "sufficiently great or important to be worthy of attention; noteworthy,"[57] rather than relating to statistical significance, though this is not

[56]This ongoing divergence of views is summarised in Pew (2019; p21): "The African Group requested more information on the source from which the ISA derives its definition of 'serious harm' and the basis on which the term was defined. The UK agreed that the term should be clarified. Germany suggested reference to the 'serious harm' guidelines issued by the Food and Agricultural Organization. MSI [Mining Standards International] suggested that a distinction be drawn between harmful consequences of approved mining operations that have been scientifically evaluated and 'serious harm' beyond that which was approved or authorised. NORI [a DSM contractor] urged that serious harm not be defined in such a way that the definition precludes the approval of virtually any variety of exploitation. NORI noted the importance of the scale of any harm, e.g. regionwide harm as opposed to harm confined to the vicinity of mining operations. GSR [a DSM contractor], supported by NORI, recommended that 'unlawful harm' be the term that denotes harm exceeding what was foreseen in the Contractor's approved Plan of Work. TOML [a DSM contractor] proposed that 'harmful effects' should only describe damages that 'significantly exceed those permitted under the exploitation contract.' Belgium sought clarification of the threshold for 'serious damage' to property under DR 48(2), as do PDOD [Center for Polar and Deep Ocean Development] and Neptune. DSCC [a coalition of environmental NGOs] said 'significance' should be elaborated."

[57] Definition derived from the Oxford English Dictionary, accessed through: https://www.lexico.com/definition/significant [Accessed Jan. 2020.]

explicitly stated. The vagueness of this and other (draft) definitions suggests the importance of the as-yet unreleased environmental standards and guidelines to clarify how ‘a significant adverse change’ might be recognised and how ‘Best Available Scientific Evidence’[58] might be collected and evaluated.[59]

As considered in Chapter 4, the ramifications of not detecting harm before it becomes ‘serious’ to marine biodiversity could be extensive. In the only paper devoted to this question on *serious harm*, from a biological / ecological perspective, Levin et al. (2016) suggest that *serious harm* for all kinds of DSM would likely include any or all of the following: i) resuspension and deposition of sediments over large spatial scales causing a substantial change to the existing ecosystem; ii) impacts that may persist for decades to centuries; iii) loss of much of the hard substrate habitat, as well as the specialized fauna; and, iv) the extinction of hundreds or more of undescribed species, especially those with small biogeographic distributions. Clearly, this broad scope will need further refining and defining before these possible harms can be monitored and assessed.

Legally, applications for exploitation may be disapproved “where <u>substantial evidence</u> indicates the risk of serious harm to the marine environment” (UNCLOS, art. 162(2)(x), 165(2)(l)); underlining added). If there are regulations taking into account anticipated cumulative impacts of an additional new operation before it has begun,[60] the stringent UNCLOS article on *serious harm* could possibly be invoked at the application stage of the process. More likely than outright rejection, however, is the eventuality that applicants will be asked to revise certain aspects of their proposed plans to reduce a variety of anticipated harms, but not necessarily just *serious harm* –as is typical of an EIA process (Clark et al., 2020). Once DSM is underway, the only time when *serious harm* can be invoked is as an ‘emergency order’, which “…may include orders for the suspension or adjustment of [ongoing] operations, to prevent serious harm to the marine environment arising out of activities in the Area” (UNCLOS, art. 162(2)(w), 165(2)(k))). Presumably, the urgent nature of an *emergency order* would make it unlikely in all but the most

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[58] The draft definition of which is: “’Best Available Scientific Evidence’ means the best scientific information and data accessible and attainable that, in the particular circumstances, is of good quality and is objective, within reasonable technical and economic constraints, and is based on internationally recognized scientific practices, standards, technologies and methodologies.” (ISA, 2019a)
[59] ‘Best Available Scientific Evidence’ is one of a collection of capitalised ‘Best’ terms being used in the draft regulations, the others of which are: ‘Best Available Techniques’ and ‘Best Environmental Practices’. Uncapitalised usages include, ‘best practices’, ‘best endeavours’, and one example each of ‘best efforts’ and ‘best available scientific results’ as suggested additions made by the ISA Council (ISA, 2019a).
[60] The ISA Council recommended inserting cumulative impacts into several places of the draft regulations, including 13(4)(e), suggesting that cumulative impacts could be sufficient cause to reject an application (ISA, 2019a). Also noteworthy, cumulative impact assessment is anticipated in guidance prepared by the LTC in 2013, and links it with the provision of data: “In addition to analyses of the data, raw data should be provided in electronic format with annual reports as agreed with the secretariat. These data will be used for regional environmental management and assessment of cumulative impacts.” (ISA, 2013b, para. 16).

extreme and pressing circumstances. (Though, the requirement for 'substantial evidence' is not present in these articles, thus potentially lowering the evidentiary requirements.) Therefore, if minimising the harm caused by non-emergency day-to-day DSM operations is seen as desirable, it will require regulatory measures that do not exclusively rely upon proving *serious harm*. Nonetheless, even if *serious harm* is the only regulatory benchmark used, monitoring of it will still need to detect less-than-serious harm in order to provide an 'early warning' that *serious harm* may be imminent. What this might entail is further explored in Chapter 4.

Ultimately, the definition of *serious harm* will be up to the regulator, the ISA. However, as argued in the ensuing chapters here, that ISA decision should be informed by open inclusive discussions with stakeholders, transparent use of scientific evidence, and the careful selection of metrics and monitoring design to provide sufficient sensitivity to detect environmental impacts arising from proximate mining operations, *before* they become serious.

1.9 The chapters ahead

In researching the policy-science interface of DSM, the limited transparency of ISA governance, including contractor data, financial arrangements, reporting and compliance, were found early on in the research to be recurring obstacles, which in turn raised research questions of their own. Therefore, Chapters 2 and 3 are devoted to examining the topic of ISA transparency in greater detail, through comparing the practices of the ISA to other institutions with similar responsibilities. Until 2020, these chapters were the only peer-reviewed assessments of the ISA's practices regarding transparency.[61] As discussed in Chapter 5, these papers appear to have made some impact, with some improvements now being considered in the future exploitation regulations.

Although transparency alone is insufficient to achieve environmental protection, scholars do broadly agree that effective scientific monitoring is a necessary component of resource governance if harm to the marine environment is to be minimised; and furthermore, if an adaptive management approach is to be taken (e.g. Allen et al., 2011; Miller et al., 2018; Jones et al., 2018; Clark et al., 2020; Craik, 2020). However, very little specific advice exists by the ISA on what effective DSM monitoring might look like. Existent ISA guidance at the time this research began, and still now, only notes the need for statistical reliability, but without elaborating what

[61] Notwithstanding the valuable reports commissioned by the ISA around the same time, which also addressed some aspects of its transparency (Seascape Consultants, 2104, 2016a, 2016b).

this might entail (ISA, 2013b).[62] Therefore, Chapter 4 concentrates on this question of statistically reliable monitoring, focussing on impacts on benthic megafauna by neighbouring nodule mining as an example, in order to arrive at some preliminary findings. Published less than one year ago, it is still too early to determine the effect that this publication may have on the ISA. Instead, Chapter 5 looks at the three environmental impact assessments that to date have been submitted to the ISA, and whether these meet the statistical rigour suggested in Chapter 4 as necessary to detect ecosystem impacts before they become 'serious.'

This thesis is structured as outlined below. Chapters 2, 3, 4, and all three appendices have been published in the peer-reviewed literature.

Chapter 2: *Transparency in the operations of the International Seabed Authority: An initial assessment* (Ardron, 2018). This chapter examines 32 indicators of transparency applied to the ISA. The objective of this research was to compare the practices of the ISA to those of regional fisheries management organisations (RFMOs), which also operate in ABNJ, to establish whether there were any notable differences. Adapting the methodology developed by Clark et al. (2015; where I am second author), this chapter looks at the basic elements of transparency which are already being practiced by (some of) the RFMOs. However, this was the first time that ISA had been compared to the RFMOs, and some ISA members later questioned whether the comparison of DSM management to fisheries management was justifiable (pers. comms.).

Chapter 3: *Incorporating transparency into the governance of deep-seabed mining in the Area beyond national jurisdiction* (Ardron, Ruhl, & Jones, 2018). Given the reluctance of some ISA members to accept the Chapter 2 comparison to fisheries management, the objective of this chapter was to provide a closer examination of global good governance practices in transparency relevant to natural resource extraction more generally, nationally and internationally, including terrestrial mining, as compared to existing practices of the ISA. Here, widely recognised and relevant standards, such as the International Marine Minerals Society (IMMS) *Code for Environmental Management of Marine Mining* (IMMS, 2011), and the OSPAR *Code of Conduct for Responsible Marine Research in the Deep Seas and High Seas of the OSPAR Maritime Area* (OSPAR, 2008), were used to develop a more nuanced understanding of what practices across related sectors are appropriate to the governance of DSM, and therefore, to the ISA. Like Chapter

[62] Further discussed in Chapter 5, this thesis research has fed into greater ISA awareness, and subsequently some limited guidance, on this question.

2, this was the first such research on the topic. As discussed in Chapter 5, the current ISA Secretary-General, after succeeding his predecessor, made improved transparency one of his strategic priorities.

Chapter 4: *Detecting the Effects of Deep-Seabed Nodule Mining: Simulations Using Megafaunal Data from the Clarion-Clipperton Zone* (Ardron, Simon-Lledó, Jones, and Ruhl, 2019). Here, using good quality megafaunal data, and building on the morpho-taxonomy by (then) fellow Southampton PhD student, Dr Erik Simon-Lledó (second author), the objective was to perform a numerical simulation and statistical power analysis of plausible DSM impacts to benthic megafauna in areas neighbouring mining operations. This was the first (and still only) simulation of DSM impacts using actual data from an area with characteristics that could plausibly be situated next to a proposed mining area –in this case, in the Clarion-Clipperton Zone. Chapter 4 provides some initial conclusions regarding statistically robust monitoring design, and explores the relative merits of commonly used measures related to 'biodiversity'.

Chapter 5: *Epilogue.* This chapter is a discussion of the governance context while the thesis was being researched, how some of its work may have already affected development of the ISA's exploitation regulations, and how this thesis research may continue to be helpful in ISA deliberations. It looks at the three environmental impact assessments (**EIA**s) that the ISA has received to date, and suggests that they may be falling short of meeting sufficient statistical robustness, as required by the ISA, and as explored in Chapter 4. Furthermore, the ISA's handling of the first two EIAs raises further questions concerning transparency and good decision making. Boiling down all the recommendations made in this thesis, the Epilogue posits three simple 'rules of thumb' for contractors and researchers alike, as well as looking at possible future research.

Appendix A: *Environmental considerations for impact and preservation reference zones for deep-sea polymetallic nodule mining* (Jones, Ardron, Colaço, & Durden, 2020 (online 2018)). For this supplementary paper, I am second author with one of my supervisors as the lead. It looks at the design of DSM monitoring more generally, and how good scientific practices could translate into good policy practices. It sets the necessary context for Chapter 4, which was written afterwards.

Appendix B: Chapter 3 supplementary materials

Appendix C: Chapter 4 supplementary materials, including R code

Chapter 2 Transparency in the operations of the International Seabed Authority: an initial assessment

This chapter was originally published as: Ardron, J. A. 2018. (Online 2016.) Transparency in the operations of the International Seabed Authority: an initial assessment. Marine Policy 95:324-331. *Because Chapters 2-4 were published separately, there is some repetition of background information.*

2.1 Abstract

In the governance of natural resources, transparency is widely viewed as desirable, in order to avoid ill effects including corruption and inequities in the benefits derived from the resources. This paper considers the International Seabed Authority (**ISA**), which is charged with managing deep seabed mining in the Area beyond national jurisdictions as part of the common heritage of humankind. The methodology of this assessment follows that of Clark et al. (2015) in their assessment of Regional Fisheries Management Organisations (**RFMOs**) using a battery of 34 scored questions, of which 30 were found applicable to this study. Two additional questions specific to the ISA are also considered. This assessment finds that while the ISA exhibits some good transparency practices, it generally scores much lower than the high seas fisheries management bodies. Across the three evaluation categories, concerning availability of information, participation in decision-making, and access to outcomes, the ISA's overall score was found to be 44%, as compared to 77% for the RFMOs. The current practices of RFMOs may therefore serve as examples of how specific operations of the ISA could be improved. It is suggested that the ISA needs to develop concrete policies concerning transparency, including: to presume that information is non-confidential unless otherwise determined; to make mining contracts publicly available; to allow observer access to pre-determined portions of the Legal and Technical Commission, and Finance Committee meetings; and, to publish annual reports of the Contractors' activities, including compliance in seabed exploration and exploitation operations and their associated environmental impacts.

2.2 Introduction

Transparency is widely recognised as a necessary component of good governance, in state governments as well as international institutions (Nye, 2001; Hollyer et al., 2011; Ardron et al., 2014a). The link between (non-) transparency and corruption is seen as an ongoing issue, and forms the core research of well-established non-governmental organisations, including Transparency International,[63] the Natural Resources Governance Institute,[64] and the U4 Anti-Corruption Resource Centre.[65] In the extractive resource industries in particular, transparency is emphasised with regard to improving governance ills (Eigen, 2006). In the concluding chapter of the comprehensive multi-authored book, *Escaping the Resource Curse,* the editors highlight the recurring importance of transparency as an "important step to resolving the multiple problems emanating from oil and gas holdings" (Humphrey et al., 2007; p357). As a first step, transparency is seen as a necessary (but alone insufficient (Stevens et al., 2015)) condition toward achieving political, fiscal, and environmental accountability in natural resource governance (Kolstad and Wiig, 2007). Naturally, many other factors, especially strong institutions, will play a role in the good governance of natural resources (Mehlum et al., 2006). However, without transparency, the details concerning allocation of national natural resources to private operators, ensuing environmental impacts, and regulatory compliance, will remain unknown and those responsible unaccountable.

In what is known as the Area beyond national jurisdictions under the United Nations Convention on the Law of the Sea (**UNCLOS**, 1982), all rights in the resources are vested in humankind as a whole, on whose behalf the International Seabed Authority (ISA) acts (UNCLOS, art. 137(2)). Financial and other economic benefits derived from activities in the Area, including deep-seabed mineral mining (DSM mining), shall be shared equitably by the ISA, again for the benefit of humankind (ibid. art. 157(1), 140(1); Bourrel et al., 2018[66]).

The ISA came into existence in 1994, upon the entry into force of UNCLOS, and became fully operational as an autonomous international organisation in 1996. UNCLOS (art. 154) requires the ISA Assembly to undertake every five years "a general and systematic review of the manner in which the international regime of the Area established in this Convention has operated in practice." Despite this requirement, the first ISA review has only just begun, in part because DSM

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[63] http://www.transparency.org/ [Accessed July 2020.]
[64] http://www.resourcegovernance.org/ [Accessed July 2020.]
[65] https://www.u4.no/ [Accessed July 2020.]
[66] Bourrel et al. appeared in the same special issue as this article, online in 2016, in print 2018.

mining as a commercially viable industry has been much slower to develop than was anticipated at the time that UNCLOS was negotiated. An interim report commissioned to independent consultants is expected for consideration by the ISA Assembly at its twenty-second session in July 2016 with the final report due in 2017.[67]

As tracked by Ardron et al. (2014a), transparency as a principle of governance began to enter into the general discussions of international marine management organisations (mainly fisheries bodies) starting in the mid- to late 1990s. In the case of fisheries, the Food and Agricultural Organization of the United Nations voluntary *Code of Conduct for Responsible Fisheries* was finalised in 1995, and states that, "States and subregional or regional fisheries management organizations and arrangements should ensure transparency in the mechanisms for fisheries management and in the related decision-making process" (FAO, 1995, art. 6(13), 7(1)&(9)). Similar language is included in the binding 1995 United Nations Fish Stocks Agreement, which says that, "States shall provide for transparency in the decision-making process and other activities of subregional and regional fisheries management organizations and arrangements"(UNGA, 1995), which is reiterated in subsequent UN General Assembly Resolutions (e.g. UNGA, 2009). For DSM mining, however, there have not been similar international drivers towards transparency. After reviewing ISA Assembly documents (available from 2000 to 2013), Ardron et al. (2014a) note that the ISA, "seldom or never mentioned transparency..." (p182). Of the 14 global and regional marine treaty bodies examined in that study, the ISA reportedly discussed transparency least of all (ibid.).

In this paper, the ISA's practices are for the first time assessed for their transparency, and are compared with the high seas fisheries sector also operating in areas beyond national jurisdictions. In the past decade, high seas fisheries management bodies have come under increasing scrutiny and criticism from civil society,[68] as well as academics (Cullis-Suzuki and Pauly, 2010), which has arguably played a role in their reform, albeit with many issues still outstanding (Weaver et al., 2011). This assessment of the ISA, it is hoped, will inform the work of the ongoing ISA review, as well as the development of its exploitation regulations. The improved policies of the high sea fisheries bodies can provide examples to the ISA of where changes may be feasible, or in some cases necessary, while being aligned with international good practices.

[67] Subsequent to publication of this paper, they have been published: Seascape Consultants (2016a, 2016b).
[68] E.g. the many publications of the High Seas Alliance: http://www.savethehighseas.org/resources/publications/ [Accessed July 2020.]

2.3 Methods

The assessment follows, as far as possible, the questions and scoring system laid out by Clark et al. (2015), which were used to examine basic elements of transparency in the operations of regional fisheries management organisations (RFMOs[69]). Although no assessment of transparency across RFMOs had been performed before, there were other RFMO assessments which included elements of transparency, from which the authors drew inspiration for many of their questions. As described in their paper, these included mainly, Lodge et al. (2007), Cullis-Suzuki and Pauly (2010), and Gilman and Kingma (2013). Reflecting the three pillars of the Aarhus Convention on Access to Information, Public Participation in Decision-Making and Access to Justice in Environmental Matters (Aarhus Convention, 1998), the authors divided their questions into three broad categories, which will be followed here: i) availability of data and basic information; ii) public participation in decision-making; and iii) access to outcomes and justice. The questions were revised several times as their analysis progressed and new information came available. The scoring system they developed deducts points (negative scores) in some cases, as can be seen, for example, in questions (Q) 1 and 2 in **Table 2-1**, in the next section. Points are deducted when the organisation does not adhere to what the authors, based on their literature review, viewed as established best practices, which in the case of Q 1 & 2 mean having a website and posting on it general contact information.

Of the 34 questions posed in the Clark et al. (2015) study, four are deemed not applicable to the ISA in its current stage of development, and are noted below. Two new questions were created to address other issues relevant to the ISA.

Unless otherwise noted, the resultant scores are derived from reviewing the ISA web site,[70] the operational rules of the ISA bodies,[71] the ISA *Mining Code*[72] (henceforth to be used as a shorthand for the collective body of regulations already in place, concerning mineral exploration), as well as UNCLOS (1982) and its 1994 Implementing Agreement (Part XI Agreement, 1994). Following the methods of Clark et al. (2015), the ISA secretariat was contacted for a factual review, and to answer specific questions not found on the web site. Unlike the Clark et al. (2015) study, which

[69] The study also included the International Whaling Commission (IWC) and the Commission for the Conservation of Antarctic Marine Living resources (CCAMLAR); however, for simplicity of language, this paper will refer to them all as RFMOs.
[70] ISA website: https://www.isa.org.jm/ [Accessed July 2020.]
[71] Individual rules will be referenced separately, but all rules of the ISA “organs” can be found here: https://www.isa.org.jm/legal-instruments [Accessed July 2020.]
[72] Individual articles will be referenced separately, but the collected Mining Code can be found here: https://www.isa.org.jm/mining-code [Accessed July 2020.]

looked at 11 organisations, this study considers only one, and thus further explores the rationale behind the scores assigned to the questions as well as producing recommendations specific to the ISA.

2.4 Results

2.4.1 Availability of data and basic information

The questions in this section can be sub-divided into two sub-themes: access to general information (**Table 2-1**, Q 1-4), and access to data (**Table 2-1**, Q 5-9, excluding 6). The ISA, like many RFMOs, received full marks on access to general information. However, regarding access to data, the ISA received only three out of a possible eight points, on par with the lowest-scoring RFMO.

Though the ISA does provide up-to-date maps of the contracted exploration areas (**Table 2-1**, Q 5 & 8), its 'Central Data Repository' does not contain any data from contractors.[73] The data contained the repository come in 169 separate spreadsheets from historical scientific cruises, some of which contain just a few records (e.g. file LONSPF8007 has just three data), without metadata concerning sampling methods, contact information, or any references to papers or reports that explain the data. The most recent cruise dataset is from 1998. Thus, for Q 8 (are the data up to date?) a score of 1 was given, reflecting that average of 2 out of 2 for the maps, but 0 out of 2 for the scientific data.

[73] For the month of January 2016, the ISA data portal web site was down. The author does not know whether this is a common occurrence. (Since this paper was published, the ISA database has been updated. See Chapter 5 herein.)

Table 2-1: Questions 1-9, concerning availability of data and basic information
Strikethrough text indicates a question that was deemed not applicable to this study. +na = not applicable. *See text for explanation. #To account for the intervening time since the Clark et al. (2015) study, two years were added to the scores in question 8. NGO = non-governmental organisation; IGO = inter-governmental organisation.

Questions (from Clark et al. 2015)	**RFMO range**	**Mean RFMO score**	**ISA score**
1. Does the organization have a web site? (No = -1; yes, but it is incomplete or difficult to navigate = 0; yes and it is easy to use / fully operational = 1)	All 1	1	**1**
2. Does it list the staff members and contact information for the Secretariat? (No= -1; Yes=0)	-1 to 0	-0.1	**0**
3. Does the organization list its members, cooperating non-members, and/or observers? (Members and cooperating non-members/observer states, IGOs & NGOs = 1)	All 1	1	**1**
4. Is there public online access to current regulations including conservation measures? (No= -1; yes but disorganized/not in one location= 0; yes and easy to find= 1)	0 to 1	0.9	**1**
5. Are summary data available publicly on the internet? (Y=1)	0 to 1	0.9	**1**
~~6. Is there an observer data collection/monitoring program for most fisheries? (Y=1, N= -1)~~	~~-1 to 1~~	~~0.5~~	**na+**
7. Are scientific / observer data available at a resolution/scale such that they can be used in independent scientific analyses? (Full resolution data available on web=5; general resolution available on the web=2; some incomplete data on the web= 1; secretariat will provide research-quality data upon request=+2)	1 to 4	2.1	**1**
8. Are the data up to date? (2012 or older=0, 2013=1, 2014 or later=2; if summary data differs from downloadable data, use average score of the two) #	0.5 to 2	1.5	**1***
9. Do the data come with metadata and/or description of their origins and collection methods? (Y=1)	0 to 1	0.8	**0***
Sub-total (excluding Q 6) out of a possible range of to -3 to 12	7 to 11	8.1	**6**

2.4.2 Participation in decision-making

In this section, the questions largely focus on the ability of non-governmental organisations (NGOs) to observe and participate in meetings (**Table 2-2**, Q 10-15; 20-21), as well as information about the meetings themselves (**Table 2-2**, Q 16-19). Note that although the ISA rules sometimes use the word “public”, general public access to meetings is not meant; rather, it is presumed that any observer will be associated with an accredited NGO or IGO (inter-governmental organisation) (ISA, 2012a, sect. XVI, rule 82). Indeed, the questions in **Table 2-2** reflect this presumption, as it is also the case for RFMOs.

The ISA received 2.5 out of a possible 4 on the first five questions in this section (**Table 2-2**, Q 10 – 14), falling short of a maximum score because a minority of Parties (i.e. States) can block an observer's application from being accepted, and because it was not clear how NGOs should apply for observer status. (Although not immediately obvious, the application letters from other NGOs can be found in the Assembly meeting documents.) However, the ISA score dropped further in the latter half of this section when it came to questions of which meetings were open to observers, how they may participate, and what information from meetings is available to the public.

Meetings of the Assembly and Council are open to observers unless otherwise specified (ibid., Assembly rule 82 and Council rule 39), but meetings of the Legal and Technical Commission (LTC) and the Finance Committee are not (ibid., LTC rule 6 and Finance Committee rule 31). The wording of Q 15 (**Table 2-2**) does not quite capture the nuances of how NGOs may participate in the ISA. Only when invited by the Chair and approved by the Assembly, may they make an intervention in Assembly (ibid., Assembly rule 82(5)). In Council they may only participate upon the Council's invitation and only "on questions affecting them or within the scope of their activities" (ibid., Council rule 75). Therefore, half points were awarded for this part of Q 15. Unlike governmental and inter-governmental observers, written statements produced by non-governmental observers will not be translated into all official languages, and it is up to the NGO observers to make enough copies for the meeting (ibid., Assembly rule 82(6)). Therefore, half points for this part of Q 15 were awarded. To date, NGO observers have not been allowed to serve on (sub-)committees, and thus no points were given for this part of Q 15.

All ISA meeting summary reports are available on its website. However, these reports do not include attributed statements, do not provide information on the nature of the discussions, nor the various positions that were put forward. For official LTC documents, documents with an L. (limited) or R. (restricted) symbol are confidential. Other official documents of the LTC can be seen on the website. However, all contractor annual reports and contract applications submitted to the LTC are treated as confidential (R. or L. designations) (IBID., LTC rules 11-13). The LTC summary reports to Council, which are meant to support their recommendations (e.g. to approve an application from a State / contractor), do not detail the rationale behind their recommendations. Therefore, while full points were given for Assembly and Council documents (1 point total) and for an historical time series (1 point), a half score was given for the LTC's reporting, adding up to 2.5 in Q 17.

Acceptance of observers to the ISA is by consensus, and therefore a minority of Parties can potentially block an observer's application from being accepted. However, the ISA has to date been welcoming to observers, and has never turned any away. Therefore, while technically a score of -1 could have been applied to Q 14, it was increased by half a point (-0.5), based on the precedent set by its practices to date.

Table 2-2: Questions 10-21, concerning participation in decision-making
Strikethrough text indicates a question that was deemed not applicable to this study. +na = not applicable. *See text for explanation. +Q 18: Attendance is recorded only for the Assembly.

Questions (from Clark et al. 2015)	**RFMO range**	**Mean RFMO score**	**ISA score**
10. Does the organization allow for non-governmental observers? (N= -1, Y=3)	All 3	3	**3**
11. Is a procedural description/required forms of how to become an observer available on the website? (Y=1)	0 to 1	0.9	**0**
12. Are the criteria exclusive/stringent (Only allowing a few organizations)? (Y= -1)	All 0	0	**0**
13. Does it take longer than a year to receive observer status? (Y = -1)	All 0	0	**0**
14. Can a minority of parties prevent a NGO from obtaining observer status? (Y= -1)	-1 to 0	-0.5	**-0.5***
15. How may NGO observers participate? (Can make presentations/comments= +0.5, Allowed to author/co-author meeting documents= +0.5, Can serve on sub-committees, working groups, panels etc.= +1)	0.5 to 2	1.2	**0.5***
16. Does the organisation publish a schedule of upcoming meetings? (Yes= 1)	All 1	1	**1**
17. Are meeting reports available to the public? (General Assembly/Council= +1, Scientific/technical/environmental = +1, both historic and current documents are available= +1, Meeting documents are available= +1. For compliance committee docs, see III.2)	1 to 4	3.2	**2.5***
18. Does the organization include an attendance list in meeting documents? (Y= 1)	All 1	1	**0.5+**
19. Are there attributed statements in meeting documents? (Y= 1)	0 to 1	0.9	**0**
20. Which meetings are open to observers? (General Assembly/Council= 1, Scientific/technical/environmental= +1, Compliance= +1)	1 to 3	2.6	**1**
21. Are observers ever asked to leave meetings? (never to seldom=1, occasionally=0, more than occasionally=-1)	All 1	1	**1**
Sub-total out of a possible range of -5 to 17	12.5 to 17	14.5	**9.0**

2.4.3 Access to outcomes

This last section has four sub-themes: reporting on objectives, organisational performance, compliance, and dispute resolution. For a number of the questions, the ISA received partial scores, as will be explained below. The first three questions in (**Table 2-3**) assume that natural resource exploitation is being actively managed; however, in the case of the ISA, the Exploitation

Code (Mining Code) is not yet established. Nevertheless, these questions were still considered because it is necessary to good governance of the seabed that the ISA have a sense of what its exploitation and conservation objectives are, and how these can be measured, reported upon, and balanced, before mineral exploitation begins. Since 2010, exploration contracts approved by the ISA have more than trebled, from 8 to 27. Notwithstanding this noticeable increase in mining interest, there has been to date no reporting on the state of the mineral resources and the environment (**Table 2-3**, Q 24), nor any baseline environmental analyses, nor any summaries of annual contractor activities.

As discussed above, UNCLOS (article 154) stipulates a performance review every five years after its entry into force, and yet 22 years have passed (20 years since ISA began its operations) before the first ISA performance review is planned to begin. The responses to Q 25 to 29 need to be read in this light. Whilst the ISA is currently beginning a review, the body is much more than ten years old (the cut-off for this question), and hence a score of -0.5 was applied to Q 25 (**Table 2-3**). While most other ISA reports have been made public, and indeed it will be difficult for Assembly to discuss it otherwise, it was decided that a point to this question could not be assigned before the fact, and it was removed from the analysis (**Table 2-3**, Q 26). Furthermore, it is hard to predict what Council and the Assembly will do with it, and hence Q 28 (**Table 2-3**) was also deemed not applicable, at this time. The review is being carried out by external independent consultants, but the Review Committee itself is made up of the ISA President and Bureau of the Assembly, and hence a score of 1 out of 2 was applied to Q 29 (**Table 2-3**) concerning the make-up of the review committee and its independence.

Although compliance is normally associated with resource exploitation, there are also requirements for contractors with exploration contracts, including the requirement to submit an annual report on their progress, technical and scientific findings (ISA, 2013a, reg. 6). However, to date these reports have been kept confidential. Furthermore, the ISA has not reported whether the contractors have been in compliance with their contractual obligations. The ISA does, however, keep track of States that have passed national mining legislation, which earned it one point for Q 31.[74] Because only exploration is occurring, the equivalent of fisheries “monitoring, control, and surveillance” does not yet fully exist in the ISA, and hence Q 32 was deemed not applicable.

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[74] ISA national legislation database: https://www.isa.org.jm/national-legislation-database [Accessed July 2020.].

Table 2-3: Questions 22-34, concerning access to outcomes and justice

Strikethrough text indicates a question that was deemed not applicable to this study. ⁺na = not applicable. *See text for explanation. #Range and mean for this section and the grand total exclude one new RFMO (SPRFMO) which was still establishing its rules and procedures.

Questions (from Clark et al. 2015)	**RFMO range**	**Mean RFMO score**	**ISA score**
22. Does the organisation publicly identify its objectives? (Yes= 1)	All 1	1	**0.5***
23. Does the organisation have publicly available quantitative indicators against which its outcomes can be assessed (e.g. "targets")? (Yes= 1)	0 to 1	0.5	**0**
24. Does the organization produce regular reports on the state of the resource/environment over time (e.g. OSPAR's Quality Status Report) and/or the organization's progress towards meeting its objectives? (Reports on some aspects of the state of the resource/environment (e.g. specific stock status) = 1, Comprehensive (e.g. including by-catch reduction, etc.) = +1, Qualitative reporting against objectives = +1, Quantitative reporting against indicators = +1)	1 to 4	2.7	**0.5***
25. Has the organization undergone a performance review? (Yes = 1, none = 0, none and the org is more than 10 years old = -1)	0 to 1	0.8	**-0.5***
~~26. Are the findings of the performance review(s) publicly available online? (Y = 1)~~	~~0 to 1~~	~~0.8~~	**na*⁺**
27. Has the organization agreed to a regular schedule of performance reviews? (Y = 1)	0 to 1	0.8	**0.5***
~~28. Has the organization responded to the performance review? (Y=1)~~	~~0 to 1~~	~~0.5~~	**na⁺**
29. Are there some independent evaluators involved in the performance review? (Yes= 1; majority independent = +1)	0 to 2	1.6	**1***
30. Are compliance reports publicly available? (Summary=1, detailed report = 2)	1 to 2	1.7	**0**
31. Are there lists of compliance measures taken by parties and/or lists of infractions (e.g. national implementing legislation, "white" and/or "black" lists, lists of vessels under investigation, successful prosecutions, etc.)? (One point per list, up to 2 points.)	1 to 2	1.6	**1**
~~32. What are the MCS [monitoring, control, and surveillance] requirements on Contracting Parties / Flag States? (No requirements = -1, voluntary reporting = 0, mandatory reporting = 1, independent verification of reporting = +1)~~	~~1 to 2~~	~~1.1~~	**na⁺**
33. Is dispute resolution covered in the Rules of Procedure or Convention text? (Y= 1, N= -1)	-1 to 1	0.7	**1**
34. Should disputes occur, are records of disputes and their outcomes available? (Not available= -1, Upon request from Secretariat= 0, Available on website= 1)	0 to 1	0.5	**1**
Sub-total out (excluding Q 26, 28, 32) of a possible range of -2 to 16	12 to 16#	11.9#	**5.0**

GRAND TOTAL out of a possible range of -10 to 45	32 to 38	34.7 (77%)[#]	**<u>20.0 (44%)</u>**

2.4.4 Two supplementary questions

While belonging to the broad constellation of international maritime organisations charged with managing resources and protecting the environment (Ardron et al., 2014b; Ardron and Warner, 2016), the ISA has some powers and obligations that set it apart, notably that: 1) it may, and has, entered into commercial contracts with its States Parties; and, 2) it is required to equitably share financial and other economic benefits derived from the activities undertaken in the Area (UNCLOS, 1982, art. 140(2)). The two new questions in **Table 2-4** begin to address these unique attributes.

ISA exploration contracts are currently not publicly available in either full or summary form. While it is known that the Mining Code (as it existed the time of signing) is attached as part of these contracts, what is not revealed are the plans of work of the contractors, including planned environmental studies; and, the financial commitments of contractors. As noted above, annual contractor progress reports are also treated as confidential, available only to the Secretariat and LTC, but not available to Council, Assembly, or the public. Without this information, it is impossible to assess whether contractors have been meeting their obligations. Thus, S1 was assigned a score of zero.

A benefit-sharing mechanism has not yet been established by the ISA, and hence it is not possible to judge its transparency. However, the practices and policies of the ISA with regard to its other finances –i.e. its current fiscal transparency– can be taken as an indication of what might be expected in the future, should the status quo remain. The Finance Committee of the ISA historically published few meeting documents (typically about four a year), and none with specific financial information. However, 2015 was very different with more meeting documents (nine) published, including the proposed 2015 budget (albeit as an annex to another document with another name (ISA, 2015a)), as well as financial information on its Endowment Fund (ISA, 2015b). Nevertheless, the ISA audited statement, while on the agenda, is still not to be found in the published documents of the Finance Committee. Available records show Council and Assembly regularly urging States Parties to pay outstanding fees, but actual figures are not published. A score of 0.5 was assigned to S2, mainly due to the increased number of Finance Committee documents available in 2015, some of which contain some financial information.

Overall, in this new section, the ISA scored 0.5 out of a possible total of 4.

Table 2-4: Supplementary questions S1 & S2, concerning contracts and finances
na = not applicable.

Questions	RFMO range	Mean RFMO score	ISA score
S1. Are ISA contracts publicly available? (0= not at all; 1 = some portions; 2= mostly or entirely.)	na	na	0
S2. Does the ISA publish its financial transactions, including monies received from contractual fees, resources rents and taxes; monies spent, invested, or shared; as well as outstanding debts and arrears? (0 = not at all; 1 = some portions; 2 = mostly or entirely.)	na	na	0.5
Sub-total out of a possible range of 0 to 4	na	na	0.5

2.5 Discussion

Transparency has come to be seen as a keystone in the good governance of natural resources on land, and increasingly so in the sea as well. While there are several legal, policy, and operational distinctions between high seas fisheries management and the regulation of DSM mining in the Area, none of these should affect the overall degree of transparency in their respective operations. Indeed, there are legal obligations unique to the Area, and bio-physical conditions particular to the deep-sea environment, which may suggest that for DSM mining management there is a justifiable expectation for greater transparency than for fisheries. In areas beyond national jurisdiction, fishing is articulated as one of seven high seas freedoms (UNCLOS, 1982, art. 87), though not an unfettered one (Brooks et al., 2014). As noted in the introduction, there is still an obligation for RFMOs to report and to share information and data. Although States may exploit the natural resources of the seabed beyond national jurisdiction, deep-sea mining is not articulated as a freedom; rather, article 136 of UNCLOS states that the Area and its resources are the “common heritage of mankind”, and in article 140, activities must be carried out “for the benefit of mankind as a whole”. This unique wording, found nowhere else in UNCLOS, would suggest that DSM mining is seen as a special situation that should presumably proceed carefully and in the best interests of humanity. This unique legal situation strongly suggests governance practices which enhance the public’s access to information, meetings, and outcomes. Further, while fisheries resources are, if managed properly, renewable, deep-seabed minerals are not being replenished on a human time scale, notwithstanding the geologically rapid growth of SMS deposits. Additionally, the deep-sea marine environment is poorly studied, but what little is known suggests that some deep-sea organisms and ecology could be particularly vulnerable to disturbance. Consequently, concerned scientists have repeatedly called for greater protections from DSM mining (Van Dover, 2011a, 2011b; Barbier et al., 2014; Wedding et al., 2015). This all suggests that the management of DSM mining should have at least as much, if not greater, transparency than in fisheries.

However, the ISA scored noticeably lower than the lowest regional fisheries management organisation. With the two new ISA-specific questions added, the ISA overall score is 42%. For just the 30 Clark et al. (2015) questions considered, the ISA receives an overall score of 44%. The RFMO scores, with the “not applicable” questions removed (and one new RFMO excluded), ranged from 71% to 84% with a mean value of 77% (Figure 1).

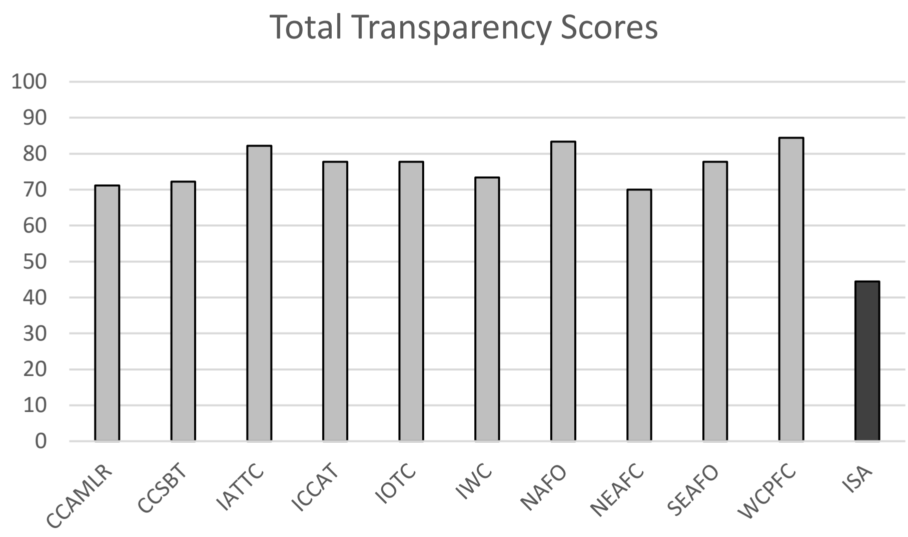

Figure 2-1: Overall score of the ISA as compared to RFMOs
The y axis is percentage of total possible scores. The x axis acronyms are as follows: CCAMLR, Commission for the Conservation of Antarctic Marine Living Resources; CCSBT, Commission for the Conservation of Southern Bluefin Tuna; IATTC, Inter-American Tropical Tuna Commission; ICCAT, International Commission for the Conservation of Atlantic Tunas; IOTC, Indian Ocean Tuna Commission; IWC, International Whaling Commission; NAFO, Northwest Atlantic Fisheries Organizaton; NEAFC, North East Atlantic Fisheries Commission; SEAFO, South East Atlantic Fisheries Organisation; WCPFC, Western and Central Pacific Fisheries Commission. Because the South Pacific Regional Fisheries Management Organisation (SPRFMO) was new at the time of the original Clark et al. analysis, with some policies still unfinished, it was removed from their final results (though it was assessed in the sub-sections).

For each of the three sections, the ISA sub-total is also lower than the lowest RFMO for that section. The ISA scores exceed the RFMO average on just four of the 30 questions (Q 2, 4, 5, 34). Never does the ISA score for a question exceed that of the highest RFMO score. For all questions, but one, at least one RFMO received a full score, and as the mean values indicate, often several scored quite highly. For the one question that was not fully met (Q 7: Are scientific / observer data available at a resolution/scale such that they can be used in independent scientific analyses?), the highest RFMO score was 4 out of 5; whereas the ISA scored 1.

The ISA received two partial negative scores of -0.5 (Q 14, 25), concerning the ability of one or more Parties to block an observer's application, and the considerable delay before the ISA embarked on its performance review.

The above assessment covers basic procedures concerning transparency. That all but one question had been fully met by at least one RFMO, suggests that these questions are aligned with current RFMO good practices, and are readily achievable. As Clark et al. (2015) note, RFMOs have come under repeated criticism for being not transparent enough, and thus for their initial analysis the standard was set rather low, to test for "very basic elements of transparency" (p 164). It is therefore all the more striking that applying these basic and general criteria, the ISA received just under half of the possible points, 29 percentage points less than the lowest scoring RFMO and 43 percent less than the highest.[75]

As suggested above, some of the lower scores can probably be explained by the ISA still readying itself for commercial DSM mining. However, over its 20 years of operations, it has developed core rules, procedures, and operations. The rules of procedure for the LTC include five clauses on confidentiality, including a written oath that members must sign (ISA, 2012a, LTC rule 11.2). Likewise the mining code devotes several clauses to confidentiality. There are no rules regarding access to information in any of the ISA's procedures. Nevertheless, UNCLOS (Annex 3, article 14) stipulates that environmental and safety related data shall not be considered proprietary, and this one transparency stipulation is reflected in the ISA Mining Code:

> "Data and information that is [sic] necessary for the formulation by the Authority of rules, regulations and procedures concerning protection and preservation of the marine environment and safety, other than proprietary equipment design data, shall not be deemed confidential" (ISA, 2010a, 2012b, 2013a).

Yet, no environmental (or safety) data provided by contractors have to date been made publicly available. In a 2014 ISA-contracted review, the state of the ISA database, which contains older data from scientific institutions, was roundly criticised. The review noted, *inter alia* that "The database was last updated in 2008, and the most recent data set in the cruise section is a cruise that took place in 1998. It does not offer access to any data from any contractor. The reason for this is not clear" (Seascape Consultants, 2014, p10).

[75] Adding questions relevant to the ISA lowered the score further. This phenomenon was noted in Clark et al. when looking at studies specific to a single RFMO, where again the scores were lower, due to the ability of the questioners to probe issues specific to the organisation.

It should also be noted that the ISA does not have procedures to determine confidentiality. Neither the ISA Secretariat nor the LTC have taken on the role of determining whether data and documents marked as confidential by contractors are indeed so. Rather, its existing internal guidance appears to leave that critical role with the contractor; that is, if a contractor deems information sensitive or confidential, then it is treated that way (ISA, 2011a, para. 20(a)).[76]

Overall, the ISA's standing in participation in decision-making is 5.5 points lower (9.0) than the lowest RFMO score (14.5 out of a possible 17. In the Clark et al. (2015) study, five RFMOs achieved more than 90% of the possible points in this section, with one achieving 100%, as compared to the ISA's score of 56%.

Regarding access to outcomes, as in the other sections, the ISA ended up with a notably lower score than the RFMOs, achieving just 7.5 out of a possible 19 points; i.e. 37.5%, whereas low ranking RFMOs achieved scores with percentages in the 60s and two high ranking ones achieved over 80 percent. However, it should be noted that because commercial mining (unlike fisheries or whaling) has never occurred, the results to some degree reflect the ISA's relatively less mature institutional structures for reporting on outcomes.

There are some signs that the ISA is improving the transparency of its practices. In the spring of 2014, it undertook its first-ever public consultation, in this case for the development of exploitation regulations, which was followed up with a second consultation in 2015. (However, whilst a third public consultation was expected to occur in 2016, it is currently unclear whether it will proceed –indicating that transparency still elicits divided opinions within the LTC.) The number of Finance Committee documents available on the ISA website has recently increased from just in four available in 2013 and 2014 to nine in 2015. Therefore, while the assessment results suggest that "the glass is less than half full" (44% or 42%, as explained above), there are some signs that the water level is perhaps rising. In this constructive context, and in light of the ongoing ISA performance review, the following section offers specific recommendations.

[76] "Information deemed sensitive shall include the following: documents created by the Authority, received from or sent to third parties, under an expectation of confidentiality." (ISA, 2011a, para. 20(a))

2.6 Recommendations

2.6.1 Availability of data and basic information

Stemming from the results of the survey as described above, this section provides some recommendations. They are by no means exhaustive of mechanisms to improve access to information, participation, or judicial review, but do represent a starting point.

1. Develop a comprehensive access to information policy, including *inter alia*:

    a. overarching principles to be adhered to by the ISA and its contractors;

    b. the presumption of non-confidentiality unless otherwise determined;

    c. rules and procedures by which to determine confidentiality; and,

    d. procedures through which confidential data and information may be released over time (embargo).

Given that it is already clear that environmental and safety related data cannot be deemed confidential, the ISA should:

2. Make publicly available environmental and safety related data provided to it by contractors:

    a. in a defined electronic format;

    b. at the spatial resolution in which they were provided;

    c. including geospatial attributes; and,

    d. metadata where they exist (including, for example, data collection methods).

In order to facilitate data collation and standardisation, the ISA is encouraged to continue its work on data standards, and:

3. Prepare clear guidance to contractors on data standards, including:

    a. acceptable defined electronic data formats;

    b. required level of detail & resolution;

    c. required attributes; and,

    d. which of the generally recognised metadata standards may be followed.

2.6.2 Participation in decision-making

Given the valuable roles that external experts, stakeholders, and the public can play, particularly when the ISA must balance its mandate to protect and preserve the environment, oversee the common heritage of humankind, and regulate DSM mining, it is recommended to:

4. Establish greater public participation in the ISA's meetings through:
    a. providing on its website a user-friendly application form for observers;
    b. providing space in the agendas of Assembly and Council meetings for public input;
    c. allowing observers to attend pre-determined portions of Finance Committee and LTC meetings;
    d. allowing observers to serve on sub-committees; and,
    e. encouraging all ISA organs, and the LTC in particular, to better engage with external expertise and organisations, through requests for advice.

2.6.3 Access to outcomes and to justice

As part of the ISA transitioning to the regulation of commercial mining, it will need to clarify what its desired outcomes are (commercial, environmental, benefit-sharing, etc.), and how these will be measured. Therefore, it is recommended that the ISA:

5. Develop objectives concerning well-regulated DSM mining, including:
    a. indicators for each objective;
    b. a programme to measure these indicators; and,
    c. annual publication of the results.

Given that exploration and exploitation of deep-sea mineral resources are in the interest of all humankind, and that contractors are already required to submit annual reports of their activities, the ISA is urged to:

6. Publish annual compliance reports concerning contractors and their required activities, including:
    a. contractor activities in the Area;
    b. compliance with the ISA's rules and regulations;

c. any reportable accidents, infractions, or other issues; and if so,

d. what actions were (are being) taken to resolve the situations.

Given the generally recognised importance of human health and safety, and the protection and preservation of the marine environment, in customary international law and in UNCLOS, as well as the status of the Area as the common heritage of humankind, the ISA is advised to:

7. Develop "whistleblower" rules protecting those who speak out concerning issues of public interest, such as human health and safety, the protection and preservation of the marine environment, and financial corruption.[77]

2.6.4 Contractual and financial transparency

Given the special legal status of the Area, and the powers invested in the ISA, it is recommended that the ISA:

8. Make contracts with States Parties and contractors available to the public, excluding only proprietary information as determined per Recommendation 1, above.

9. Establish financial public reporting rules, drawing upon internationally recognised best practices, including those of the Extractive Industries Transparency Initiative,[78] the Equator Principles,[79] the International Finance Corporation,[80] and others as appropriate.

2.7 Conclusion

As the deep-sea minerals exploitation regulations are being readied, and the ISA undertakes its first organisational review, it is an appropriate time to pause and consider its accomplishments so far. Much institutional development has been achieved. Looking to the future, however, particular care will be required to ensure that decisions made now do not unduly jeopardise the options of future generations to both a healthy marine environment and to the mineral wealth of the deep seabed. Public access to information, decision-making, compliance reporting and justice, would greatly improve the chances of the ISA achieving long-term regulatory success.

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[77] There are several examples of national whistleblower legislation which could serve as models; e.g. the UK's Public Interest Disclosure Act 1998: http://www.legislation.gov.uk/ukpga/1998/23/ [Accessed July 2020.]

[78] https://eiti.org/ [Accessed July 2020.]

[79] http://www.equator-principles.com/ [Accessed July 2020.]

[80] https://www.ifc.org/wps/wcm/connect/7483641d-ced7-48cf-affe-616fefa0aaa5/PS_Intro.pdf?MOD=AJPERES&CVID=jkC.DZR [Accessed July 2020.]

Chapter 3 Incorporating transparency into the governance of deep-seabed mining in the Area beyond national jurisdiction

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JA conceived, researched, and wrote the text. HR and DJ, as supervisors, provided several rounds of in-depth comments that strengthened the research rigour and quality of presentation.

3.1 Abstract

In the governance of natural resources, transparency has been linked to improved accountability, as well as enforceability, compliance, sustainability, and ultimately more equitable outcomes. Here, good practices in transparency relevant to the emerging governance of deep-seabed mining in the Area beyond national jurisdiction are identified and compared with current practices of the International Seabed Authority (**ISA**). The analysis found six areas of good transparency practice that could improve the accountability of deep-seabed mining: i) access to information; ii) reporting; iii) quality assurance; iv) compliance information / accreditation; v) public participation; and vi) ability to review / appeal decisions. The ISA has in some instances adopted progressive practices regarding its rules, regulations, and procedures (e.g. including the precautionary approach). However, the results here show that overall the ISA will need to consider improvements in each of the six categories above, in order to reflect contemporary best transparency practices, as well as meeting historical expectations embodied in the principle of the 'common heritage of mankind'. This would involve a revision of its rules and procedures. The ongoing review and drafting of the ISA's deep-seabed mining exploitation regulations offers a once-in-a-generation opportunity to improve upon the current situation. Findings from this analysis are summarised in 18 recommendations, including publication of annual reports submitted by contractors, publication of annual financial statements, development of a transparency policy, compliance reporting, and dedicated access to Committee meetings.

3.2 Introduction

This paper identifies good practices in transparency that could lead to improved accountability in the emerging governance of deep-seabed mining in ‘the Area’ beyond national jurisdiction. To do so, recognised best practices from related marine and natural resource sectors are considered.

3.2.1 Transparency in the governance of natural resources

In the governance of natural resources, transparency is found to be a necessary factor for improved accountability, as well as enforceability, compliance, sustainability, and ultimately more equitable outcomes (Eigen, 2006; Humphreys et al., 2007). In the extractive resource industries in particular, transparency is emphasised with regard to improving governance ills, particularly accountability (Eigen, 2006), and has been hailed as an important step to resolving governance-related problems emanating from natural resources in national jurisdiction, such as fiscal responsibility, the choice of investments, and project suitability (Humphreys et al., 2007; Kolstad and Wiig, 2007). Well-established non-governmental organisations, including Transparency International,[81] the Natural Resources Governance Institute,[82] and the U4 Anti-Corruption Resource Centre[83] promote transparency as a way to deter corruption (Chene, 2017). Other factors, such as political stability, regulatory quality, and institutional competence, also play critical roles in the good governance of marine natural resources (Mehlum et al., 2006; Kaufmann et al., 2011; Chene, 2017). However, without transparency in deep-seabed mining, the details concerning allocation of international seabed mineral resources to private and state operators, ensuing environmental impacts, and regulatory compliance, will remain largely unknown. Greater transparency is necessary to allow for meaningful review or appeals, and can lead to greater public accountability and engagement, which has been interpreted as consistent with the principle of the common heritage of humankind (Jaeckel et al., 2017).

3.2.2 Deep-Seabed Mining

The potentially vast mineral wealth of the ocean was popularised over fifty years ago in an academic book, ‘The Mineral Resources of the Sea’, that captured the imagination of scientists, businessmen, and government representatives alike (Mero, 1965; Glasby, 2000). Spurred by

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[81] https://www.transparency.org/ accessed Oct. 2017.
[82] https://resourcegovernance.org/ accessed Oct. 2017.
[83] http://www.u4.no/ accessed Oct. 2017.

record-high mineral commodity prices in 2011,[84] the evolution of technical capabilities, and the approval of international regulations for prospecting and exploration, the prospect of deep-seabed mining (**DSM**) has had renewed attention. In the three years from 2011 to 2014, thirteen applications were made to the International Seabed Authority (ISA) for exploration licenses –more than any period before or since. As of summer 2017, there had been a total of twenty-nine exploration applications to the ISA, including seven that were carried over from 'pioneer' contractors in the 1970s and 80s. In response to this renewed industrial interest, DSM has also attracted renewed scientific, legal, and policy attention (e.g. MIDAS, 2016; Jakobsen & Matz-Lück, 2016; Bourrel et al., 2018).

Combined with the pending expiration of the original 15-year contracts issued in the early 2000s, this renewed interest spurred the ISA towards development of its *exploitation* regulations. A preliminary 'Zero Draft' of these regulations was released for public comment in July 2016 (ISA, 2016a). Subsequently, a 'tentative working draft' discussion document concerning environmental aspects of these regulations was released in early 2017 (henceforth, 'Discussion Document'; ISA, 2017a). In the summer of 2017, the ISA released 'Draft Regulations on Exploitation of Mineral Resources in the Area' (henceforth, 'Draft Regulations'; ISA, 2017b).

The deep seabed beyond national jurisdiction, administered through the ISA, has a unique legal status. In 1970, the United Nations (**UN**) General Assembly Resolution 25/2749 declared the seabed and its resources to be the 'common heritage of mankind' (**UNGA**, 1970) – language that was later incorporated into the UN Convention on the Law of the Sea (**UNCLOS**, 1982; art. 136).[85] In what is termed 'the Area' beyond national jurisdiction, UNCLOS stipulates that all rights in seabed natural resources are vested in humankind[86] as a whole (art. 137(2). Financial and other economic benefits derived from activities in the Area, including DSM, are to be shared equitably (art. 157(1), again for the benefit of humankind (art. 140(1); Thiele and Bourrel, 2016). Also, DSM activities in the Area shall be carried out in such a manner as to foster healthy development of the world economy and balanced growth of international trade, and to promote international cooperation for the overall development of all countries, especially developing States (art. 150). However, it has been questioned whether deep-seabed mining will actually achieve these lofty

[84] World Bank Commodity Price Data (The Pink Sheet); http://www.worldbank.org/en/research/commodity-markets#1 accessed Oct. 2017.

[85] Reflecting the internationalist spirit of those times, similar text can be found in the Outer Space Treaty (1967; 'common interest of mankind') and the Moon Treaty (1979; 'common heritage of mankind'), though these have proven to be far less influential than UNCLOS. Arguably the other side of the same coin, the UN Declaration on the Establishment of a New International Economic Order (1975) emphasised regaining effective state control of natural resources from foreign interests.

[86] Although UNCLOS uses the term 'mankind,' this paper shall use the more contemporary 'humankind' unless in direct quotation.

benefits, with some calling for a pause in developing the industry until there is a re-assessment of the legal obligations and whether these are being met (Jaeckel et al., 2017; Kim, 2017; Van Dover et al., 2017).

Concerning the common heritage of the seabed's mineral resources, it has been suggested that the ISA's States Parties are "…meant to act as a kind of trustee on behalf of mankind as a whole." (Wolfrum, 2009). The principle, in being so defined, necessarily brings with it governance requirements beyond normal business-as-usual, particularly concerning fair and equitable benefit-sharing, and protection and preservation of the marine environment (Jaekel et al., 2016; Jaeckel et al., 2017). Given the as yet unknown impacts of full-scale commercial DSM on the environment and ecosystems, a precautionary approach has been identified by the ISA in its 'Mining Code'[87] (e.g. ISA, 2010a; reg. 33.2) to reduce risk of unintended outcomes. The Seabed Disputes Chamber of the International Tribunal for the Law of the Sea (ITLOS) in its 2011 Advisory Opinion noted this as part of a trend towards making the precautionary approach part of customary international law (ITLOS, 2011, para 135).

When discussing the contractual agreements between a sponsoring State and a Contractor, the Seabed Disputes Chamber linked the need for transparency with the common heritage of humankind principle. The Chamber noted that the contractual arrangement would, "…moreover, lack transparency. It will be difficult to verify, through publicly available measures, that the sponsoring State had met its obligations." (ITLOS, 2011, para 225). It goes on to say that "…the role of the sponsoring State is to contribute to the common interest of all States in the proper implementation of the principle of the common heritage of mankind […] Contractual arrangements alone cannot satisfy the obligation undertaken by the sponsoring State." (ibid. para 226). Thus, the lack of transparency that can arise from confidential contractual arrangements is seen by the Chamber as a hindrance to the proper implementation of the common heritage of humankind principle. Contractual agreements have to date been the basis of sponsoring State-Contractor relationships, and the relationships between the ISA and these parties.

The transparency of the ISA has been evaluated by stakeholders as insufficient, particularly concerning access to Commission meetings, data, and information to assess if a Contractor has met its obligations (RESOLVE, 2016). When compared to the management of international fish stocks by regional fisheries management organisations, the ISA's practices were found to be least transparent (Ardron, 2016). Whilst many international maritime-focussed organisations began

[87] The ISA uses the term 'mining Code' to collectively refer to all its regulations concerning mining exploration and exploitation. Currently, only exploration regulations have been finalised.

discussing transparency in the mid-late 1990s, such discussions did not occur within the ISA, and only appear in the records of the ISA's annual meetings very recently, after 2014 when a study on the topic was published (Ardron et al., 2014a).[88] However, over the past two years, the procedures of the ISA appear to be opening up somewhat to external participation; for example, proceedings have included internet-based consultations for the first time.

3.2.3 Elements of good governance

Aguilera and Cuervo-Cazurra (2004) compiled a database of codes of good governance developed worldwide from 1978 until the end of 1999. According to their research, these codes of governance began in the corporate sector, mainly in the late 1980s and early 1990s. Only in the late 1990s did governments and inter-governmental bodies begin to issue their own codes of good governance. In 1997, the United Nations Development Program (UNDP) published a policy document, *Governance for Sustainable Human Development*, which set the mould for many others that would follow (UNDP, 1997; Graham et al., 2003).

Codes and guidance concerning good governance generally include transparency, public inclusiveness & participation, accountability, and rule of law (supplementary materials, **Table B-**, Appendix B). These four elements are inter-dependent in practice. The focus of this paper is mainly on the first two of them – transparency, which is taken to include public participation, as well as to some extent the third element, accountability, as reflected in the ability to review and appeal decisions.

The purpose here is not to further evaluate the above good governance elements beyond what has already been published by these authors and many others. However, it is worth noting that in natural resource governance, positive outcomes as a result of transparency can be difficult to demonstrate (Keblusek, 2010). The limited mandate and power of voluntary initiatives, stakeholder resistance, and dependence on strong civil society (which is absent in many developing states interested in DSM (Brown, 2013, 2104; Lily, 2016)) can lead to the apparent failure of resource governance transparency initiatives such as the Extractive Industries Transparency Initiative (EITI)[89] (Sovacool et al., 2016).[90] Lack of timely data and lack of concrete enforcement measures (e.g. affirmative action from investors) have also been postulated as

[88] Since that study was published in 2014, the ISA has begun to discuss transparency in its 2015 and 2016 meetings.
[89] EITI does not currently apply to DSM in the Area beyond national jurisdiction.
[90] However, this assessment necessarily relies upon generalised indicators (mainly from the World Bank) which are composite indices composed of sometimes poor quality or out of date data, and hence not very sensitive or quick to detect change.

reasons why transparency initiatives have not always ushered in anticipated change.[91] Nevertheless, transparency is still seen to be necessary, though far from sufficient, in ensuring good resource governance (Stevens et al., 2015). In short, it is the tentative first step, often made haltingly, on a long road toward natural resource governance reform and greater accountability. The importance ascribed to transparency is reflected in its near-universal appearance in codes of conduct and best practices that have emerged since the 1990s, as outlined in supplementary **Table B-1**, Appendix B.

3.2.4 Analytical objectives

In order to place DSM into a broader context of international practices, a broad review was undertaken of rules, regulations and codes of conduct that are plausibly relevant to the emerging governance of deep-seabed mining in the Area beyond national jurisdiction. These were then compared with current and emerging practices of the ISA. Here, the work is summarised and we draw some general conclusions, highlighting areas that may need further consideration and improvement. We assume here that if these elements of transparency have been found to be important in the governance of other kinds of natural resources, then they are likely to be so for deep-seabed mineral resources as well.

3.3 Methods

To identify elements of transparency that constitute existing and emerging best practices plausibly applicable to the good governance of DSM, a review of existing codes of conduct, regulations, international agreements, and voluntary standards was undertaken (henceforth, *standards*). From these, 14 indicative standards were selected using four general criteria: 1) it should in some way be applicable or comparable to DSM; e.g. land-based mining, natural resource finance, etc.; 2) when seen to be covering similar issues, international standards are favoured over national ones for reasons of their broader applicability (13 of the 14); 3) in order to gauge current and emerging best practices, newer standards are favoured over older ones, when covering similar content (ranging from 1996 - present); and 4) better-known standards emerging from larger established institutions were favoured over more obscure or niche industry examples.

Several standards were rejected owing to a lack of specificity; i.e. being without language that can be translated into specific rules, policies, or actions. For example, the *World Economic Forum's Responsible Mineral Development Initiative* encourages "transparent processes & arrangements",

[91] Blogged news item: http://news.trust.org//item/20130526220927-0eaiq

but does not elaborate on what elements would characterise such arrangements (WEF, 2013). Likewise, the widely recognised *UN Global Compact* uses language that is too general to interpret specifically into best practices; for example, Principle 10 suggests that "Businesses should work against corruption in all its forms, including extortion and bribery," but does not say how.[92] Other standards that were not included have limited universal applicability (e.g. national freedom of information legislation – which varies considerably across time and jurisdictions[93]); inapplicability to DSM (e.g. consumer right-to-know laws); or, redundancy, as discussed below.

The 14 standards of focus in this paper are representative of three general kinds, regarding: i) operators' activities (9); ii) regulators' conduct (5); and iii) third party[94] conduct (2[95]). Each of these three focal points are (or could be) regulated by the ISA through its mining code and, concerning itself, through its internal rules of procedure. Transparency is a common theme throughout the 14 standards (**Table 3-1**).

International and national standards are not covered exhaustively; i.e. there are other standards, similar to those selected. For example, the ten principles of the *International Council on Mining & Metals* (ICMM, n.d. [updated 2020]), considered here, are similar to elements contained in national codes such as *Towards Sustainable Mining* of the Mining Association of Canada[96] and the *Chinese Responsible Mining Guidelines*, not considered here. There is only one code of conduct explicitly aimed at DSM, the *International Marine Minerals Society Code for Environmental Management of Marine Mining,* which is included here. One national code was included, the Chinese Due Diligence Guidelines (CCCMMC, 2015), as an example of current voluntary best practices in mineral supply chain disclosure, and also because China is the world's single largest producer, importer and exporter of minerals and metals, as well as an ISA Party sponsoring the most DSM exploration contracts. Although the Initiative for Responsible Mining Assurance code (IRMA) is still in draft, undergoing revisions (which are publicly viewable), it was decided to

[92] There are related UN guidance documents, but these too are rather unspecific. For example, the latest report (forward-dated 2018) says, "Transparency is fast becoming the new paradigm for conducting business; stakeholders are calling for companies to adopt sustainable practices and integrate relevant data into reporting cycles. Through the ongoing Reporting for the SDGs Action Platform, the UN Global Compact — together with the Global Reporting Initiative — will help companies align reporting on the SDGs, and advise on communicating this data in a meaningful and usable way." https://www.unglobalcompact.org/docs/publications/2018_Toolbox.pdf accessed June 2017.

[93] Reflected, for example, in the incomplete but extensive Wikipedia page on this topic: https://en.wikipedia.org/wiki/Freedom_of_information_laws_by_country

[94] Concerning third parties, the ISA's situation is unique in that it has entered into contractual arrangements with both mining entities and their State sponsors, which in turn are its members and participate in its various governance organs and decision-making.

[95] Numbers exceed the total because two standards are directed at more than one principal audience (EITI; London convention and Protocol).

[96] http://mining.ca/towards-sustainable-mining

include it in order to provide insight on some of the latest ideas concerning good practices in the land-based mining industry. Other standards constitute either a broadly accepted standard (e.g. the Equator Principles with regard to financing), or a recognised international agreement that could conceivably be applicable to aspects of DSM operations (e.g. the London Convention and Protocol with regard to dumping waste materials at sea), or an internationally recognised voluntary certification scheme seeking to set out best practices in the natural resource sector (e.g. EITI). In addition, the *United Nations Economic Commission for Europe (UNECE) Convention on Access to Information, Public Participation in Decision-Making and Access to Justice in Environmental Matters* (henceforth, the 'Aarhus Convention'; 1998) is used alongside the UN Law of the Sea and the ISA's Mining Code, as another point of legal comparison as that several of the ISA State Parties are also Parties to that convention, and hence bound to its terms and conditions.

3.4 Results and Discussion

Expectations concerning transparency and resultant improved accountability were expressed in six general ways: i) access to information; ii) reporting; iii) quality assurance; iv) compliance information / accreditation; v) public participation; and, vi) the ability to review and appeal decisions (**Table 3-1** and supplementary **Table B-2**, Appendix B). Points (i), (v), and (vi) are considered the 'three pillars' of the Aarhus Convention (1998). Points (ii)-(iv) reflect the emphasis on reporting seen in most of the standards, beginning with the expectation of some sort of publicly available report (ii), providing evidence / assurance of quality of information in that report (iii), and assuring compliance with the standard itself (iv). These six expressions of transparency are discussed below, and compared with the ISA's current practices.

Table 3-1: Standards reviewed & summary of their components related to transparency
A checkmark (✓) indicates inclusion in the standard; an "O" indicates partial inclusion; an "✗" indicates that the component is not included. **Bolded text** indicates the abbreviations used in this paper. More details can be found in supplementary **Table B-2**, Appendix B.

	Reviewed Standards	**Transparency Components**					
		Access to Information	**Reporting**	**Quality Assurance**	**Compliance Reporting / Accreditation**	**Public Participation**	**Review / Appeal**
1	China Chamber of Commerce of Metals, Minerals & Chemical Importers and Exporters: Due Diligence Guidelines for Responsible Mineral Supply Chains (**CCCMMC**, 2015)	✓[97]	✓[i]	✓	✓	O	O [98]
2	Convention for the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (**London Convention**; 1972), and the **London Protocol** (1996)	*O*[99]	✓	✓	✓	✗	✓[100]
3	**Equator Principles** (2013) III: a financial industry benchmark for determining, assessing and managing environmental and social risk in projects	✓	✓	✓	✓	✓	✓
4	Extractive Industries Transparency Initiative (**EITI**) Standard (EITI, 2016)	✓	✓	✓	✓	✓	✓
5	Global Reporting Initiative (**GRI**) Reporting Standards - GRI 101: Foundation 2016, GRI 102: General Disclosures 2016; GRI 103: Management Approach 2016 (GBSS, 2016a, 2016b, 2016c)	✓	✓	✓	✓[101]	✓	✓

[97] The CCCMMC guidelines call for companies to adopt a company policy on the mineral supply chain from high-risk conflict areas. This policy should be communicated not only to suppliers but to the general public. One of the risks defined as a Type 1 risk (contributing to serious human rights abuses) is failure to disclose royalties, taxes or other payments from conflict or high-risk areas in accordance with the EITI principles. Another risk defined as Type 2 (associated with serious misconduct in environmental, social and ethical issues) is failure to report impacts and disclose environmental or social performance to stakeholders in an appropriate and timely manner, and includes obtaining stakeholder feedback.
[98]Stakeholders can submit complaints concerning the guidelines. The main text references a grievance mechanism as being in the appendix, but it could not be found (CCCMMC, P. 32).
[99] Under Article 11 of the London Protocol, the compliance procedures and mechanisms are to allow "full and open exchange of information". Contracting parties under Article 14 Parties are to "promote the availability of relevant information to other Contracting Parties" upon request. It is not stated that this information be publicly available. Most documents on the International Maritime Organization's web site are password protected for use by Contracting Parties.
[100] Article X, XI (Settlement of Disputes) of the London Convention and Article 16 of the London Protocol.
[101] GRI accreditation and compliance is self-assessed.

6	Initiative for Responsible Mining Assurance (**IRMA**) Standard for Responsible Mining IRMA-STD-001, Draft v2.0 (IRMA, 2016)	✓	✓	✓[102]	O[103]	✓	✓
7	International Council on Mining & Metals: **ICMM** 10 Principles (ICMM, nd)	✗	✓	✗	✗	✓	✗
8	International Finance Corporation (**IFC**) Performance Standards on Environmental and Social Sustainability (IFC, 2012)	✓	✓	✓	✓	✓	✓
9	International Marine Minerals Society (**IMMS**) Code for Environmental Management of Marine Mining (IMMS, 2011)	✓	✓	✓	✗	✓	✗
10	**InterRidge** (2006) statement of commitment to responsible research practices at deep-sea hydrothermal vents	✓[104]	✗	✗	✗	✗	✗
11	**Madang Guidelines**: Principles for the Development of National Offshore Mineral Policies (Madang Guidelines, 1999)	✓	✗	✗	✗	✓	✗
12	**OSPAR** Code of Conduct for Responsible Marine Research in the Deep Seas and High Seas of the OSPAR Maritime Area (OSPAR, 2008)	✓	✗	✗	✗	✗	✗
13	Pacific-ACP States Regional Legislative and Regulatory Framework for Deep Sea Minerals Exploration and Exploitation (**SPC-EU Deep Sea Minerals Project**, 2012)	✓	✓	✓	✗	✓	✓
14	**World Bank** Environmental and Social Framework (ESF) (World Bank, 2016)	✓	✓	✓	✓	✓	✓

[102] Additionally, there is an IRMA requirement for public reporting of due diligence undertaken to ensure that mining activities in high risk conflict areas do not support armed conflict or human rights abuses.
[103] The current draft allows for access to compliance information upon request (the previous draft allowed for public reporting).
[104] One of the Responsible Research Practices is to ensure research is well known and this includes utilisation of public domain databases to share information. A public InterRidge database has been in development.

3.4.1 Access to Information

Reasonable access to information is recognised as a central transparency expectation in all but one of the standards examined (ICMM).[105] Access to environmental information in particular is associated with the right of every person "to live in an environment adequate to his or her health and well-being," for present and future generations (Aarhus Convention, art. 1). Likewise, UNCLOS specifies that data necessary for the formulation by the ISA of rules, regulations and procedures concerning protection of the marine environment and safety shall not be deemed proprietary (UNCLOS, Annex III, 14(2)).

The ISA's current rules and regulations, however, have very little language about transparency or access to information. Regarding non-confidentiality of information, the aforementioned requirement in the Law of the Sea (UNCLOS, Annex III, 14(2)) is repeated in the Mining Code, but not elaborated. In contrast, the ISA's operational rules and regulations elaborate considerably upon *confidentiality* (e.g. clauses 12.1-12.3 concerning information presented to the Legal and Technical Commission (ISA, 2102a)). Indeed, the ISA's focus on confidential information continues through to present, with new confidentiality protocols under consideration (ISA, 2017b, 2017d). In Draft Regulations, transparency is only mentioned twice, in both cases without elaboration or specific requirements (ISA, 2017b; reg. 17(e), 81(b)). Confidentiality, on the other hand, appears in 37 places.

Critically, the proposed and existing rules do not specify how confidentiality is to be determined. The draft documents to date broadly describe the nature of what could be confidential and what should constitute publicly available information, but currently leave the decision of confidentiality to be the prerogative of the Contractor and the Secretary General, based on designations provided by the Contractor (ISA, 2016a, art. 46, esp. 46(6); ISA, 2017b; reg. 75). If the Secretary-General disagrees with the Contractor, the Draft Regulations specify that there are just 30 days to register that disagreement (ISA, 2017b, reg. 75(3)). Otherwise, the applicant's / Contractor's designation of confidentiality will presumably stand for the duration of the application or contract (proposed to be 30 years). The opinions of external experts will only be sought if the matter is taken by the Contractor to a formal dispute panel (ISA, 2017b, reg. 75(3) & 92). Third parties, such as ISA members and observers, other experts, or the general public, are not able to dispute confidentiality.

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[105] In another, however, access to documents is limited to signatories (London Convention and Protocol.

The existing Mining Code specifies that "…data and information relating to the protection and preservation of the marine environment, in particular those from environmental monitoring programmes, shall not be considered confidential" (ISA, 2013a, reg. 7(1)). Nevertheless, no such data have yet been released. Madureira et al. (2016) suggest that the lack of environmental data sharing is not intentional but rather a result of a failure to implement modern data reporting standards, which the authors (some of whom are members of the ISA's Legal and Technical Commission (LTC)) claim will be solved by the use of a new reporting template recently developed by the LTC.

The 14 standards examined do not generally specify the format / form of the information or data to be made available, though this can greatly affect the utility of the information. Up-to-date data (and meta-data) standards that reflect commonly adopted technologies help ensure that the data are usable. The Aarhus Convention simply specifies 'in the form requested' unless another format is already publicly available or otherwise more practical (Aarhus convention, 1998, 4.1(b)[106]). The ISA has recently created reporting forms (ISA, 2015c), but has not yet agreed to digital data standards. Given the oceanographic setting for seabed mining, adherence to standards adopted by the UN International Oceanographic Commission and the Global Ocean Observing System could provide valuable guidance for the environmental observing data and reporting standards.

Only about one third of the standards (5/14) explicitly recognise that some information may be held as confidential, usually characterised as being commercially sensitive or proprietary. Only one of the 14 standards we examined outlines a procedure to determine confidentiality (GSSB, 2016b, section 3.2). In all cases, however, there is an assumption that once confidential / exempted information is separated out, the remainder of the information will be made available.

Consideration for embargoing information, whereby there is a possibility that proprietary information can be released after a certain time, is not mentioned in the standards (0/14). However, this is now a common feature of publicly funded research grants, where data and publications must be released "within a reasonable time" (e.g. American Recovery and Reinvestment Act, 2009; art. 9[107]), which typically ranges from 6 to 24 months (RCUK, 2013; section 3.6[108]). Likewise, it is a consideration in the ISA's Mining Code, whereby information

[106] The Aarhus Convention also specifies that data shall progressively be made available in publicly accessible electronic databases (art. 5.3).
[107] Applicable to granting by US National Science Foundation.
[108] Applicable to granting by the UK Natural Environment Research Council.

associated with exploration contracts more than 10 years old may be released.[109] To our knowledge, however, no data have yet been released by the ISA under this provision.

In contrast to the exploration contracts, the Draft Regulations do specify that exploitation contracts, redacted of confidential information, should be made publicly available (ISA, 2017b; draft reg. 12(3)).

3.4.2 Reporting

Reporting is related to, but distinct from, access to information, in that it involves disclosure – either voluntary or mandatory. Reporting typically summarises activities and data for the benefit of the regulator and/or the public. Whilst reporting alone has been criticised as sometimes being conflated with sustainability (Milne and Gray, 2013) and that companies' reported claims under voluntary initiatives need to be treated with caution, reporting can bring to light good practices as well as areas of possible concern that might otherwise go undetected (Hamann and Kapelus, 2004). However, there is also a need to critically engage the mining industry towards more accurate reporting (Hamann and Kapelus, 2004).

In one standard examined (Global Reporting Initiative; GRI), reporting is the central theme. Most of the standards have some sort of reporting requirement, outline what needs to be reported upon and the level of detail (11/14). Most of these also specify the reporting frequency (9/14). In the standards reviewed, which party makes the reports available varies, sometimes being the proponent (e.g. businesses adhering to the GRI) and sometimes the regulator (e.g. International Maritime Organisation; IMO) as regards the London Convention and Protocol), or in the case of third party accreditation, the third party (e.g. extractive industries transparency initiative; EITI) and often the proponent as well (e.g. World Bank). There does not appear to be a best practice in this regard, and this question is still under discussion in the one draft standard we examined (IRMA). Reporting can also apply to State Parties, such as under the Aarhus Convention, or in the case of the ISA, contracting States.

Although the ISA has longstanding reporting requirements, now using a reporting template effective as of 2016, none of the Contractor's annual reports submitted to the ISA have been

[109] E.g. ISA Nodule regulations, ISBA/19/C/17, 36(4): "Ten years after the date of submission of confidential data and information to the Authority or the expiration of the contract for exploration, whichever is the later, and every five years thereafter, the Secretary-General and the contractor shall review such data and information to determine whether they should remain confidential. Such data and information shall remain confidential if the contractor establishes that there would be a substantial risk of serious and unfair economic prejudice if the data and information were to be released […]"

made publicly available. Neither has the LTC explained the rationale behind its recommendations to accept these reports (none have been rejected). Likewise, Finance Committee reports do not include audited statements or similar explanatory details. Therefore, it is difficult to assess whether ISA reporting requirements have been met, and whether the reporting (and the forthcoming data) templates are being adhered to.

The ISA's Draft Regulations are currently silent on the question of releasing Contractors' annual reports (ISA, 2017b; draft reg. 37). The Draft Regulations do, however, stipulate that the draft environmental scoping report, environmental impact assessment, environmental monitoring plan, and closure plan be posted on the ISA website for public comment (ISA, 2017b, draft reg. 18(1), 20(2)).

3.4.3 Quality assurance

Quality assurance mechanisms instil confidence in the information being provided. Quality assurance can extend from the collection of raw data, their analyses, through to reporting. Regulators will typically set minimum standards for baseline data. It may be up to the regulator to monitor for quality assurance, or in the case of third-party certification, the third party (or an assessor certified by it). Voluntary codes of conduct often rely upon the respondent to self-monitor. While quality assurance is a broadly accepted best practice (10/14), most of the standards examined did not explicitly require public *reporting* of quality assurance (just 2/14, with limited requirements –**Table 3-1**), though in some instances it may be inferred as part of the general reporting requirement.

Public access to scientific information (i.e. to raw data and metadata) could allow for further independent verification of reported results and also provide another avenue of quality assurance through public scrutiny. In the standards examined, however, the possibility of public verification does not appear as a rationale for access to information.

In the ISA, quality assurance of applications and annual reporting is carried out by its Legal and Technical Commission; however, the details of these assessments are not made public.

3.4.4 Compliance information / accreditation

Although the standards range from voluntary to mandatory, there is the expectation in all of them that signatories / parties will seek to abide by them. However, a means by which to assess how well parties are actually adhering to the standard (i.e. a compliance information mechanism and/or an accreditation process) is not always a component of the standards, particularly the 'softer' principle-based ones, and appears in half of the standards here (7/14). Clearly there is some disincentive on the part of the parties to self-report non-compliance. Nevertheless, the value of compliance reporting in voluntary standards should not be under-estimated, as that in the absence of more formal legal structures, this is one of the few ways by which volunteer parties can point out problems in the standard, request technical assistance, and ultimately demonstrate their adherence. Determining compliance can be difficult, and has been a key driver of revisions to some of the standards here, particularly those that provide accreditation (e.g., EITI, GRI). In the absence of compliance reporting, it has proven difficult for responsible secretariats to determine whether well-intended voluntary standards are indeed being followed (pers. comms. with the OSPAR Secretariat and the IMMS, 2015).

The ISA currently does not publish compliance information (nor does it accredit activities). It is therefore unknown the degree to which compliance is being evaluated. Likewise, the degree to which Contractors accurately report their activities is also unknown.

3.4.5 Public Participation

Public notification and participation in environmental decision-making is now broadly accepted to be international best practice. Principle 10 of the Rio Declaration on Environment and Development (Rio Declaration, 1992) and the Aarhus Convention (1998) both recognise the need for public participation and the importance of public access to information in facilitating participation. The standards examined likewise broadly reflect this principle (11/14 to an extent; 10/14 more specifically –**Table 3-1**). However, application of this principle varies widely. The Aarhus Convention specifies a clear procedure (art. 6.1(d).) It continues: "Procedures for public participation shall allow the public to submit, in writing or, as appropriate, at a public hearing or inquiry with the applicant, any comments, information, analyses or opinions that it considers relevant to the proposed activity" (art. 6.7). Such an approach is now common in national environmental impact assessment procedures (Lallier and Maes, 2016) and could be implemented at multiple points throughout the life of a deep-sea mining project (Durden et al., 2017).

With regard to assessing possible environmental impacts of DSM exploration applications and the awarding of said contracts, the ISA has not to date consulted the public, relying exclusively on the recommendations of its Legal and Technical Commission (LTC), which deliberates behind closed doors. (To date, all exploration applications have been approved.) However, concerning exploitation and the ongoing development of these regulations, the process has been more inclusive. The ISA has since 2015 used the internet to solicit public comments.

The ISA Discussion Document (2017a) uses the term 'transparency' frequently, mainly with regard to public participation and access to decisions. However, the 'public' is differentiated from 'Interested Persons' and 'Appropriately Qualified Experts.' The former is used mainly with regard to public awareness and public concerns; but with regard to consultations, the latter two terms are employed. Much of the public consultation discussed in the January 2017 Discussion Document is not reflected in the August 2017 Draft Regulations; however, the term Interested Person(s) is retained, and defined as: "a natural or juristic person or an association of persons that, in the opinion of the Authority, is directly affected by the carrying out of Exploitation Activities in the Area or who has relevant information or expertise" (ISA, 2017b; schedule 1). Note that neither ISA State Parties nor Observers are necessarily included in this draft definition, relying upon the opinion of the ISA.

3.4.6 Ability to review and appeal decisions

In addition to a public consultation procedure, most of the standards (such as those of the World Bank and IFC) also recognise the need for a public appeal / grievance mechanism; i.e. the 'third pillar' of the Aarhus Convention (9/14 broadly, 8/14 more specifically –**Table 3-1**). The purpose of such a mechanism is to allow reasonable public concern to be heard, with the possibility of revising or reversing a decision.

The ISA currently has no analogous review and appeal procedure in place. All contracts are ultimately to be approved by the State Parties of its largest body, the Assembly, after having been recommended by the LTC and approved by its executive body, the Council. In practice, this has occurred within the two-week period of its annual meeting. Legally, it is possible that Assembly may delay a vote pending an advisory opinion of the Seabed Disputes Chamber of the International Tribunal for the law of the Sea (ITLOS; UNCLOS, art. 159.10), though this has never occurred. State Parties and other related parties (e.g. Contractors) may raise certain issues with ITLOS, for example concerning interpretation of the terms of their contract, and such hearings would be public unless the Tribunal decides otherwise, or unless the parties demand that the public not be admitted (UNCLOS, Annex VI, 3.26.2).[110] However, with regard to reviewing ISA decisions, ITLOS's powers are strictly limited by UNCLOS Article 189, which effectively removes ITLOS as a possible avenue for grievance or appeal:

> "The Seabed Disputes Chamber shall have no jurisdiction with regard to the exercise by the Authority of its discretionary powers in accordance with this Part; in no case shall it

[110] To date, no such hearings have ever been held.

> substitute its discretion for that of the Authority […] the Seabed Disputes Chamber shall not pronounce itself on the question of whether any rules, regulations and procedures of the Authority are in conformity with this Convention, nor declare invalid any such rules, regulations and procedures […].”

The Zero Draft (ISA, 2016a) allows for only the Contractor to appeal decisions regarding the awarding, prolongation, or termination of their contract, and confidentiality of their information. Third party requests (e.g. from civil society) for appeal or review are not considered. The Draft Regulations (ISA, 2017b) contains no specified appeal procedures.

3.4.7 ISA’s internal review process with regard to transparency

UNCLOS article 154 requires the ISA to undergo an internal review every five years. The ISA began operating in 1996 and commenced its first review in 2015. An independent consultancy released its interim report in 2016 (Seascape Consultants, 2016a), which was subsequently revised based on comments at the ISA’s 2016 session and afterwards (Seascape Consultants, 2016b). In these two reports by the consultants, there were many instances where transparency was raised, and four (of 34) final recommendations have transparency as the central focus (Seascape Consultants, 2016b; rec. 31-34).

In early 2017, the ISA’s internal review committee published its own report in response. The differences in opinion between the external consultancy and the internal ISA committee are striking. Variants of some of the consultants’ recommendations can be found; e.g. opening up portions of LTC meetings (ISA, 2017c; rec. 16). However, concerning data sharing, there is only provisional recognition that there might be an issue (“…the sharing and accessing of environmental data collected by contractors seems to require improvement” (ISA, 2017c; rec. 6)). The consultants, however, suggest that the ISA should develop a policy on transparency and conflicts of interest and revise its regulations to set standards for confidentiality (Seascape Consultants, 2016b; rec. 31). However, no such recommendation appears in the ISA’s review committee report. The general rationale provided for not including some of the consultants’ recommendations is:

> “[…] The Committee decided not to pursue some of the recommendations as it became evident during its deliberations that they were quite far removed from the practices that the Authority had developed over the past 20 years and were currently unlikely to be accepted by consensus. […]” (ISA, 2017c.; para. 7)

It is worth recalling that in the ISA's rules of procedure, voting is permitted in both Council and Assembly when consensus cannot be found (ISA, 2012a; rules 56 and 61, reflecting the annex to the Part XI Agreement (1994), section 3.5). However, the core of the Committee's explanation risks giving the impression that because the ISA has not developed policies on data transparency, conflicts of interest, or standards for confidentiality, it is unlikely to do so. The Article 154 Review Committee report was subsequently accepted at the ISA's 2017 annual session in August.

3.5 Conclusions

The six components of good practice that emerged from this analysis are: i) access to information; ii) reporting; iii) quality assurance; iv) compliance information / accreditation; v) public participation; and vi) ability to review / appeal. It is posited here that these six expressions of best practices in transparency, which appear consistently across natural resource governance, should also be applicable to DSM.

The rules and regulations of the ISA have been forward thinking in some respects, such as allowing for the release of information after a given time period, and calling upon a precautionary approach. Furthermore, the Draft Regulations do indicate that transparency may be improving in some regards (e.g. making exploitation contracts publicly available). In many other ways, however, the ISA's rules, regulations, and procedures do not reflect modern best practices. Applying to the ISA the six expressions of best practices in transparency found here, several deficiencies were revealed: environmental and safety information have not been made available; annual reports are treated as confidential; quality assurance is unclear and not reported upon; compliance of States and contractors to ISA and related obligations is not reported upon; public participation is limited, with observers unable to participate in, or observe, key committee meetings; and, there are very limited avenues for civil society (or States Parties) to seek review or appeal of ISA decisions.

By not providing access to critical information, the ISA is at the mercy of its detractors. DSM is contentious, and spurious accusations are very difficult to evaluate or to defuse. [111] However, with limited information being shared, neither can such accusations be dispelled. Improved transparency, while not sufficient on its own, is nonetheless a key element of natural resource governance that is accountable, and thus more likely to yield desired trust from, and enduring benefits for, civil society and humankind as a whole. The ongoing drafting of ISA's DSM

[111] https://secure.avaaz.org/en/deep_sea_mining_loc/?pv=103&rc=fb

exploitation regulations offers a once-in-a-generation opportunity to build greater accountability and trust through greater transparency and public cooperation.

The results of our analysis clearly suggest that the International Seabed Authority will need to develop additional rules, regulations, and procedures if it wants to align with the international standards evaluated here. Contemporary transparency practices that have arisen from experiences in analogous industries could improve the long-term stability of the ISA. The rationale of the ISA's Article 154 Review Committee to not pursue several of the recommendations of the independent consultancy, including the development a transparency policy, remains obscure (Seascape Consultants, 2016b; rec. 31). This recommendation and other possible areas of improvement as a result of our analysis are summarised below (**Table 3-2**).

Because current ISA practices do not generally reflect international best practices in transparency, ensuring accountability from either the institution or its contractual parties engaged in mining will be difficult. Adding transparency to the ISA's rules, regulations, and procedures would further enable critical scrutiny, open debate, and informed decision making concerning the common heritage resources of the Area beyond national jurisdiction.

Table 3-2: Recommendations arising from this analysis

	Component	**Recommendations**[112]
i	Access to information	• Develop ISA policies on a) transparency, b) criteria and a process for determining when information is confidential. • Strengthen Draft Regulations to *require* publicly accessible data and information relating to the protection and preservation of the Marine Environment, as well as health and safety. • Develop an electronic database(s) compatible with existing international standards, capable of housing all data collected by contractors. • Require publication of exploration and exploitation[113] contracts.
ii	Reporting	• Publish annual reports submitted by Contractors. • Publish annual (audited) financial statements. • Require Committees to explain in their reporting to Council the rationale behind recommendations, including alternatives that were considered, and any dissenting opinions. • Publish environmental scoping reports, environmental impact assessments, environmental monitoring and closure plans.[114]

[112] Recommendations concerning the release of information assume that any confidential information will be identified and redacted (see recommendation 1b).
[113] The Draft Regulations require publication of exploitation contracts but existing exploration regulations do not.
[114] The Draft Regulations are silent on the question of final reports, but do require publication of the drafts.

iii	Quality assurance	• Develop quality assurance / quality control (QA / QC) standards that the LTC and Finance Committee will follow when assessing data and reports.
iv	Compliance information / accreditation	• Require ISA Committees to report annually on QA / QC results for each active Contract, as well as compliance with reporting requirements. • Allow for independent third-party verification of scientific data and financial information. • Establish a publicly visible process for addressing non-compliance.
v	Public participation	• Continue to solicit public comments on the development of regulations. • Report back on comments received and how they were addressed. • Expand public participation as discussed in the 2017 Discussion Document, including dedicated access to Committee meetings. • Broaden the definition of 'Interested Persons' to include, *inter alia*, ISA State Parties and Observers, and a process to determine eligibility.
vi	Ability to review / appeal decisions	• Establish a mechanism to allow for review and appeal of ISA decisions, including requests from third parties, concerning, *inter alia*, awarding and terms of contracts; approval of plans of work, environmental assessments and closure plans. • Re-consider the next Article 154 review committee structure such that a balance of external experts are included in its membership.[115]

[115] Equal balance of internal – external membership in review committees is commonly accepted practice in regional fisheries management organisations.

Chapter 4 Detecting the effects of deep-seabed nodule mining: simulations using megafaunal data from the Clarion-Clipperton Zone

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JA, HR, and DJ conceptualised the study. JA designed the simulations. JA wrote the R code, incorporating some code written by ES-L from another study. JA analysed the results and wrote the manuscript with contributions from DJ, HR, and ES-L. DJ and ES-L participated in the earlier research cruise which collected the data. ES-L previously processed and analysed the morphospecies and geomorphic classes of the photo data (published elsewhere).

Abstract

The International Seabed Authority is in the process of preparing exploitation regulations for deep-seabed mining (DSM). DSM has the potential to disturb the seabed over wide areas, yet there is little information on the ecological consequences, both at the site of mining and surrounding areas where disturbance such as sediment smothering could occur. Of critical regulatory concern is whether the impacts cause "serious harm" to the environment. Using metazoan megafaunal data from the Clarion-Clipperton Zone (northern equatorial Pacific), we simulate a range of disturbances from very low to severe, to determine the effect on community-level metrics. Two kinds of stressors were simulated: one that impacts organisms based on their affinity to nodules, and another that applies spatially stochastic stress to all organisms. These simulations are then assessed using power analysis to determine the amount of sampling required to distinguish the disturbances. This analysis is limited to modelling lethal impacts on megafauna. It provides a first indication of the effect sizes and ecological nature of mining impacts that might be expected across a broader range of taxa. To detect our simulated 'tipping point', power analyses suggest impact monitoring samples should each have at least 500-750 individual megafauna; and, at least five such samples, as well as control samples should be assessed. In the region studied, this translates to approximately 1500 – 2300 m^2 seabed per impact monitoring sample; i.e., 7500 - 11 500 m^2 in total for a given location and/or habitat. Detecting less severe disturbances requires more sampling. The numerical density of individuals and Pielou's evenness of communities appear most sensitive to simulated disturbances and may provide suitable 'early warning' metrics for monitoring. To determine the sampling details for detecting the desired

threshold(s) for harm, statistical effect sizes will need to be determined and validated. The determination of what constitutes *serious harm* is a legal question that will need to consider socially acceptable levels of long-term harm to deep-sea life. Monitoring details, data, and results including power analyses should be made fully available, to facilitate independent review and informed policy discussions.

4.1 Introduction

Originally proposed in the 1960s, commercial scale deep-seabed mining (DSM) has not yet occurred for a variety of economic, technological, and political reasons (e.g. Glasby, 2000). In the past ten years, however, interest has resurged. Here we look at possible effects from the mining one type of deep-sea mineral resource —polymetallic nodules—in the Clarion-Clipperton Zone (CCZ) of the northern equatorial Pacific. As of June 2019, there are 16 exploration contracts for polymetallic nodules in the CCZ (as well as one in the central Indian Ocean), with a 17th application in approval.

Because commercial DSM has not yet commenced, the exact nature and effects of such broad-scale stressors on deep-sea ecology are not yet known; however, there have been an increasing number of scientific studies that suggest effects will be long-lasting and widespread (e.g. Miljutin et al., 2011; Vanreusel et al., 2016; MIDAS, 2016; Stratmann et al., 2018; Simon-Lledó et al., 2019c). When looking at historical nodule mining simulations, most sites are still significantly depauperate in most faunal groups assessed over decadal time-scales (Jones et al., 2017). Organisms of different sizes and functional groups typically exhibit a different sensitivity to mining impact experiments (Jones et al., 2017), with suspension feeding megafauna usually showing the clearest responses to disturbance over decadal scales, both within the directly disturbed area and outside of it (Vanreusel et al., 2016; Simon-Lledo et al., 2019c). Assessing each aspect of potential harm will require statistically robust environmental monitoring that is designed beforehand to be able to answer regulatory concerns (Jones et al., 2017, 2018a) –a focus of this paper.

Under the United Nations Convention on the Law of the Sea (UNCLOS, 1982), states are required to ensure effective protection for the marine environment from harmful effects which may arise from their activities, including, “the prevention, reduction and control of pollution and other hazards to the marine environment […] interference with the ecological balance of the marine environment…” and ensure “the protection and conservation of the natural resources…” (UNCLOS, 1982; art. 145(a)(b)). The International Seabed Authority (ISA), has been given the mandate to oversee DSM in the legal ‘Area’ beyond national jurisdictions. It is currently preparing DSM exploitation regulations in which it must take actions to prevent “serious harm” to the marine environment, which can include rejecting applications as well as suspending mining operations already underway (UNCLOS, 1982; art. 162(2)(w)(x), 165(2)(k)(l)).

Although interpretation of *serious harm* is still under discussion, in the case of nodule mining it could be extensive. Levin et al. (2016) suggest that it would likely include: i) resuspension and deposition of sediments over large spatial scales causing a substantial change to the existing ecosystem; ii) impacts that may persist for decades to centuries; iii) loss of much of the hard substrate habitat, as well as the specialized nodule fauna; and, iv) the extinction of hundreds or more of undescribed species, especially those with small biogeographic distributions. The areal footprint of polymetallic nodule DSM is expected to be the largest of any kind of DSM (and larger than terrestrial mining) on the scale of several hundred square kilometres of seafloor each year per operation (Oebius et al., 2001; Smith et al., 2008; Ruhlemann & Knodt, 2015). Additionally, it is thought that the effects of sediment plumes arising from the collection of nodules and waste water return could considerably amplify the footprint of affected biology beyond that of the immediate mined area (Smith et al., 2008; Jones et al., 2018b; Aleynik et al., 2017). The extent and nature of sediment plume impacts, long suspected to be a major environmental stressor (Burns, 1980) has been a topic of recent and ongoing research projects (MIDAS, 2016; JPI Oceans, 2018). Neighbouring nodules and other hard substrata, and their associated suspension-feeding organisms, are at risk of being (partially) buried in plume sediments and may be unsuccessful in colonising new locations nearby. Nodules are generally associated with suspension feeders (Tilot, 2006, Vanreusel et al., 2016; Simon-Lledó et al., 2019a).

The use of photogrammetric methods in deep-sea exploration has led to megafauna being defined as those organisms large enough (typically > 1 cm length) to be detected in photographs (Grassle et al., 1975), which can be readily acquired nowadays using remotely operated or autonomous underwater vehicles (e.g. Jones et al., 2009; Morris et al., 2014). They are typically the target of disturbance assessments aimed to aid management and conservation activities (Bluhm, 2001; Jones et al., 2012; Bo et al., 2014; Boschen et al., 2015; Vanreusel et al., 2016; Simon-Lledó et al., 2019c). Numerical ecology studies targeting megafauna have emerged in the past decade as a cost-effective approach for the biological monitoring of deep-sea habitats, given the large seabed areas that can be surveyed using ROVs and AUVs and the improved efficiency of ship time investment. Megafaunal taxa richness in the CCZ is one of the highest in the abyssal ocean (Simon-Lledó et al., 2019a), reaching over 200 morphospecies even in local assessments (Amon et al., 2016). Assessments based on images are also expected to underestimate true species diversity (Glover et al., 2016). Although megafaunal diversities are high, densities are low (e.g. ~0.5 ind. m^2, Simon-Lledó et al., 2019a), possibly as a result of the low food availability in the abyssal environment (Lutz et al., 2007). However, megafauna living in areas with higher nodule coverage appear to have relatively higher densities (Vanreusel et al., 2016; Simon-Lledó et al., 2019b) and many species, particularly suspension feeders, exclusively live on the hard substratum provided by nodules (Dahlgren et al., 2016; Taboada et al., 2018). Areas with lower nodule coverage have a higher proportion of deposit feeders, such as holothurians (Stoyanova, 2012). Using the same data as used here, an investigation of metazoan megafauna along nodule density gradients has revealed complex non-linear associations. However, the megafaunal community differences between non-nodule areas and nodule areas were much greater than the differences within the nodule gradient (Simon-Lledó et al., 2019b).

This paper seeks to improve the methodology used to detect and monitor local harm associated with the nearby mining of polymetallic nodules. It uses a numerical model that simulates a variety of impacts on CCZ megafauna. Then, looking at what little is known about statistical effect sizes of mining-related stressors on deep-sea ecology, initial conclusions can be drawn on what monitoring design may be necessary to detect changes before they exceed policy thresholds and interfere with the 'ecological balance' of the surrounding area, causing 'serious harm'. This paper will restrict itself to impacts peripheral to mining operations spread across spatial and ecological gradients, which can be expected to be less severe (and therefore harder to detect) than in directly mined areas. It seeks to answer the question: *what monitoring design, as a minimum, is likely to be necessary to reliably detect impacts of polymetallic nodule mining on neighbouring biodiversity, before serious harm occurs?* We consider the statistical power associated with a range of impacts, and associated statistical effect sizes, using different metrics of ecological community structure and biological diversity. From these simulations we discuss the potential of leading indicator metrics of impact, and recommend sample size and replication.

4.2 Materials and Methods

4.2.1 Data collection and identification

Data collection methods and seafloor characteristics are described in detail by Simon-Lledó (2019) and Simon-Lledó et al. (2019a), briefly summarised here. The data are from a photographic survey of a 5500 km^2 rectangular region of seafloor centred on 122° 55' W 17° 16' N within the southwest corner of an 'Area of Particular Environmental Interest' (APEI) designated by the ISA as APEI-6. The survey location within the APEI was selected to have similar topographic relief to mining contract areas in the central CCZ. Water depth is from 3950 to 4250 m.

Photographic data were collected using the Autosub6000 (see e.g. Morris et al., 2014) with a target altitude of 3 m +/- 1 m above the seafloor. At the target altitude, individual photographs imaged 1.71 m^2 of seabed. A total of 40 zig-zag sampling units each containing thousands of photographs were surveyed in each of three landscape types (troughs, flats, ridges). Four zig-zag sampling units per landscape type were randomly selected for subsequent analysis. Images taken as the vehicle changed course were discarded. Additionally, every second image was removed to avoid overlap between consecutive images, the risk of double counting, and to reduce the effects of auto-correlation.

Nodule coverage was calculated from imagery using the Compact-Morphology-based poly-metallic Nodule Delineation method (CoMoNoD; Schoening et al., 2017). Only nodules ranging from 0.5 to 60 cm^2 (i.e. with maximum diameters of ~1 to ~10 cm) were considered to avoid inclusion of atypically small or large nodules or non-nodule formations.

Images used for metazoan megafauna data generation were reviewed in random order to minimise time or sequence-related bias (Durden et al., 2016). To ensure consistency in specimen detection, after analysing the detectability of organisms, only individuals greater than 1 cm in length were considered (Grassle et al., 1975; Simon-Lledó (2019), pp 14-15). Numbers of individuals detected rises consistently, the smaller they are, up until this cut-off (Figure S2, supplementary materials). A megafauna morphospecies catalogue was developed and maintained in consultation with international taxonomic experts and by reference to the existing literature (Amon et al., 2017; Dahlgren et al., 2016a; Molodtsova et al., 2017). Individuals that could not be placed into a morphospecies category were removed from the degradation analysis dataset but were assigned a higher-order identification for their inclusion in overview statistics (e.g. overall metazoan density). Attachment of individuals to nodules and other hard substrates was recorded.

4.2.2 Habitat classification

The study area was treated as a whole ('All' class) and also classified into areas with 'No-Nodules', and with 'Nodules'. The No-Nodule class constitutes areas with 1% or less nodule coverage and the Nodule class comprises areas with >1% nodule coverage (Simon-Lledó et al., 2019b). Separately, the Nodule class was further stratified based on previous work by Simon-Lledó et al. (2019a) into three geomorphic classes: 'Trough', 'Flat' (<3° slope), and 'Ridge'.

4.2.3 Species-level degradation treatments

Morphospecies-level stress processes were simulated to predict community-level responses to mining disturbance. Two general types of possible stressors were simulated: one that impacts morphospecies selectively, based on their affinity with nodules; and another that randomly affects all morphospecies present, based on their location. The first stressor can be expected to affect rank abundance of morphospecies, community structure and composition; whereas the second affects the overall abundance (i.e. density) of morphospecies more generally, albeit differently in different places. Two magnitudes of each stressor (n = 3, including the no stress condition) are applied alone and in combination for a total of nine *treatments*, including no degradation, which is used as the baseline comparison case. The stressor magnitudes and combined treatments presented here were selected after exploration of a broader range of possibilities, chosen to illustrate a range of effects with a minimum number of examples. The simulations were also designed to emulate non-linear responses, such that low amounts of a given stressor when applied alone could be absorbed with little or no mortality. Each of the nine degradation treatments (including the no-stress baseline) were applied to the six habitat classes described above (including the All class) for a total of 54 combinations.

The survival / mortality of observed individuals in a given sub-sample was simulated on the scale of the survey photos. Sub-samples of specified sizes (see below) were randomly created from the pool of survey photos, each of which was then subjected to the combinations of stressors (treatments). When conceptualising the quantum of the impacts, it is helpful to know that mean metazoan megafauna density is very low in the CCZ seabed. In almost all non-zero observations (95.8%), morphospecies in a photo are encountered as single individuals (mean value = 1.0106), with a maximum of three individuals of a given morphospecies ever found in a single photo (7 of 132 morphospecies were ever observed as n=3 in a photo; accounting for just 0.42% of all non-zero observations). Thus, in our simulations, individuals usually either ‘survive’ or ‘die’, but very occasionally can be ‘culled,’ if two or three are present. Survival is a value that equals, or is rounded up to, a whole number; whereas death is that which equals or is rounded down to a lower whole number than was present to begin with, usually being zero. A value of 0.5 is rounded up (=1, survival).

4.2.3.1 Nodule affinity stressor

The first simulated stressor is based on nodule affinity. The more a morphospecies is associated with nodules, the greater the impact of the stressor. There is no stochasticity built into this stressor. The degradation formula for each morphospecies in a photo of sub-sample ‘i’ is:

AffinityDegradedAbundance(i) = Abundance(i) – (Abundance(i) x NoduleAffinity x StressorFactor)

Where: NoduleAffinity is the proportion of observations where a morphospecies is seen on, or otherwise associated with, a nodule, ranging from 0 to 100%. StressorFactors used are: 0, 25% and 51%.

A StressorFactor of 51% was chosen instead of 50% to avoid all individuals of morphospecies 'surviving' owing to rounding up. Note that under the 25% stressor, all singletons and doubletons in a photo are guaranteed to survive; i.e. at this low level, the impact of the stressor is largely invisible. In general, its effect can only be seen when it is combined with the second stressor, described below. For this reason, it is not displayed in the results panels.

(In the unusual situation where there are three individuals of the same morphospecies observed in a photo (0.42% of non-zero observations), the 25% stressor could produce mortality, but only if the level of nodule affinity is greater than 83.3%.)

This simulated stressor assumes that those suspension feeders associated with nodules will be vulnerable to sediment plumes, and that the impacts on nodule-associated morphospecies are the same in all locations, unlike the stressor below. Suspension feeders not reliant on nodules are not affected by this simulated stressor, though in reality they may also be vulnerable; thus, this simulated stressor is conservative in its assumptions.

4.2.3.2 Stochastic areal stressor

The second stressor type is applied stochastically to each sub-sample, such that some places will be affected more than others. A sediment plume, for example, is unlikely to fall evenly in the monitoring sites surrounding a mining operation, even though on average it can be expected to diminish moving further away from operations. The resultant stressor mimics varying areal impacts and can vary stochastically +/- the value of the stressor factor. The stochastic modifier is a random linear function, with all values in its range equally probable. Since its range is +/- the value of the stressor factor, over many runs it will tend to converge on its central value, the stressor factor. Stressor factors of 0 (i.e. none), 26% (i.e. ranging from 0-52% under the influence of the stochastic modifier), and 50% (0-100%) are applied separately and in combination with the first treatment described above. The formula is like the one above, with StocasticModifier replacing nodule affinity, for each sub-sample 'i':

ArealDegradedAbundance(i) = Abundance(i) – (Abundance(i) x StocasticModifier x StressorFactor)

Note that a StressorFactor of 26% was chosen instead of 25% so that occasionally the result of this treatment when applied alone would exceed 50% (range 0-52%) and randomly 'kill' an individual. (Recall that 95.8% of all non-zero observations in a photo were of single individuals.) Its effect is therefore small, but visible, and is displayed in the results.

Unlike the nodule affinity stressor above, this simulated stressor treatment assumes that the impacts are the same across all morphospecies in a given sub-sample; i.e. not affected by biology. However, it further assumes that the impacts will not be uniform in space, and some areas will be impacted more than others.

4.2.3.3 Combined treatments and assumptions

When stressors from each treatment are combined, to an extent their individual assumptions above are addressed; i.e. both location and biology now affect the results. Numerically, the two formulae are added together, but the resultant value is rounded only after the addition. Although a morphospecies may have survived either stressor in isolation, the addition of them together will often be sufficient to cause rounding down – a mortality. The two degradation stressors are commutative; i.e. they are not affected by ordering and the same treatment could be calculated with the second applied first. Combined treatments assume that the individual stressors are additive (e.g. they are not multiplicative or work differently in different combinations or environments).

4.2.4 Metrics

In order to detect the above-described degradation treatments, metrics need to be selected. There is no single measure of biological diversity, community structure, or indeed ecosystem health. Nevertheless, more robust assessments can be expected to result from the exploration of different components of biological diversity and community structure, such as species abundance (density), number (richness), and variety (e.g. taxonomic distinctness, phylogenetic distances, and/or functional roles) (Chao et al., 2010). The first two of these attributes are commonly measured, whereas the third requires information currently unavailable for most deep-sea organisms, requiring further assumptions, and is not considered here.

For some of the more commonly used biodiversity metrics to be comparable and intuitive, they can be transformed into a general framework put forward by Sibson (1969, cited by Hill (1973)) and further developed by Mark Hill (1973), known as the 'effective number of species;' i.e., the number of equally abundant species that are needed to give the same value of the diversity measure (Jost, 2006; Chao & Jost, 2012). From these are derived the so-called Hill numbers, reflecting the degree to which relative abundance affects the result. For Hill no. = 0 (species richness), the relative abundance of species has no influence at all; whereas for Hill no. = 2 (inverse Simpson) the most common species have the most influence, and rare species very little. For this analysis, metrics for Hill numbers 0, 1, 2 are explored; i.e. richness, exponent Shannon, and inverse Simpson.

Other metrics (density, geometric mean, Fisher's alpha, Pielou's evenness, and Chao1 estimator) are also considered owing to their potential to be sensitive to changes in the abundance and population structure of (degraded) ecological communities (**Table 4-1**).

Table 4-1: Metrics used to detect changes in biodiversity & other ecological properties
Metrics with an asterisk (*) are presented in the supplementary materials in Appendix C, **Figure 5-5**, **Figure 5-6**, **Figure 5-9**, & **Figure 5-10**.

Measure	**Explanation of units**	**Comments**
Density	Number of individuals per m^2	A measure of abundance, corrected for area. Does not consider the number of species.
Geometric mean*	Mean abundance of [morpho]species, zeros removed	A measure of abundance, corrected for ecological dominance. Assumes species distribution follows a geometric series, sometimes associated with ecological niche apportionment (He & Tang, 2008). Cannot handle before-after comparisons with zero values.
Richness	Number of [morpho]species (Hill number 0)	A simple measure of diversity. Every species is given the same weighting, rare and common alike. No accounting for abundance.
Exponent Shannon*	'Effective number' of [morpho]species (Hill number 1)	A combined measure of diversity: richness and evenness of community structure. Some weighting given to relative species abundance.
Inverse Simpson	'Effective number' of [morpho]species (Hill number 2)	A combined measure of diversity: richness and evenness of community structure. Much weighting given to relative abundance; i.e. the common species.
Pielou's evenness (Pielou, 1975)	Non-dimensional ratio of Shannon evenness corrected for richness, a so-called 'Hill ratio'.	A measure of relative evenness of community structure. It provides the amount of evenness relative to the maximum and minimum possible for a given richness (Jost, 2010).
Fisher's alpha*	Non-dimensional constant derived from logarithmic fitting of species distribution	A measure of community structure (conceptually related to evenness). Assumes a logarithmic species distribution, which many deep-sea communities follow, including these data.
Chao1 estimator* (Chao, 2005)	Estimated total number of [morpho]species in a sampled region.	An estimate of total species richness, influenced by singletons and doubletons in the sample (which are commonly found in the deep sea).

4.2.5 Power analyses

The statistical power of detecting changes from the baseline condition was calculated for each treatment and measure. Custom R scripts (R Core Team, 2018) - using the ‘vegan’ package (Oksanen et al., 2016) and the ‘pwr’ package (Champely et al., 2018) - simulated degradation, while calculating the metrics and their statistical power (our R code is provided in Appendix C, section C.4).

The number of sampling sites required to reliably detect a treatment is dependent upon the magnitude of the stressors being measured, the metric, sample size, and desired error thresholds (type I and type II). For each of the degradation treatments and metrics, power analyses were conducted, using two-tailed t-tests with a significance of 0.05 and confidence levels (avoidance of type II error) of 80%, 90%, and 95%. Statistical effect size was calculated for each treatment and measure, using Cohen’s *d,* corrected for using sampled data. (Cohen's *d* is the difference between two means divided by their pooled standard deviation.) As that megafaunal sub-sample sizes were larger here than what historically has been collected, Hedge’s *g* was not used to correct for small samples as had been done in an earlier meta-analysis (Jones et al., 2017).

4.2.6 Sub-sampling size and replication

Drawing from the larger dataset with replacement, 2000 random sub-samples were created for each of the nine degradation treatments for a range of surveyed area sizes. Regarding the size of the sub-samples, Simon-Lledó et al. (2019a) note that when using the same APEI-6 data set as here, stable estimation of biodiversity-related parameters was extremely variable. For example, estimation of mean richness required the largest sub-sample size to plateau (>1000 individuals) while density required the smallest (>30 individuals). Arithmetic mean within sample dissimilarity (autosimilarity) required sub-sample sizes >250 individuals to stabilise, whereas mean exponent Shannon stabilised with sub-sample sizes >350 individuals. Based on these results, and upon the expectation that the abundance of individuals will decline after degradation treatments, starting sub-samples of 250, 500, 750, and 1000 individuals were explored.

Consideration was also given to developing methods that could be cost-effectively applied in commercial operations, and for that reason it was decided to use fixed-area replicates, rather than fixed-abundance replicates, which require greater survey effort and post-hoc processing. Calibration runs were used to translate the desired numbers of individuals into fixed-area sub-samples (**Table 4-2**).

Table 4-2: Mean number of individuals, standard deviation, & mean area of sub-samples across 2000 randomisations.

		Sub-sample targets (individuals)			
Habitat		**250**	**500**	**750**	**1000**
	mean	249.1	497.9	748.6	998.1
No Nodules	**standard deviation**	15.5	22.2	25.9	31.9
	sub-sample area (m^2)	1963.9	3922.1	5879.2	7835.6
	mean	249.6	499.5	748.3	1000.1
Nodules	**standard deviation**	16.4	23.1	28.3	39.0
	sub-sample area (m^2)	722.1	1441.5	2159.5	2877.2
	mean	249.7	499.7	750.3	1000.2
All	**standard deviation**	16.4	22.4	28.8	32.2
	sub-sample area (m^2)	777.3	1550.9	2323.9	3096.8

4.3 Results

In our simulations of impacts, using deep-sea data from the CCZ ensured that the salient mathematical properties of its deep-sea species distributions were captured in the measurements; namely, the log-linear rank abundance distribution, low density (on average < 0.33 ind. m^{-2}), high [morpho]species richness (which did not plateau at any of the sub-sample sizes, indicating that morphospecies richness was not fully characterized in any of the sample unit sizes used), and the 'long tail' of singletons, doubletons, and tripletons that accounted for more than one-third of all observations within the study area (> 18 000 m^2) (c.f. supplementary **Figure 5-3**, **Figure 5-4**, **Table C-3: Summary of the habitat classes**; Simon-Lledó et al., 2019a, Jones et al., 2017; Amon et al., 2016; Durden et al., 2016; Tilot, 2006).

4.3.1 Degradation treatments

The eight degradation treatments caused a wide range of impacts; morphospecies abundance can be reduced by more than 75%, and morphospecies richness by nearly 40% (**Table 4-3**). As might be expected, the nodule affinity stressors, which affected only a subset of morphospecies, had less of a detectable impact than the broader stochastic areal treatments (**Figure 4-1**). As intended in the numerical model, their combined effect is greater than the sum of their separate effects (**Table 4-3**). Initial impacts by just one stressor alone are more difficult to detect, but then emerge when the second stressor is applied, increasing rapidly when either stressor is increased. This can be seen in the transition from a 26% stochastic areal stressor alone (notated as '0 + 26a' per **Table 4-3**) to when a 25% nodule affinity stressor is added to it ('25n + 26a'; **Table 4-3**). In the case of sub-samples starting with 750 individuals, the first stressor reduces mean abundance to about 709 individuals (-5.5%), but the introduction of the second stressor reduces it further to about 574 individuals (-23.5%). In this example, morphospecies richness has declined from 79 (baseline) to 78 to 76. However, the addition of any further stressor, reduces morphospecies richness much more, to 69, then 61, 58, and 53 (**Figure 4-1**).

Table 4-3: Degradation treatments, their mean impacts on abundance & morphospecies richness

Applied across the four sub-sample sizes (250, 500, 750, 1000 individuals), without differentiating habitat (i.e. the 'All' class)**.** *The centre column lists the treatment codes used in the figures throughout this paper*, where 'n' is for nodule affinity-based degradation and 'a' is for area-based stochastic degradation (both in percent). The 26% areal stressor can stochastically vary +/- 26%; i.e. 0-52%. Likewise, the 50% areal stressor has a stochastic range of 0-100%. Total number of simulations summarised here are: 4 sub-sample sizes x 9 treatments (including the baseline) x 2000 randomisations x 1 class = 72 000.

Stressors		**Treatments**	**Mean impacts**	
Nodule affinity	**Stochastic Areal**	**Code**	**Abundance**	**Richness**
25%	0	25n + 0	-0.23%	-0.02%
51%	0	51n + 0	-3.07%	-1.81%
0	26%	0 +26a	-5.49%	-1.35%
0	50%	0 +50a	-49.81%	-23.44%
25%	26%	25n +26a	-23.68%	-4.69%
25%	50%	25n +50a	-59.37%	-26.45%
51%	26%	51n +26a	-54.84%	-14.43%
51%	50%	51n +50a	-76.24%	-37.31%

The impacts associated with the (25n+26a) treatment presage increased losses of morphospecies (i.e. local extirpations), should the simulated stressors continue to increase. We focus on this treatment in particular when considering the properties of the various metrics below, as a simulated 'tipping point'.

Losses of abundance and morphospecies can be readily measured through density and richness, respectively. However, richness is a relatively insensitive measure as it requires complete removal of a species to detect a change. Six metrics more sensitive to ongoing changes were also considered. Of these, exponent Shannon, inverse Simpson, Pielou's evenness, and Fisher's alpha each take into account both density and richness.

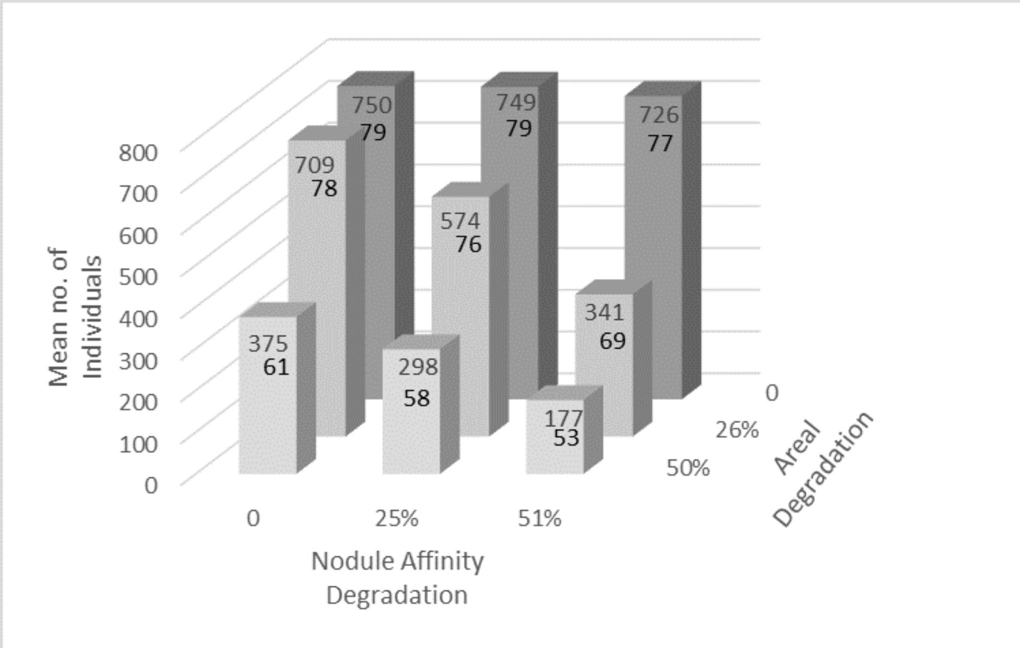

Figure 4-1: Example of impacts of the degradation treatments
on mean abundance (upper number) and mean morphospecies richness (lower number), for 2000 sub-samples calibrated to contain approximately 750 individuals initially (y-axis). For simplicity, just the 'All' class is shown; i.e. without any data stratification. Note that the nodule affinity stressor alone (x-axis, back row of dark columns) has little or no impact, but that its influence becomes apparent when combined with the stochastic areal stressor (z-axis). These two different 'StressorFactors' (in percent) and how they were applied, are described in the methods.

Perhaps counter-intuitively, these four metrics at first generally *increase* as the stressors used in this analysis increase, before dropping off again. This is because the stressors tended to impact the more abundant morphospecies that are more widespread, many of which are also associated with nodules (e.g. porifera). Reducing the dominance of the most common morphospecies increased evenness and hence the heterogeneity diversity metrics increased. When No-Nodule and Nodule classes are separated out, the effect is further heightened in the Nodule class owing to the nodule affinity stressor, and dampened in the No-Nodule class, as would be expected (**Figure 4-2**).

Exponent Shannon and inverse Simpson perform very similarly across all treatments. As impacts increase and richness drops, Pielou's evenness, being a measure of evenness corrected for richness, does not decline like the other metrics, but stays at a value higher than the baseline throughout the treatment regime, suggesting a change to the 'ecological balance' of the data; i.e. a flattening (and foreshortening) of the log-linear rank abundance distribution of the morphospecies (**Figure 4-2** and supplementary **Figure 5-5**). It has generally less variability across randomisations (narrower error bars) than the three other related metrics, with Fisher's Alpha being the most variable (**Figure 4-2** and supplementary **Figure 5-5**, **Figure 5-7**, & **Figure 5-9**).

The remaining two metrics considered here, geometric mean of morphospecies abundance and the Chao1 estimator, are alternative ways to measure abundance and richness, respectively. They both decline steadily under the treatment regime. Having greater variability, however, neither measure appears to provide any additional information to what is already captured in the simpler metrics of density and richness (compare **Figure 4-2** and Supplementary **Figure 5-5**).

Given the lethal nature of the simulations on individuals, changes in density were most apparent, as would be expected. Unlike the other metrics, changes in density were readily detectable at lower impact treatments (e.g. (0 + 26a)) across all sub-sample sizes, even the smallest (250 individuals). Density was the only measure that was significantly different (i.e. at or outside the 95% error bars) across all habitat classes. Although not a biodiversity metric per se, changes in total density preceded broader impacts upon biodiversity yet to come. Treatments more severe than the (0 + 26a) treatment (i.e. (25n + 26a) and greater) were detected by all eight of the metrics (**Figure 4-2**, & **Figure 5-5**). However, unlike density, their power of detection is not visually obvious from the plots, and power analysis is required.

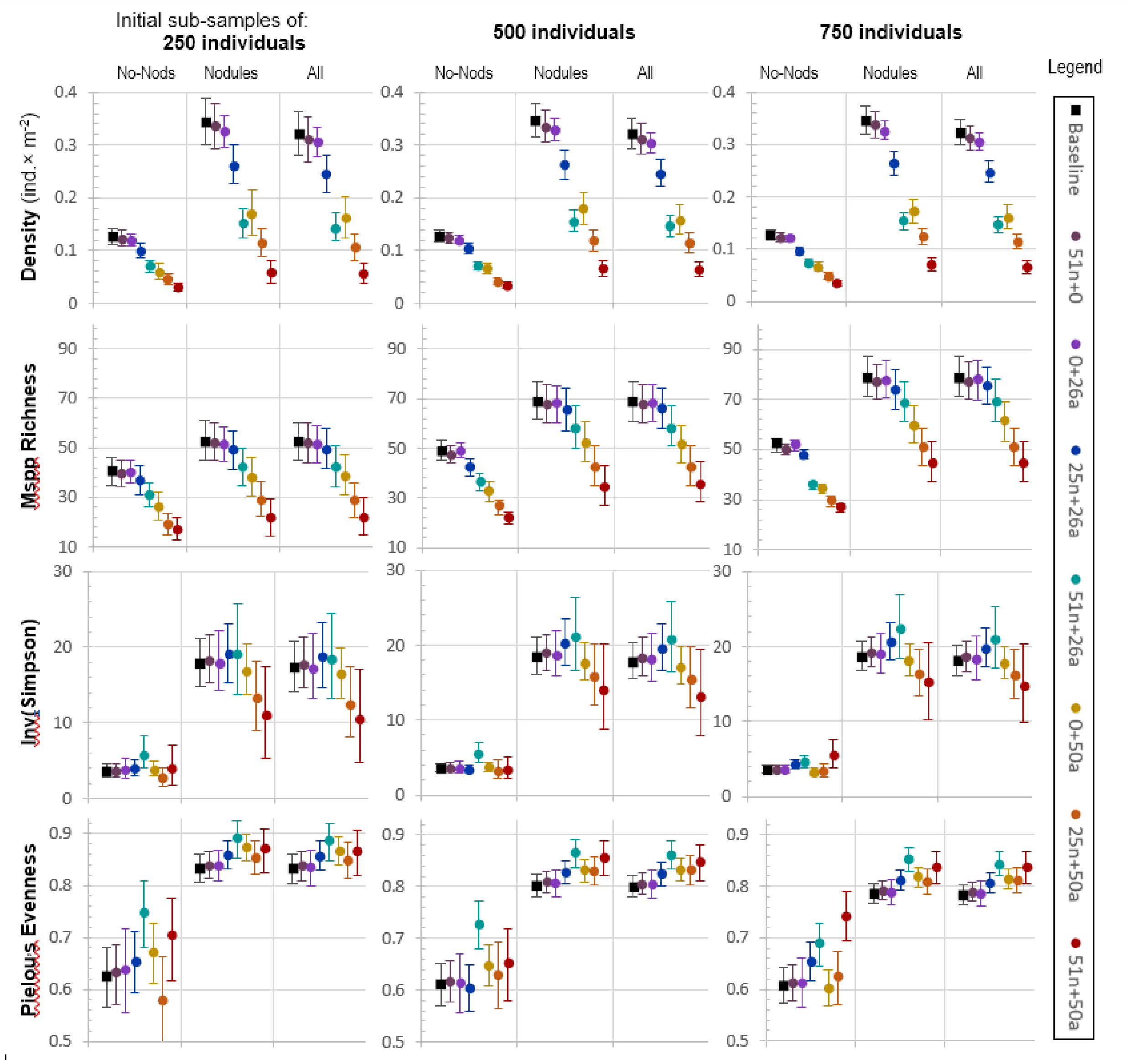

Figure 4-2: Seven degradation treatments
(plus baseline) across three sub-sample sizes (250, 500, 750 individuals), captured using four metrics: density, morphospecies richness, inverse Simpson, and Pielou's evenness (leftmost labels). The treatment codes in the rightmost legend are explained in **Table 4-3**. They are ordered according to increasing combined impacts left to right, violet to red. Error bars depict the 95% range of results (a proxy for confidence) over 2000 simulations. One of the treatments (25n + 0) is not displayed because in isolation it had very little impact. Sub-samples of 1000 individuals performed very similarly to 750 and are therefore not shown. Four additional metrics are displayed in Supplementary Materials, **Figure 5-5**.

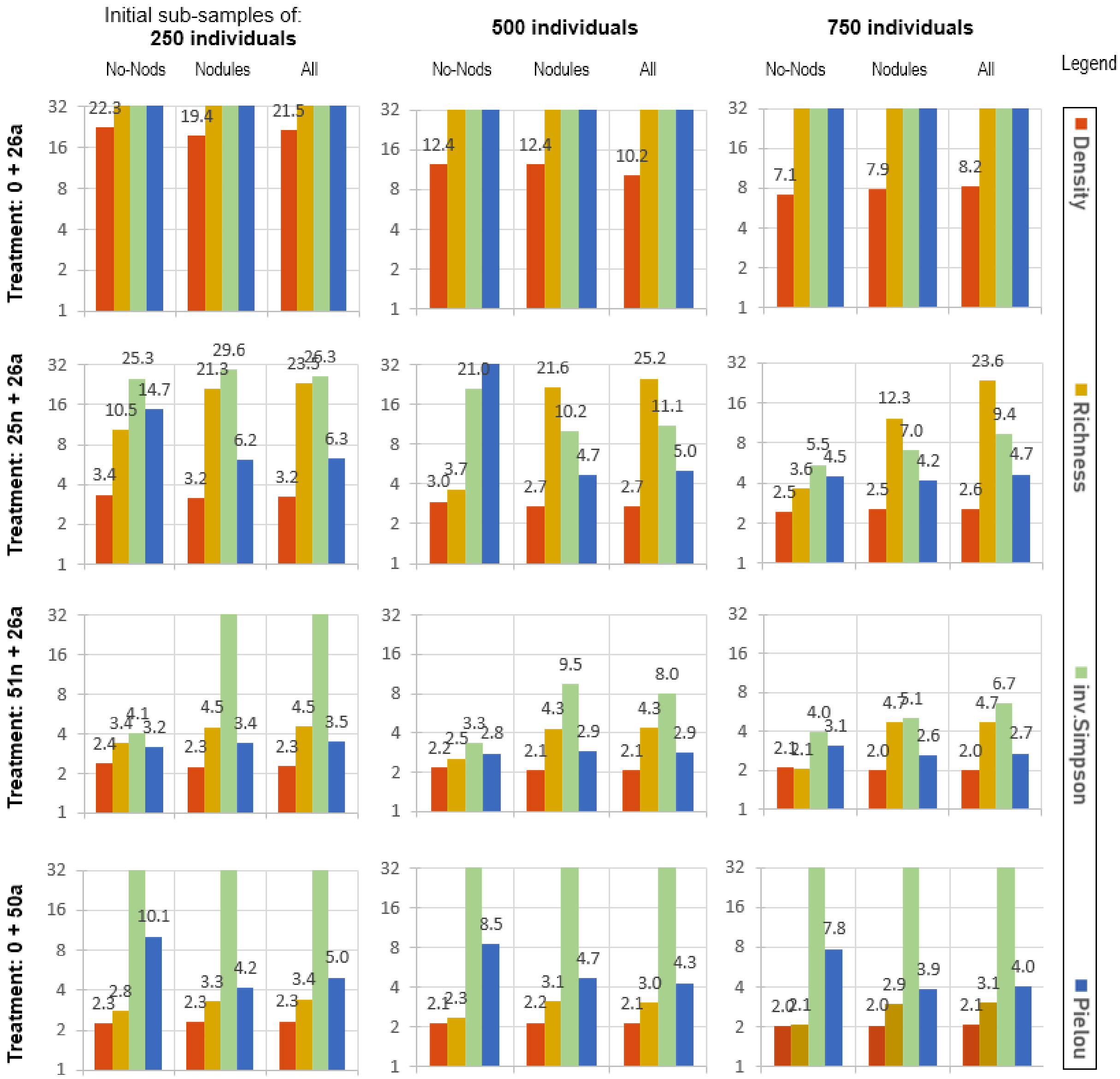

Figure 4-3: Power analysis of the four metrics in Figure 4-2 above (rightmost labels), across three initial sub-sample sizes (250, 500, 750), under the four middle degradation treatments (leftmost legend, explained in **Table 4-3**), increasing in severity from top to bottom. Two-tailed t-test error thresholds: significance ≤ 0.05; power (type II confidence) ≥ 95%. The y-axis is logarithmic, depicting the theoretical number of sampling sites required to meet these error thresholds (≥ 2). Values greater than 32 are not fully displayed, as they would be impractical to implement. Additional metrics are displayed in Supplementary Materials (Appendix C) **Figure 5-5** & **Figure 5-6**.

4.3.2 Power analyses

As would be expected, the larger impacts require fewer monitoring sites to be detected. Also as expected, larger area monitoring sites (i.e. sub-samples with more individuals) produce less variability than smaller ones, and require fewer replicates, though the relationship is non-linear. The statistical effect size varied according to treatments, sub-sample size, *and* metrics. For example, the (25n + 26a) treatment, 'All' class, with sub-samples of 250 individuals, Cohen's *d* was about -3.86 with regard to density, 1.80 for Pielou's evenness, and -0.78 for richness (**Table 4-5**).

As noted above, density requires the fewest sites to detect changes in abundance (usually 3 is sufficient; **Figure 4-3**), though its ecological interpretation is limited because it does not detect compositional changes. Richness, which does detect compositional change, is unable to detect early declines when a given morphospecies is still present. For the (25n + 26a) treatment, for example, richness declined only about 5%, and thus about 24 replicates would be required to detect that change (significance ≤ 0.05, confidence ≥ 95%; sub-sample size of 750 individuals; **Figure 4-3**).

In detecting compositional change before [morpho]species are lost, exponent Shannon and inverse Simpson perform similarly. To detect the (25n + 26a) treatment, about 10 sites (of 750 individuals) are required –as compared to the more than 20 required by the richness measure. However, detecting change in evenness alone, using Pielou's evenness, requires half that again (~5; **Figure 4-3** and **Figure 5-6**).

Increasing the confidence from 80% to 95% often means adding only one more monitoring site (**Table 4-4**). The effect of sub-sample size is often non-linear; i.e., the power gained through using large monitoring sites of 1000 individuals is not usually twice as great as for 500 (though see exponent Shannon, **Table 4-4**). The statistical effect size, per Cohen's *d,* increases for most metrics (except richness) as sub-sample size increases (**Table 4-5**).

Table 4-4: Number of monitoring sites required to detect the (25n + 26a) treatment as compared to the baseline. Treatments greater than (25n + 26a) cause disproportionately greater losses of biodiversity; hence the value in detecting this one. Power analysis results for five metrics, for three different levels of confidence (avoidance of type II errors; 1-β), across four sub-sample sizes (number of individuals), using a two-tailed t-test with desired significance held at ≤ 0.05. No habitat classification was used.

Measure	Confidence	Sub-sample size			
		250	**500**	**750**	**1000**
Density	**80%**	2.76	2.41	2.28	2.16
	90%	3.03	2.59	2.43	2.29
	95%	3.25	2.74	2.56	2.39
Richness	**80%**	14.99	16.01	15.08	11.35
	90%	19.37	20.73	19.49	14.49
	95%	23.46	25.16	23.62	17.42
exponent Shannon	**80%**	30.10	9.19	6.47	4.23
	90%	39.62	11.59	7.92	4.93
	95%	48.53	13.82	9.27	5.57
inverse Simpson	**80%**	16.68	7.59	6.55	4.25
	90%	21.63	9.43	8.03	4.95
	95%	26.27	11.15	9.41	5.59
Pielou's evenness	**80%**	4.67	3.91	3.68	3.03
	90%	5.51	4.50	4.20	3.35
	95%	6.29	5.03	4.67	3.64

Table 4-5: Cohen's d, a measure of effect size, for the (25n + 26a) treatment for five different metrics across four sub-sample sizes. Cohen's *d* is the difference between two means divided by their pooled standard deviation.

		density	richness	inv. Simp.	exp. Shannon	Pielou's evenness
Sub-Sample Size (individuals)	**250**	-3.86	-0.78	0.73	0.53	1.80
	500	-5.51	-0.75	1.20	1.05	2.19
	750	-6.60	-0.78	1.34	1.35	2.36
	1000	-8.12	-0.92	1.99	1.99	3.21

4.3.3 Impacts to different habitats

Some habitat-specific impacts were observed. For example, the (51n + 26a) treatment is much more easily detected for the Flats habitat (which has the highest density of nodules) than for Troughs or Ridges (Pielou's evenness & inv. Simpson, **Figure 5-7**).

Usually, the addition of classes means additional monitoring sites (**Figure 4-3** vs. **Figure 5-8** & **Figure 5-10**). An exception is richness. For the (25n + 26a) treatment, with sub-samples of 750 individuals, the two-part classification based on no-nodules / nodules requires 12.3 sites (nodules class) plus 3.6 (no-nodules class) totalling to 15.9 sites in all. No classification ('All') requires 23.6. Hence, in this example, using this two-part classification would be more cost effective. However, if smaller sub-samples of 500 individuals are used, this economy is lost, and the total number of sites require is approximately the same with or without the classification (~25; **Figure 4-3**, 3rd row).

4.4 Discussion

To reliably detect the impacts of polymetallic nodule mining, before serious harm occurs, our results suggest the use of impact monitoring sampling unit sizes of at least 500-750 individuals each and a minimum replication of five of such samples collected in both disturbed and control sites. In the northeast CCZ, this translates to approximately 1500 – 2300 m^2 per impact monitoring site; i.e., 7500 - 11 500 m^2 of seafloor surveyed in total for reliable detection of disturbance-mediated variations in megabenthic features at a local scale. These particular details will change if different license areas in the CCZ have different megafaunal species distributions. However, the approach and choice of metrics presented here should remain relevant. For example, while the community composition and species present will indeed vary from place to place or time to time, total macroecological metrics tend to vary less than those that are species specific (e.g. Ernest et al., 2008, 2009; Ruhl et al., 2014). Ecological parameters such as numerical density and Pielou's evenness can be used to track loss of abundance and changes to some aspects of community structure (evenness), respectively. If severe damage occurs, the more readily communicated and understood metric of richness can also be used to help characterise it; however, richness is unable to detect early warnings before species extirpation occurs.

Larger sampling unit sizes typically yield more accurate characterizations of biological communities (Gotelli and Colwell, 2001). Here, the smallest sub-sample size considered (250 individuals) displayed disproportionately greater variability across metrics, making detection of the smaller impacts more difficult (i.e. of lower statistical power), and therefore cannot be recommended. Furthermore, effect size usually increased with sample unit size; hence the treatments became more detectable as sample unit size increased.

Increasing the desired confidence from 80% to 95% often required just one more monitoring site. Because a false negative result could mean that harmful impacts are not detected, the more precautionary 95% confidence threshold is recommended here, as displayed in the results (**Figure 4-3** and supplementary **Figure 5-6**, **Figure 5-8**, & **Figure 5-10**).

In our simulations, two commonly used measures of 'diversity' (exponent Shannon and inverse Simpson) both increased under initial degradation treatments, before declining. No new species were added; rather, the measures increased solely as a result of increased evenness. For this reason, Pielou's evenness, which separates out evenness from richness (Jost, 2010), was more sensitive in detecting this change than all the other diversity measures tested. Because our simulations show that commonly used metrics of biodiversity may increase initially when measuring the impacts of DSM on deep-sea communities, there is the possibility that they could be misinterpreted, perhaps as indicating some sort of 'intermediate disturbance' benefit (Connell 1978). While it is possible that intermediate disturbance may increase richness in reality, through creation of a patch mosaic of conditions promoting settlement of a greater range of species (Grassle and Sanders, 1973), the extremely low recolonization rates expected in the CCZ and lack of obvious r-selected species (Jones et al., 2017, 2018b), would make it unlikely.

Although lower levels of the simulated stressors in isolation were difficult to detect, requiring many replicates, their statistical effect sizes would suggest that they could still be simulating ecologically important stress, likely to have (perhaps sub-lethal) consequences. For example, the (0+26a) treatment still had what is commonly called a 'medium' effect size (d= 0.42) when measured using Pielou's evenness (sub-samples of 750). However, its reliable detection ($p = 0.5$, $1-\beta = 0.95$) would require 77 replicate sites –a number that would be very costly to implement in the CCZ. Indeed, many of the metrics tested here required more than 32 replicates to detect the (simulated) impacts, which in the context of the deep sea is likely to be argued as being too expensive to economically justify their usage (e.g. those measures in Supplementary Materials, **Figure 5-5**, **Figure 5-6**, **Figure 5-9**, & **Figure 5-10**).

It has not yet been determined what is an acceptable effect size for deep-sea ecology. Long-term results from historical studies typically yield results around 1, with 2 not being unusual (Jones et al., 2017). However, in other fields, these effects would be characterised as large or even huge. In developing his measure for the field of psychology, Cohen (1988) suggested that an absolute value of d = 0.2 be considered a 'small' effect size, 0.5 represents a 'medium' effect size, and 0.8 a 'large' effect size. Sawilowsky (2009) expanded upon this, suggesting that 1.2 is 'very large', and greater than 2 is 'huge'. Thus, for the (25n + 26a) treatment, the effect on richness could be characterised as 'large'; on evenness (as measured by Pielou's measure) as approaching 'huge'; and density as off the scale. If sub-sample size is increased, the effect size also increases, such that for sub-samples of 1000, all metrics in **Table 4-5**, except richness, are now 'huge'. However, owing to the low density of organisms and inherent variability of the CCZ data, several replicates are still required to detect these ‘huge’ changes (**Table 4-4**).

Determining analogous early warnings in real-world DSM is yet to be done. The results presented here, which simulate possible threshold effects, should be seen as indicative. Given that Cohen’s *d* was already very large for some metrics, translating actual ecosystem effects into statistical effect sizes should be seen as a priority area for future research. For deep-sea benthic ecosystems, a global study of 116 sites found that deep-sea ecosystem functioning is exponentially related to deep-sea biodiversity and that ecosystem efficiency is also exponentially linked to functional biodiversity (Danovaro et al., 2008). In the CCZ it is thus conceivable that a small loss of benthic richness could actually translate to a much greater loss of ecosystem efficiency and functionality. Total density and diversity measures represent a first step in monitoring. However, should they pass a threshold value, further analysis could be triggered, including the identification of particularly impacted species. The use of indicator species is widely used in understanding change in managed areas and this concept could be added to track a limited number of taxa with better baseline knowledge of their ecology and variation. The choice of suitable indicator taxa requires further research.

Although benthic metazoan megafauna are just one aspect of deep-sea ecological communities, they are an important part of nodule-dominated systems, readily surveyed through ROV and AUV photography or videography. If deposition of plumes does indeed occur in areas adjacent to DSM operations, then megafauna, particularly the filter feeders, are likely to be particularly affected. However, the detection of change will depend, in part, on the resolution of the camera employed. Lower resolution equipment than used here would require larger samples and greater replication to achieve similar results. Likewise, higher quality equipment could reduce these requirements.

The treatments used here are simplistic in that only the survival / mortality of observed individuals was simulated. Non-lethal injuries that could affect the growth, feeding, reproduction, or other factors affecting the long-term health of an ecological community were not simulated. The importance of measuring sub-lethal effects is well recognised for other offshore industries (e.g. Trannum et al., 2011; Hughes et al., 2010), and deserves further attention in the DSM context. In order to be comprehensive, a DSM monitoring plan will also need to consider a much wider range of species, scales, and impacts than what has been presented here (Jones et al., 2017 & 2018a). However, the same techniques could be applied in their monitoring. An understanding of natural variability (e.g. species turnover rates, etc.) will be necessary through the use of control sites (called ‘Preservation Reference Zones’ in ISA nomenclature) to better separate out mining impacts from natural changes (Jones et al., 2018a). If the use of control sites indicates that some areas are undergoing changes that are detectable at the time scale of local mining activities, then more replicates would be required to achieve a comparable level of statistical power. For other terrains and resource types, such as seafloor massive sulphides, the detectability of organisms would likely differ, though the analytical techniques would remain the same. Desktop simulations such as ours can, and should, be improved by *in situ* DSM experiments and monitoring.

The International Seabed Authority has an obligation to prevent, reduce and control deleterious effects arising from DSM, before serious harm occurs. Additionally, nation states are to avoid interference with the ecological balance of the marine environment. The metrics tested here have been demonstrated to detect changes to both ‘balance’ (evenness) and abundance, which are likely to form part of any such assessment. Future discussions would benefit from a quantification of harm, that can be understood, properly evaluated and compared between studies. This would enable much clearer guidance for contractors on what is the nature of serious harm. Statistical effect sizes are commonly used for this purpose. However, as demonstrated here, effect size will vary depending upon the nature of the impact, sample size, *and the metric being used to detect it*. Therefore, regulatory thresholds will need to be linked to the details of the monitoring regime.

Regulations of this new industry will need to recognise that detection of impacts before serious harm occurs requires the reliable detection of impacts that are *less than serious*. Evaluation of statistical power in assessment of monitoring plans proposed by contractors to the ISA can move the assessment of less-than-serious harm towards a more repeatable and objective format. However, monitoring plans submitted to date have either not been made publicly available or have not been detailed enough to determine their statistical properties. Thus, the power of current and proposed monitoring plans to measure impacts, and at what level, is unknown. Furthermore, the criteria and assessments of the ISA’s responsible committee (Legal and Technical Commission) have also not been made publicly available, leaving unanswered whether the proposed monitoring plans are statistically adequate (Ardron et al., 2018a; Ardron, 2018b). Making monitoring details available, including power analyses, would help facilitate independent review and informed policy discussions.

Scientists, amongst others, have expressed concern over possible ecological impacts of commercial scale DSM (e.g. Wedding et al., 2015; Van Dover et al., 2017). As that deep-seabed resources beyond national jurisdictions are legally the ‘common heritage of mankind’ (UNCLOS, 1982), there is a need for international bodies (e.g. the ISA or the United Nations) to determine what level of impact is acceptable to society more broadly (Jaeckel et al., 2017).

This study simulates the comparison of initial baseline assessment information (‘before’) with subsequent adjacent mining impacts (‘after’) to explore how commonly used metrics of biodiversity respond in the context of morphospecies distributions found in the CCZ. Our recommendations, as discussed above, are summarised below (**Table 4-6**).

Table 4-6: Summary of findings and recommendations
(in the order presented in the Discussion). Values of results should be seen as indicative. Actual in situ values can be expected to vary from site to site.

1	**Sampling size**	At least 500-750 individuals per site. (A sample size of 250 individuals was found to produce results with high variability and is not recommended.)
2	**Replication**	At least 5 sampling sites per location, plus controls.
3	**Metrics**	Density and Pielou's evenness were found to be sensitive to early impacts.
4	**Richness**	This metric is widely used, readily communicated and understood, but is not sensitive to early impacts.
5	**Power analysis parameters**	Two-tailed t-test (because some metrics may increase): significance of at least 0.05 and confidence of at least 95% is recommended.
6	**Increased evenness**	Commonly used metrics of biodiversity may increase initially due to increased evenness. This should not be interpreted as indicating some sort of 'intermediate disturbance' benefit.
7	**Effect size**	In the simulations, Cohen's *d* was very large. Understanding actual ecosystem effects, and translating these into statistical effect sizes, should be seen as a priority area of research.
8	**Sub-lethal effects**	Sub-lethal effects were not considered here. Their ecological importance is well recognised and deserves further attention in the DSM context.
9	**Monitored species**	Only benthic megafauna were considered here. Actual monitoring will need to consider a broader range of communities of species, including infauna and pelagic species.
10	**Control sites**	Control sites will be necessary to separate out mining impacts from natural changes. Greater natural variability will lead to a greater number of required replicate sites.
11	**Regulatory thresholds**	Regulatory thresholds will need to be linked to the details of the monitoring regime. Effect sizes will vary according to these details.
12	**Power of detection**	Reliable detection of change before serious harm occurs requires the necessary statistical power to detect impacts that are *less than serious*.
13	**Transparency**	[Proposed] Monitoring details, data, and results including power analyses, should be made fully available, facilitating independent review and informed policy decisions.

Chapter 5 Epilogue

5.1 Abstract

This chapter considers some of the governance context during the researching of the thesis, and developments since the chapters were published. Notably, about the same time this thesis research began, the International Seabed Authority (**ISA**) began consultations and drafting of its draft exploitation regulations (now in third draft) and elected a new Secretary-General, among other activities; meanwhile, three Contractors have submitted to the ISA Environmental Impact Statements (**EIAs**) for the testing of mining equipment in their exploration contract areas. The recommendations from Chapters 2 and 3 appear to be more than 1/3 (~38%) addressed under the current draft ISA exploitation regulations, with certain aspects potentially being further addressed in the next draft. However, all three EIAs submitted to date appear to suffer from under-sampling of biota and consequently are probably not statistically robust. Looking at both themes that have run throughout this thesis: i) *transparency* and ii) *statistically robust monitoring of impacts*, three overarching good practices have repeatedly emerged as requiring further attention, not only by the ISA but by Contractors and researchers as well: 1) ensure DSM environmental data are readily available; 2) establish robust statistical practices in the analysis of environmental data; and, 3) be inclusive when discussing the results of environmental data analyses. The chapter concludes with thoughts on future research.

5.2 Introduction

Research question (introduced and defined in Chapter 1, section 1.7)*: In the development of rules and regulations for deep-seabed mining in the Area beyond national jurisdictions, what policy and science elements will be amongst the most critical to ensure good governance that minimises harm to the marine environment, particularly serious harm?*

In sorting through the many policy-science elements that could affect the outcome of DSM governance, three general filtering criteria were used: i) Is it widely acknowledged to be critical to the good governance of natural resources outside of deep-seabed minerals? ii) Is it currently poorly developed within the DSM context? iii) Could good practices be captured by the new ISA exploitation regulations? The two emergent themes, broadly summarised here as *transparency* and *statistically robust monitoring of impacts,* have been discussed in the preceding chapters, providing specificity as to what is meant by the use of these headings here. In each of the preceding chapters, recommendations were made. Here, some further context, updates, and reflections are provided, sub-divided along these two broad themes. In the case of transparency, the degree to which some of the recommendations have since been addressed is considered. It is too soon after publication to re-visit the situation concerning the recommendations of Chapter 4. Instead, three EIAs for test mining that have been submitted to the ISA are briefly considered, with particular attention on the statistical robustness (power) of their megafauna monitoring, in light of what has been learned from the research presented in Chapter 4.

5.3 Transparency and the ISA

5.3.1 Overview

Chapters 2 and 3 remained, until very recently[116], the only published analyses of transparency and stakeholder inclusiveness in the ISA's rules, procedures, and operations. Since their publication, transparency was named in the Secretary-General's 2019-2023 strategic plan as one of his nine priorities (ISA, 2018a; *strategic direction 9: commit to transparency*):

> "Transparency is an essential element of good governance and is therefore a guiding principle for the Authority in the conduct of its business as a publicly accountable international organization. This includes transparency in the internal administration of the Authority, as well as its internal procedures, the procedures of its various organs and subsidiary bodies and its procedures towards States. Transparency plays a fundamental role in building trust in the Authority and in enhancing the Authority's accountability, credibility and support across its stakeholder base." (ibid., para 25)

As found in Chapter 2, the basic elements of transparency have generally been weaker in the operations and procedures of the ISA than seen in regional fisheries management organisations and similar bodies. Likewise, the ISA had implemented only a small subset of good and best practices currently expected in the governance of terrestrial mining and natural resources more generally (Chapter 3). However, as will be examined in further detail below, the draft exploitation regulations represent a genuine opportunity for the ISA to improve in this regard.

[116] Recently, 30 April 2020, a third paper on ISA transparency was published (Komaki & Fluharty, 2020). Focussed on environmental monitoring, the paper references our two papers from Chapters 2 and 3 fourteen times in all.

5.3.2 ISA developments while Chapters 2 and 3 were being written

Previous research had found that transparency had hitherto not factored in the discussions of the ISA's Assembly or Council, whilst it had been central in the discussions of several other international organisations (Ardron et al., 2014a). This thesis research began in December 2014, with further examination of the transparency of the ISA, including stakeholder inclusiveness, as an early focus.

In spring 2014, the International Seabed Authority (ISA) opened an internet-based consultation on what stakeholders would like to see in its as-yet undrafted exploitation regulations.[117] Of the 39 responses, 31 (79.5%) included comments on increased transparency. In July 2014, at the twentieth annual Assembly, 'Transparency and openness' was discussed.[118] The next year, the Secretariat followed up with the release of a draft regulatory framework, again inviting comments from stakeholders (ISA, 2015c). These were the first times the ISA had performed such public consultations, and that they occurred two years in a row suggested an unprecedented openness to public engagement –a move that was widely welcomed by the stakeholders (e.g. SPREP, 2015).[119] These two public consultations suggested the stirrings of governance reform. The closed nature of the ISA's governance had already been well noted by researchers.[120] It now appeared that some of the (newer, non-state) contractors also shared these concerns and were supportive of changes being made to ISA practices:

> "Lack of access to ISA scientific data (submitted by Contractors) is a serious shortcoming. We encourage the development of a central database that is publicly accessible, using open source standards (e.g., Open Geospatial Consortium) that allow for 'communication' and integration with other global scientific databases." (GSR, 2015)

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[117] Before UNCLOS, and hence the ISA, had come into force, the Preparatory Commission for the ISA had already begun work on combined regulations for exploration and exploitation, including environmental regulations (ISA Preparatory Commission, 1990). Although not referenced in the current drafting process, some language from the 1990 draft can be found in some of the current wording (e.g. the draft definition of *serious harm*, as discussed in Chapter 1).
[118] "There was discussion of the issue of 'transparency and openness' as an essential element in the Commission's work and that of the Authority as a whole. It was recommended that the Commission should continue to explore initiatives, including holding open meetings and publishing surveys, particularly on issues of general interest to ensure broad participation." ISA press release, July 2014.
[119] Of the 48 parties that permitted their responses to be posted in the second consultation, these included: 9 governments, 3 inter-governmental / regional organisations, 9 contractors, 23 NGOs (industry associations, scientific, environmental, and others), and 4 individuals.
[120] E.g. "Overall, I think the ISA could benefit from greater transparency and public engagement […] The ISA […] seems almost hidden away in its headquarters in Jamaica, with a website that is rather impenetrable to non-technical visitors […] as far as I am aware, it has never held any kind of public dialogue about its activities." –J. Copley, March 2014, just before the first ISA public consultation was announced. http://moocs.southampton.ac.uk/oceans/2014/03/09/shedding-some-light-on-the-international-seabed-authority/ [Accessed Feb. 2020.])

> "UKSR supports the greatest transparency possible for data collected, with the only exception being that of commercially sensitive data relating to site-specific mineral content and density, and any proprietary techniques employed in connection with the gathering of such data. The scientific and environmental communities stand to benefit considerably from the sharing of data collected, providing the most insight into the least known part of our planet." (UK Seabed Resources, 2015)

Given that the ISA had been in operation for about twenty years and had hitherto never shared Contractor data, these were remarkable suggestions, particularly as they were coming from some of the Contractors themselves.

The ISA's first organisational review was initiated in 2015, with comprehensive interim results by the consultant released the following year pointing to many areas where governance could be improved, including greater transparency and inclusiveness (Seascape, 2016a, 2016b). In July 2016, a new Secretary-General was elected for a four-year term beginning January 2017, further suggesting that a change in the ISA was in the offing. At that same annual ISA session, a side event was held over the weekend on transparency, attended by the (about to be elected, then Deputy) Secretary-General, where I presented the results from Chapter 2. At the meeting:

> "Participants, including the ISA delegates to the Council and Assembly praised the event. Michael Lodge, ISA Deputy to the Secretary-General and Legal Counsel, thanked the broad cross section of stakeholders for attending the day long workshop and for engaging in the rich conversation around participation and transparency in the ISA process. He closed by recognizing the hard work of the LTC to develop the draft exploitation code, noting that transparency is an important component of the draft, and encouraged all stakeholders to comment on the draft." (Resolve, et al., 2016, p8)

However, in the ISA summer session of 2017, the movement towards greater transparency encountered resistance. The ISA Article 154 Review Committee, populated exclusively by diplomats representing state parties to the ISA,[121] weakened, or removed, the consultants' transparency-related recommendations. For example, "Consider making the work of LTC more

[121] Members of the Article 154 Review Committee were: Amb. Helmut Tuerk (Austria) - President of the Assembly; (ii) Amb. Peter Thomson (Fiji) - President of the Council (iii); Amb. Tommo Monthe (Cameroon) - African Group (Bureau Member); (iv) Amb. Lim Jong Seon (Republic of Korea) - Asia Pacific (Bureau Member); (v) Amb. Vladimir M. Polenov (Russia) - Eastern European (Bureau Member); (vi) Amb. Eduardo J.B. Menchaca (Chile) - Group of Latin American and Caribbean Member States (Bureau Member). Observers were (i) H.C. Mathu Theda Joyini (South Africa) - Chair of the African Group; (ii) Amb. Mahe Tupouniua (Tonga) - Coordinator of the ISA A/P Group; (iii) Amb. Ariel Fernandez (Argentina) - Chair of GRULAC (iv); Amb. Jiménez Abascal (Spain) - Chair of Western European And Others Group. (ISA, 2016b).

transparent, limiting closed sessions to commercial in-confidence matters only" (Seascape, 2016a, Recommendation 17) and "Transparency in the LTC needs to be addressed with urgency, and consideration should be given to opening up the LTC meetings more often" (Seascape, 2016b, Recommendation 33) became, "The Legal and Technical Commission should be encouraged to hold more open meetings in order to allow for greater transparency in its work" (ISA, 2017c, Recommendation 16).[122] As noted in Chapter 3, the Review Committee's central argument appeared to be that because the ISA had not yet developed new policies (on data transparency, etc.) it was unlikely to do so –at least, not through consensus (ISA, 2017c, para 7). Amongst these diplomats, the desire for consensus was paramount, outweighing other possibilities such as majority voting.

5.3.3 Developments since Chapters 2 and 3 were written

Chapter 2's text was accepted for publication in June 2016. Chapter 3's text was accepted in Nov. 2017. Developments since then (as of May 2020) are briefly presented below. Using the recommendations from Chapters 2 and 3 as the evaluation framework (presented in italics) the most recent draft exploitation regulations (**DR**) released in March 2019 (ISA, 2019c) are assessed, along with suggestions made by the ISA Council regarding the DR made in the July 2019 session (ISA, 2019a), and the subsequent note by the ISA Secretariat released in December 2019 (ISA, 2019b). Take together, these three documents are assumed to represent a reasonable picture of what may come into being in the future regulations. However, until the regulations are actually passed, it must be emphasised that the observations made in this section are tentative. Furthermore, as was also the case in Chapters 2 and 3, there is a certain amount of professional judgement that goes into evaluating whether a recommendation may be met, or not. All attempts were made to be fair-minded, but it is possible that internal information outside of the three above-listed public documents could have changed the results. Finally, it must be noted that the implementation of rules and regulations can vary. It is assumed here that the regulations will be followed, and in the absence of specific definitions, their plain English meanings shall prevail.

Overall, of the 32 recommendations contained in the chapters, 6 would be met or mostly met (~19%) by the latest draft regulations, 11 would be partially met (~34%), and 14 are not met (~44%). One recommendation was found to no longer be applicable, and two recommendations from each chapter overlapped each other sufficiently to be considered duplicates (noted in the sections below). If those three recommendations are removed from the analysis, the summary

[122] Since the Review Committee's report, the LTC has not held any open meetings, despite being regularly 'encouraged' to do so by the Council (e.g. ISA, 2018d, para18).

values increase somewhat (+1.9%, +0.1%, +1.0%, respectively) but the overall picture is maintained (**Table 5-1**, righthand column).

Concerning the nature of the recommendations met, or not, the results below present a mixed picture. Some key recommendations, such as transparency of contracts and reporting, may be met. However, other key recommendations, such as developing access to information policy, or sharing high quality monitoring data, may only be partially met. Furthermore, there does not appear to have been any progress towards some recommendations, such as allowing observers to attend pre-determined portions of Finance Committee and LTC meetings, or requiring Committees to explain in their reporting to Council the rationale behind their recommendations.

Table 5-1: Summary of Chapter 2 & 3 recommendations in the draft ISA regulations
Ch = Chapter; n/a = not applicable; dup. = duplicates (2). Details are provided in the sections below.

Recommendations	Ch 2	Ch 3	Total	Overall	Less n/a & dup.
Mostly met	2	4	**6**	**18.8%**	**20.7%**
Partially met	7	4	**11**	**34.4%**	**34.5%**
Mostly not met	7	7	**14**	**43.8%**	**44.8%**
Not applicable	0	1	1	3.1%	0.0%
Subtotal	16	16	32	100.0%	100.0%

5.3.3.1 Assessment using Chapter 2’s recommendations

Here, the draft 2019 ISA exploitation regulations and associated documents are examined against the recommendations from Chapter 2 (2016).

5.3.3.1.1 Availability of data and basic information

1. *Develop a comprehensive access to information policy, including inter alia:*

    a) *overarching principles to be adhered to by the ISA and its contractors;*

        i. **Partially met**. ‘Fundamental policies and principles’ are listed in DR 2, which includes 2(b)(vi) accountability and transparency in decision-making, and 2(b)(vii) encouragement of effective public participation. However, these are not supported with further explanation.

    b. *the presumption of non-confidentiality unless otherwise determined;*

- **Partially**. DR 89(1) appears to be limited in scope, not applying to scientific monitoring or other data: "There shall be a presumption that any data and information regarding the Plan of Work, exploitation contract, its schedules and annexes or the activities taken under the exploitation contract are public, other than Confidential Information" (Underlining added). Wording in other articles is weaker; e.g. DR 3(a) "Members of the Authority and Contractors shall use their best endeavours to cooperate with the Authority to provide such data and information as is reasonably necessary for the Authority to discharge its duties and responsibilities under the Convention" (underlining added); and DR 44(d) "[The Authority, sponsoring States and Contractors shall…] Promote accountability and transparency in the assessment, evaluation and management of Environmental Effects from Exploitation in the Area, including through the timely release of and access to relevant environmental data and information and opportunities for stakeholder participation" (underlining added).

c. *rules and procedures by which to determine confidentiality; and,*

   i. **No**. However, the Secretariat notes the gap: "Confidentiality of information drew a number of comments, with suggestions to further clarify what data and information is confidential by setting criteria or specifying which minimum data and information must be shared, including in relation to information to be published in the Seabed Mining Register." (ISA, 2019b, para 30)

d. *procedures through which confidential data and information may be released over time (embargo).*

   i. **Partially.** DR 89(3)(i) with a 10-year holding period, echoes existing exploration regulations. However DR 89(3)(f) provides a loophole for withholding environmental information "…for a reasonable period where there are bona fide academic reasons" which has attracted negative comments and suggested revisions (ISA,2019a,b).

2. *Make publicly available environmental and safety related data provided to it by contractors:*

   a. *in a defined electronic format;*

   b. *at the spatial resolution in which they were provided;*

c. *including geospatial attributes; and,*

d. *metadata where they exist (including, for example, data collection methods).*

i. **Partially**. All of these criteria were expected to be met with the much-anticipated ISA Central Data Repository that went live in 2019. However, exploration of this database has shown it to be remarkably opaque, with few of these attributes readily available (further discussed below). According to the website, it appears to be still in development, and will be *restricted access*: “The integrated database system will be developed for use as a management and research tool that will be made accessible to authorized representatives of member States, scientists and researchers to further assist the Authority in its mandated work.” (Underlining added.)[123] This is in contrast to previous statements by the Secretariat; e.g. “The new database will also result in greater transparency, with secure access to confidential data for authorized users, and an intuitive and informative website that includes a geographic information system for public access to non-confidential data and information.” (ISA, 2018c, para 24)

3. *Prepare clear guidance to contractors on data standards, including:*

a. *acceptable defined electronic data formats;*

b. *required level of detail & resolution;*

c. *required attributes; and,*

d. *which of the generally recognised metadata standards may be followed.*

i. **Partially**. ISA reporting templates came into effect 01 Jan. 2016.[124] However, (b) & (d) are not covered.

5.3.3.1.2 Participation in decision-making

4. *Establish greater public participation in the ISA’s meetings through:*

a. *providing on its website a user-friendly application form for observers;*

i. **No.**

[123] https://www.isa.org.jm/central-data-repository [Accessed Feb. 2020.]
[124] https://www.isa.org.jm/reporting-templates [Accessed Feb. 2020.]

b. *providing space in the agendas of Assembly and Council meetings for public input;*

   i. **Partially**. As has always been the case, Observers are allowed to speak after Members, if there is time.

c. *allowing observers to attend pre-determined portions of Finance Committee and LTC meetings;*

   i. **No**. The closed nature of ISA Committees has been commented upon several times and the Secretariat appears to acknowledge this concern, though no action is suggested, "The need for transparency and inclusiveness in the development of standards and guidelines was emphasized. It is noted that the Legal and Technical Commission proposed, and the Council took note of, a process and schedule for the development of the necessary guidelines in 2020…" (ISA, 2019b, para 6)

d. *allowing observers to serve on sub-committees; and,*

   i. **No**, observers are not allowed any official roles, other than observing. (However, the wording of the Ch. 2 recommendation could have been clearer on what was meant by sub-committee.)

e. *encouraging all ISA organs, and the LTC in particular, to better engage with external expertise and organisations, through requests for advice.*

   i. **Partially**. The LTC continues to seldom request external advice, other than through ISA workshops. However, it appears to also be open to considering advice from workshops organised by third parties –though due to its terse reporting, this is difficult to confirm.

5.3.3.1.3 Access to outcomes and to justice

5. *Develop objectives concerning well-regulated DSM mining, including:*

   a. *indicators for each objective;*

   b. *a programme to measure these indicators; and,*

   c. *annual publication of the results.*

      i. **No**. These will need to be developed at both the scale of the individual DSM operation, as well as regionally.

6. *Publish annual compliance reports concerning contractors and their required activities, including:*

    a. *contractor activities in the Area;*

    b. *compliance with the ISA's rules and regulations;*

    c. *any reportable accidents, infractions, or other issues; and if so,*

    d. what actions were (are being) taken to resolve the situations.

        i. **Yes, mostly**, as regards (draft) exploitation. However, compliance of *exploration* contracts is still not reported upon or made public, despite a request from Council for such information, and recommendations from the Secretary-General to that effect (ISA, 2018c, para. 28). It is unclear whether the exploration regulations will be revised to better reflect the exploitation regulations. DR 38(1), (2) & (3) which calls for self-reporting by the Contractor.

7. *Develop "whistleblower" rules protecting those who speak out concerning issues of public interest, such as human health and safety, the protection and preservation of the marine environment, and financial corruption.*

        i. **No**.

5.3.3.1.4 Contractual and financial transparency

8. *Make contracts with States Parties and contractors available to the public, excluding only proprietary information as determined per Recommendation 1, above.*

    a. **Yes, mostly,** as regards exploitation. It is unclear whether the exploration regulations will be revised to reflect the good practice in the exploitation regulations. DR 17(3): "The exploitation contract and its schedules is a public document, and shall be published in the Seabed Mining Register, except for Confidential Information, which shall be redacted."

9. *Establish financial public reporting rules, drawing upon internationally recognised best practices, including those of the Extractive Industries Transparency Initiative,*[125] *the Equator Principles,*[126] *the International Finance Corporation,*[127] *and others as appropriate.*

    a. **No**. However, these kinds of standards are listed as optional in DR Annex 4 (Environmental Impact Statement template), 2.4, "Discuss applicable standards and guidelines that will be adhered to or aligned with throughout the operation, such as…"

5.3.3.2 Assessment using Chapter 3 recommendations

Here, the draft 2019 ISA exploitation regulations and associated documents are examined against the recommendations from Chapter 3 (2017).

5.3.3.2.1 Access to information

1. *Develop ISA policies on a) transparency, b) criteria and a transparent process for determining when information is confidential.*

    a. **No**. This is a common comment made by NGO stakeholders, which has not as yet been addressed (ISA, 2019b, para 30). (*This recommendation is mostly duplicated with 1(c), above section, and has been removed from the overall tally*.)

2. *Strengthen Draft Regulations to require publicly accessible data and information relating to the protection and preservation of the Marine Environment, as well as health and safety.*

    a. **No**. This is a pre-existing requirement under the *United Nations Convention on the Law of the Sea* (**UNCLOS**, Annex III, 14(2)); however, no new language has been added to broaden its scope or strengthen its compliance. Indeed, current language in the DR appears to be a very narrow reading of this UNCLOS article.

3. *Develop an electronic database(s) compatible with existing international standards, concerning physical, biological, and genetic datasets.*

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[125]https://eiti.org/
[126]http://www.equator-principles.com/
[127] http://www.ifc.org/wps/wcm/connect/topics_ext_content/ifc_external_corporate_site/ifc+sustainability/our+approach/risk+management/performance+standards/environmental+and+social+performance+standards+and+guidance+notes

a. **Partially**. The database has been created. Its compatibility is unclear. Meaningful access does not appear to be public. (*This recommendation is duplicated with 2 (a-d), above section, and has been removed from the overall tally*.)

4. *Require publication of exploration and exploitation contracts.*

   a. **Yes, mostly,** as regards exploitation. It is unclear whether the exploration regulations will be revised to better reflect the exploitation regulations. See 8(a), above section.

5.3.3.2.2 Reporting

5. *Publish annual reports submitted by Contractors.*

   a. **Yes, mostly,** as regards exploitation. It is unclear whether the exploration regulations will be revised to better reflect the exploitation regulations. See 6(a-d), above section

6. *Publish annual (audited) financial statements.*

   a. **No, mostly not,** except as regards the Environmental Compensation Fund, DR 54(3), to be distributed to Members.

7. *Require Committees to explain in their reporting to Council the rationale behind recommendations, including alternatives that were considered, and any dissenting views.*

   a. **No**. However, edits submitted by Council members may strengthen such requirements (ISA, 2019a).

8. *Publish draft and final environmental scoping reports, environmental impact assessments, environmental monitoring and closure plans.*

   a. **Yes, mostly,** as regards exploitation. It is unclear whether the exploration regulations will be revised to better reflect the exploitation regulations. DR 11(1)(a), 11(5), 38(3), 92.

5.3.3.2.3 Quality assurance

9. *Develop quality assurance / quality control (QA / QC) standards that the LTC and Finance Committee will follow when assessing data and reports.*

   a. **No.**

5.3.3.2.4 Compliance information / accreditation

10. *Require ISA Committees to report annually on QA / QC results for each active Contract, as well as compliance with reporting requirements.*

    a. **Partially.** Compliance (self-) reporting, but not QA / QC. See also point 5, above.

11. *Allow for independent third-party verification of scientific data and financial information.*

    a. **No, mostly not**. The LTC technically can call upon third-party verification (i.e. it is allowed), but it is not anticipated in the DR. (The wording in this recommendation could have been better, *requiring* periodic verification.)

12. *Establish a publicly visible process for addressing non-compliance.*

    a. **Partially.** There are some compliance provisions throughout the DR, but how transparent they are is unclear.

5.3.3.2.5 Public participation

13. *Continue to solicit public comments on the development of regulations.*

    a. **Yes**.

14. *Report back on comments received and how they were addressed.*

    a. **Partially**. Comments are reported, but how they are addressed is not.

15. *Expand public participation as discussed in the Discussion Document, including dedicated access to Committee meetings.*

    a. **No, mostly not**. Commission meetings are still closed as a rule, with occasional exceptions, though none have occurred in the past two and a half years.

16. *Clarify and broaden the definition of 'Interested Persons' to include, inter alia, ISA State Parties and Observers.*

    a. **Not applicable**. This term has been removed from the DR.

5.3.3.2.6 Ability to review / appeal decisions

17. *Establish a mechanism to allow for review and appeal of ISA decisions, including requests from third parties, concerning, inter alia, awarding and terms of contracts; approval of plans of work, environmental assessments and closure plans.*

a. **No.** Nothing has changed. There are very limited opportunities for reviewing or appealing decisions, as outlined in Chapter 3.

18. *Re-consider the Article 154 review committee structure such that external expertise is included in its deliberations and in the writing of the final report.*

a. **No**, although equal balance of internal / external membership in review committees is commonly accepted practice in regional fisheries management organisations, there has been no discussion to change the committee's fully internal membership.

5.3.4 Summary of progress in ISA transparency

This thesis has identified good and best transparency practices recognised and being implemented in international fisheries management (Chapter 2), and in terrestrial mining and related sectors (Chapter 3). Assessment of the ISA against these good / best practices produced 32 recommendations in all, 29 which remain relevant after duplicates are removed. The ongoing development of DSM exploitation regulations by the ISA provides a valuable opportunity to rapidly assess (potential) progress since the research was published. If a single point were given for each transparency recommendation met, and half a point for those partially met, then the current draft ISA exploitation regulations would receive a score of 11 out of a possible 29 points (~38%). Thus, the potential future governance of DSM by the ISA, as indicated in the draft exploitation regulations, has progressed more than one-third of the way towards meeting good / best practices, as were identified in Chapters 2 and 3. However, as noted above, the picture is mixed. Despite the simple uniform scoring system, in actuality not all of the recommendations are necessarily of equal ecological or regulatory impact. Nonetheless, that there is more than one-third of these various recommendations potentially being met by the future regulations is still noteworthy progress.

5.4 Statistically robust monitoring of impacts

5.4.1 Overview

The second overarching DSM governance theme of this thesis is regarding the statistically robust monitoring of environmental impacts, including the collection of baseline data, and the design of control and impact sites. Chapter 4 used megafaunal data collected in Clarion-Clipperton Zone (**CCZ**) as an example dataset from which to simulate possible disturbance scenarios causing megafaunal mortalities, and how they might best be measured. The ISA guidance for the assessment of the possible environmental impacts arising from exploration for polymetallic nodules, suggests that "[t]he plan for testing of collecting systems will include strategies to ensure that sampling is based on sound statistical methods…" and that the plan will be reviewed by the LTC [Legal and Technical Commission] "for completeness, accuracy and statistical reliability" (ISA, 2019d; paras 66, 65, underlining added). Similarly, the ISA guidance for environmental impact assessments (**EIA**s) requires that they "…must be based on a properly designed monitoring programme that should be able to detect impacts in time and space and to provide statistically defensible data" and that a "…statistically defensible number of samples should be taken" (ISA, 2013b, paras 21, 32(d)[128], underlining added). However, there is no further ISA guidance on what is meant exactly by these (underlined) terms. The simulations and power analyses undertaken in Chapter 4 could be one way of fulfilling the above criteria, particularly 'statistical reliability'.

The limitations of historic *in situ* DSM disturbance experiments have been discussed elsewhere (Jones et al., 2017; Simon-Lledó, 2019c). In brief, the lack of sampling consistency, small samples, and sometimes inappropriate control sites, all leading to low statistical power, have hampered interpretation of the results. Chapter 4 remains the only published simulations of DSM-related mortalities and their detection. It uses large volumes of consistently collected survey data (>10,000 photos)[129], explicitly taking into account varying sample sizes (N = 250, 500, 750, 1000 individuals), replication (2000 pseudo-replicates), and statistical power (type 1 & type 2 error ≤ 0.05). However, Chapter 4's limited focus on benthic megafauna and the use of biodiversity-related indices only 'scratches the surface' of what is likely to be required in a commercial DSM environmental monitoring plan (cf. ISA, 2010b, 2013b, 2018b, 2019d; Clark et al., 2020). It provides preliminary findings and insights into the scope of the challenge, raising hitherto unasked questions that will need to be addressed if the environmental protection objectives of DSM policy are going to be supported by reliable scientific monitoring.

[128] This language has more-or-less been copied over to the 2019 exploration impact guidance (ISA, 2019d). Para 32(d) of ISA (2013b) applies to SMS. Crusts have similar language (para 33(f)), but notably, there is no such provision for nodules. Indeed the section for nodules is very short: "In addition to the information provided above, the following information is specific to polymetallic nodules: environmental impact assessment is required if any one sampling activity by epibenthic sled, dredge or trawl, or a similar technique, exceeds 10,000 m^2" (para 31). However, as estimated in Chapter 4, the minimum area for monitoring impacts, including replicate sites, could exceed this 10 000 m^2 threshold (7500 - 11 500 m^2).

[129] At the time of this thesis, research into of some of the numerical considerations relevant to DSM monitoring was already underway –by fellow University of Southampton (then) PhD candidate, Dr Erik Simon-Lledó, who very generously shared his data and early results. With the labour-intensive task of morpho-species identification already completed by him, I was able to focus on the statistical properties of deep-seabed megafauna (in APEI-6 of the Clarion-Clipperton Zone), and how conventional metrics of biodiversity and related measures might fare in the ecological context of deep-sea nodule fields.

5.4.2 ISA developments while Chapter 4 was being researched and written

In September 2017, the ISA held a workshop in Berlin, Germany, on the design *of Impact Reference Zones* and *Preservation Reference Zones* (ISA, 2017e). I attended the workshop and presented initial findings from what would become Chapter 4, concluding:

> "…agreement on effect sizes will be necessary in order to determine the experimental design and management responses, before mining proceeds. To do so will require extensive baseline surveys with sufficient sample sizes and replication to scope out the statistical properties of the ecology of the area." (ibid., para 18; co-authored with D. Jones & E. Simon-Lledó)

Although the Chapter 4's R simulations had not yet been fully run, already it was clear that designing an effective monitoring protocol would require knowing in advance what it sought to detect, and at what level of sensitivity (i.e. statistical power). However, these questions were not being discussed by the ISA or its contractors, at the Berlin workshop or elsewhere. In 2018, the LTC released its draft template for EIAs, in which there are no references to statistical properties such as resolution, error, accuracy, sensitivity/power, or variance (ISA, 2018b). In 2019, the LTC updated its guidance for the assessment of the possible environmental impacts arising from exploration, but again without any further guidance on statistical considerations (ISA, 2019d).

Also in 2018, the ISA received two EIA submissions from Contractors wishing to test equipment within their exploration contract areas. Although these EIA reports are lengthy, 209 and 337 pages each, few details are provided about past or future experimental design or statistical robustness. In both reports, it appears that the baseline monitoring results to date have been equivocal, and that both contractors were very possibly under-sampling:

> "In consideration of potential future mining of the IRZ, the preliminary results above show that roughly one-third of the putative species live in both areas. Many more putative species were found exclusively in the PRZ than in the IRZ. The results suggest that a) these species are endemic to the PRZ or, <u>more likely, that b) the amount of analysed samples is too small to obtain an accurate picture of the entire community</u>. Presently it is still difficult to estimate the number of samples that would be required to reflect the whole community with any sort of statistical significance." (BGR, 2018, p94, underlining added.)

> "At the sub-zone B4S03, Shannon-Wiener diversity H' and Pielou's evenness J' were significantly <u>affected by the factor "Expedition</u>" with higher values in GSRNOD15A (Figure 67, center) compared to GSRNOD17." (GSR, 2018, p118, underlining added.)

To clarify this second quotation, the biodiversity measures varied greatly between two separate sampling trips (the 'Expedition' variable). However, because no other details are provided, it is impossible to determine why. Most likely, as per the first contractor's quotation, the sample sizes were too small, with too few replicates to "obtain an accurate picture of the entire community;" i.e., to attain sufficient statistical power. If so, then the differences between the two sampling trips could simply have fallen within the range of spatial variability present within the sampling locations. If the number of samples taken had been larger, this spatial variability could have been better quantified, and thus the degree that random temporal, annual or seasonal variability may also have been present could have been better ascertained.

In both cases, it is unclear why no power analyse were attempted, or indeed, why BGR was of the opinion that "…it is still difficult to estimate the number of samples that would be required to reflect the whole community with any sort of statistical significance." In any case, these are worrying findings, suggesting that environmental impacts resulting from equipment testing may well be lost within the statistical variability (noise) inherent in the two contractors' limited monitoring regimes.

Public reviews of the above two EIAs occurred within the jurisdictions of the Sponsoring States. The ISA Secretary-General summarised the process that was followed, but did not provide substantive details such as what questions or concerns were expressed, and ended by saying, "…the Commission [LTC] is also invited to note that, unless it has further comments and suggestions to make to the contractors that are specific to the test of a pre-prototype nodule collector vehicle, this concludes the process of review required under the recommendations." (ISA, 2019e, para 10.) Thus, the first two EIAs submitted to the ISA appear to have been concluded without any recorded comments, responses, or revisions. It remains unclear what impact monitoring design will be undertaken, or indeed, whether the collected data and monitoring results will be statistically defensible (or made publicly available). However, if the baseline surveys continue to be conducted without consideration to both effect size and statistical power, it is conceivable that no impacts, or perhaps only the very largest of them, will be detected.

The lack of clear ISA rationale in assessing these two EIAs, as well as the lack of access to the contractors' data, underline some of the detrimental effects of limited transparency on good decision making, per Chapters 2 and 3. Furthermore, in these two cases, quite conceivably weak statistical practices do not appear to have been reviewed by the LTC, despite its obligation to do so (ISA, 2019d).

5.4.3 Developments since Chapter 4 was written

Chapter 4 was published in October 2019. In January 2020, the India Ministry of Earth Sciences (henceforth, 'India') submitted to the ISA an EIA for nodule collection trials to be held in its exploration area in the central Indian Ocean (India, 2020). Like the two other EIAs described above, this one is lengthy (348pp). However, just seven pages are devoted to the proposed environmental monitoring plan (ibid., Ch. 8, pp332-339). The majority of this EIA covers previous studies, with particular emphasis on geology, such as the geological setting, geophysical features, physical and chemical properties of the sediments, as well as nodule occurrence, composition, and density.

To facilitate comparisons with Chapter 4, here the focus will be on megafauna. Megafauna are described in the baseline study chapters (ibid., 5.4.1), but were not part an historical benthic impact experiment (ibid., 6.2.2) –each further discussed below. Megafauna will be included in the future monitoring for the proposed single preservation reference zone (PRZ) and single impact reference zone (IRZ). However, how the megafauna will be sampled and possible impacts detected, is not explained (ibid., 8.1.1).

Concerning the prior baseline surveys, results from 17 different photo transects of varying lengths are presented (ibid., fig. 5.4.1.1).[130] About 300 photos (exact number not provided) that showed presence of megafauna (~0.6% of the ~50,000 total) were analysed (ibid., sect. 5.4.1). Few methodological details are provided; e.g. dimensions of the transects, equipment used, altitude, resolution, (range of) area captured by an image, or what is the minimum size (length) defining 'megafauna'.[131] These considerations are inter-linked, in that reliable detection of organisms of a certain minimum size will require equipment, methods, and sampling that produce the required resolution and frequency of detection –as discussed in Chapter 4 as well as Simon-Lledó et al (2019a), among many other sources.

Reported richness of taxonomic categories, per selected transect, ranges from 2 to 11, with the variation in richness very closely following the relative variation in megafaunal density (India, 2020, Fig. 5.4.1.6). The unusually close visual correlation between density and richness is notable, suggesting possible under-sampling, further discussed below. Furthermore, because only photos that had megafauna present were analysed, the true density of megafauna is not accurately represented.

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[130] The number of transects shown on the map (Fig. 5.4.1.1) is 19; however, subsequent presentations of results have 17. Transects 4.3 and 10.1 have been excluded from further presentations of results.
[131] Chapter 4 followed the majority of the literature in setting the minimum size to 1cm; however, the ISA EIA guidance suggests a 2cm cut-off, without explanation (ISA, 2019d).

In stark contrast to the wide variation in density, Pielou's Evenness (J') appears to be nearly constant, visually hovering at, or just below, unity (ibid., Fig. 5.4.1.7). This value is very revealing. The calculation for J' can be expressed as: H' / H'(max), where H' is Shannon-Wiener diversity.[132] Thus, a value of 1 means that the numerator (H') nearly equals H'(max). In turn, H'(max) represents the maximum diversity possible in a given sample of individuals; i.e. that each one is different. Thus, these results can be interpreted to mean that in each of the 17 transects, most categorised taxa appear only once; i.e. the sub-sampled transects are composed almost exclusively of singletons! In contrast, Chapter 4's values for J' generally hovered around 0.8 (depending on the sub-sample size). After simulations of severe degradation, the value of J' shifted up about 0.5 (Fig. 4.1). In no cases, however, did the mean value of J' exceed 0.9.

Given the above, the results presented in the India baseline study suggest extreme under-sampling of megafauna. In Chapter 4, Pielou's evenness was identified as a promising measure to detect changes to community structure. However, in the case of India's surveys, because J' is already its maximum possible value, detecting impacts using J' would be mathematically impossible. The first possible remedy to this under-sampling situation would be to return to the raw data and process more photos. Recall that for the analyses in Chapter 4, 10,052 photos (18,582 m^2) were processed; i.e. considerably more (33.5 times) than that ~300 considered in the Indian baseline. However, without further information on the detectability of the megafauna –i.e. the methods and technology used to survey and identify them– it is uncertain whether processing more photos will alone address all the issues.

Also presented as part of the Indian EIA is a prior impact experiment, run from 1995 to 2005. Megafauna were not sampled there; however, macrofauna density data presented suggest anomalies. Their density declined proportionally more in the reference site than in the disturbance site (!): 197 to 96 individuals per square metre in the reference site (a decline of ~51%) versus 229 to 179 in the disturbance site –a decline of ~22% (India, 2020, tables 6.2.7.2 & 6.2.7.1, columns 2 & 3). Macrofauna and meiofauna density universally, in both control and impact sites, remained lower after the impact experiment. The authors posit:

> "The macrofaunal and meiofaunal density show that although restoration was initiated after the experiment, their numbers have been very low subsequently, not only in the experimental area but in the reference area as well probably due to natural underwater disturbances."

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[132] H' and J' are presented in the EIA but not actually named. However, it is assumed here that normal symbology is intended, representing Shannon-Weaner Diversity and Pielou's Evenness, respectively.

In other words, they are suggesting that natural variability / disturbances played a greater role in their results than the experimental treatment. If true, then it can also be said that the monitoring design and statistical power of this experiment was insufficient meet the objectives of the experiment; i.e. to detect the treatment. The authors continue:

> "From the above observations, it can be inferred that although the environmental conditions have not been restored to the pre-disturbance / baseline levels, the different parameters appear to be under the influence of natural variability and the initial effect of the disturbance experiment has waned off." (ibid., p269)

It is a common logical error to assume that because no effect was detected (or statistically 'significant' (Amrhein et al., 2019)) it means there was no effect. The above quotations omit this real possibility and raise questions; namely, given the sample number and variance, what effect size could have been detected? Without knowing the answer to this question, it is pure conjecture to suggest that the 'effect of the disturbance experiment has waned off'. More likely, the experiment lacked the statistical sensitivity/power to detect the impacts in the first place, and these effects could indeed be long lasting, as other similar experiments have suggested (Jones et al, 2017; Simon-Lledó et al, 2019c). Unlike the baseline surveys, discussed above, it does not appear that any additional sampling data exist for this experiment. Therefore, it is unlikely that these analyses can be strengthened post-hoc.

5.4.4 Summary of the statistical robustness of EIAs to date

As pointed out in Chapter 4, megafauna surveys have emerged in the past decade as a cost-effective approach for the biological monitoring of deep-sea habitats, given the large seabed areas that can be surveyed and the improved efficiency of ship time investment. Megafauna are therefore typically included in baseline studies and disturbance assessments[133] aimed to guide future DSM management (Bluhm, 2001; Jones et al., 2012; Bo et al., 2014; Boschen et al., 2015; Vanreusel et al., 2016; Simon-Lledó et al., 2019c). Furthermore, megafaunal taxa richness in the CCZ has been found to be one of the highest in the abyssal ocean (Simon-Lledó et al., 2019a; Amon et al., 2016). However, the density of individuals is low, and despite the large area sampled in Chapter 4 (18,582 m^2), singletons, doubletons and tripletons still account for over one-third (35.6%) of the taxa in the dataset. Therefore, special care is necessary to ensure that sufficient data are collected to provide statistically robust analyses with results that can reliably inform management of DSM activities.

[133] Notwithstanding the exclusion of megafauna from the Indian disturbance experiment.

To date, none of the three EIAs submitted to the ISA have considered statistical power, or use other means to assess the statistical robustness of their baseline monitoring, and in the case of India, its earlier disturbance experiment. Indeed, the above examination of the results presented in each of the three EIAs strongly suggest under-sampling. If so, then the baseline data being used by Contractors have insufficient statistical power to be used as a 'before' condition to detect possible 'after' impacts of their proposed equipment tests. Revisions should be made to their monitoring plans, such that sufficiently robust data are collected prior to testing of equipment.

The lack of transparency in how the EIAs have been evaluated by the LTC (or others), and the minimal reporting of their findings, does not instil confidence that due diligence is being followed. Future decisions on these and other EIAs should be informed by the information available, including access to the data, stakeholder questions and proponent responses, LTC (or other expert) evaluations and resultant EIA revisions. Thus, some of the transparency issues identified in Chapters 2 and 3, and as re-reviewed above, do not yet appear to have been resolved in current practices associated with *exploration*. Namely, the ISA has not required the LTC to explain in its reporting to Council the rationale behind its recommendations (Chapter 3, recommendation 7).

5.5 Discussion

5.5.1 Context

UNCLOS provides the legal foundation for delineating good governance of DSM in the area beyond national jurisdiction. Article 136 states that the Area and its resources are the 'common heritage of mankind', and in article 140, that activities must be carried out 'for the benefit of mankind as a whole'. This unique wording, found nowhere else in UNCLOS, places a heavy onus on the ISA to govern in such a way as to balance the interests of Contractors with the benefits to humankind –even more so than other extractive sectors such as fisheries. Yet, Chapter 2 found that the ISA's practices were less transparent or inclusive than those of regional fisheries management organisations.

Throughout this thesis, good / best practices in other comparable sectors, including accepted statistical practices, have informed its recommendations. Modern good / best transparency practices, as researched in Chapter 3, are summarised as: i) access to information; ii) reporting; iii) quality assurance; iv) compliance information / accreditation; v) public participation; and vi) ability to review / appeal. Chapter 3 argues that these six expressions of best practices in transparency, which appear consistently across natural resource governance, are relevant and applicable to the ISA's governance of DSM, including obligations placed upon its Contractors, and are consistent with UNCLOS and its implementing agreements.

Chapters 1, 4, and this chapter posit that without access to Contractor survey data, and without proper statistical analyses being performed, it is impossible to determine whether proposed environmental monitoring will be of sufficient quality and sensitivity/power to detect mining / testing impacts, thereby avoiding *serious harm*. Indeed, UNCLOS (Annex 3, art. 14(2)) explicitly links access to data and information with the governance and protection of the marine environment:

> "Data necessary for the formulation by the Authority [ISA] of rules, regulations and procedures concerning protection of the marine environment and safety, other than equipment design data, shall not be deemed proprietary."

This transparency stipulation is echoed across the ISA's Mining Code.[134] To date, however, if a Contractor deems environmental information sensitive or confidential, then it is treated that way by the ISA Secretariat (ISA, 2011a, para 20(a)).

Despite the ISA's unprecedented efforts develop *future* DSM exploitation regulations, the *current* policy situation is not very different from when this thesis research began. Although, as examined above, some of the recommendations contained in Chapters 2 – 4 will likely be implemented in the future ISA regulations and LTC guidance, many of the methodological and governance issues identified during the course of this research could still remain. For example, the ISA Central Data Repository[135] may not be as publicly accessible as earlier communications had suggested. Currently, only very basic metadata[136] are readily available. Accessing environmental data considered to be publicly available is greatly hampered by the design of the database and its search engine. For example, there are 179 'PMN' (polymetallic nodule) files attributed to UK Seabed Resources, all with identical naming in the search engine results, each requiring a separate download to examine their contents. Some database files are '.dat' files that link to other files in the database, others are more typical spreadsheets, while others are components of multi-part geospatial shapefiles. Because these various file formats and kinds of data are not differentiated

[134] In the Mining Code, the wording is slightly different: "Data and information that is [sic] necessary for the formulation by the Authority of rules, regulations and procedures concerning protection and preservation of the marine environment and safety, other than proprietary equipment design data, shall not be deemed confidential."
[135] Also known as *DeepData*: https://data.isa.org.jm/ [Accessed April 2019]
[136] Several fields are often blank; e.g. *StationIS, SampleID, TrawlID, AreaofImage, CameraSpecs, Remarks*.

by the search engine, the repository's current usefulness is moot.[137] Komaki & Fluharty (2020) similarly note that the ISA Data Repository is not much improved from when I reviewed it in 2016 (referencing my paper).

Though this should change under the new (currently draft) exploitation regulations, there is also presently no requirement for Contractors to make public (or to submit) the data supporting their EIAs. As examined above, the three EIAs submitted to date suggest chronic and widespread under-sampling, as well as possibly other experimental design and methodological shortcomings. However, the data supporting them have not been made available, and therefore comprehensive external peer-review and analysis has not been possible.

The good governance of DSM is reliant upon good science supporting informed decision-making. As Chapter 4 demonstrates, the avoidance of *serious harm* will not be a trivial issue. Its resolution will depend upon open informed discussions concerning what effect sizes, indicators, limits and thresholds will need to be set, and how these can be reliably monitored and measured. The research undertaken in Chapter 4 was only possible due to the availability of properly processed survey data. Likewise, external peer-review and follow-on research, including the work of future PhD students like myself, will depend upon access to such good quality data. As the ISA prepares to manage commercial exploitation, the basic transparency and statistical issues outlined in this thesis will be critical to its good governance, and will need to be resolved.

5.5.2 Three overarching recommendations ('rules of thumb' for everyone)

The previous chapters' recommendations paid particular attention to the ISA and its draft DSM exploitation regulations as a vehicle for instituting methodological, procedural, and behavioural improvements. These recommendations remain very relevant.[138] Below, three simply worded, overarching recommendations are presented that are different from those of the earlier chapters in that they are general, without policy specificity; in a word, they are *simpler*, more like 'rules of thumb', directed not just towards the ISA, but to any party engaged in DSM research, policy development, and its operationalisation.

In the good governance of DSM, everyone has a role to play. A DSM Contractor, for example, could post on its own web site (or that of a third party) the same data that it has been submitting

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[137] Consequently, I have been unable to locate any megafauna data associated with the area sampled in Chapter 4, if indeed they are present in the database.

[138] With one exception: Chapter 3's recommendation to: "*Clarify and broaden the definition of 'Interested Persons' to include, inter alia, ISA State Parties and Observers*" is no longer relevant because *'Interested Persons'* as a term has been removed from the draft regulations.

to the ISA annually, in some cases for decades, which to date have remained largely hidden from view. Moreover, these data could be corrected and otherwise kept up to date more frequently than the annual ISA submission process allows. The only obstacle to any Contractor (or research institution) fulfilling this simple task appears to be its willingness to do so. However, it is only through small actions such as these, that a revised view of what is normal and expected good practice can spread.

5.5.2.1 Ensure DSM environmental data are readily available

Commentary: In these three rules of thumb, the term 'environmental data' is meant to include all variants, such as survey, baseline and monitoring data. DSM is an emerging research and policy arena that can only benefit from the widest possible sharing of what limited information is currently available. The ISA through its Central Data Repository, the Contractors through their own web sites, and researchers through the various online academic databases, could make their environmental data publicly available, without limiting access to only 'authorised representatives' –as has been suggested by the ISA Secretariat (2018c, para 24), or otherwise rendering the data difficult to access (discussed above). In the broader international community, there is already recognition of the advantages of readily accessible machine-readable data, as encapsulated in the 'FAIR' Data Principles (Wilkinson et al., 2016), increasingly being adopted by other oceans-related United Nations bodies.[139] From the Contractor's perspective, it would be simpler. The data could be left in whatever recognised format used in its baseline assessments, EIAs, and impact monitoring. From the established researcher's perspective, sharing data is also consistent with the policies of an increasing number of journals. Providing data through peer-reviewed journal publications also better ensures that data and appropriate metadata are made available. (Some of the more commercial contractors are already encouraging this practice, recognising the benefits of the peer-review process.) For the young research student, perhaps in a developing country university that does not have access to a research ship, open access to DSM data could be instrumental to her academic success.

5.5.2.2 Establish robust statistical practices in the analysis of environmental data

Commentary: Rules and regulations are blunt tools, limited in their ability to instil good / best practices in experimental design and scientific analysis. Although the LTC *guidance* (effectively considered by the ISA to be *rules* (Bräger et al., 2020)) calls for 'sound statistical methods', leading to results that are complete, accurate and statistically reliable (ISA, 2019d; paras 65-66), in

[139] FAIR: Findability, Accessibility, Interoperability, and Reusability. E.g. https://www.un.org/Depts/los/consultative_process/icp20presentations/belov.pdf [Accessed April 2019.]

practice the LTC and ISA Council have not enforced this requirement, as demonstrated by the three EIAs considered above. While the regulator has an important role to play, ultimately the development of good and best practices must come from the researchers and operators themselves. There is growing awareness and concern regarding how the inappropriate use of common statistics has harmed the advance of science (Amrhein et al., 2019). Hopefully, the 2019 publication of the research in Chapter 4 will play a role in its improvement.

5.5.2.3 Be inclusive when considering the results of environmental data analyses

Commentary: The academic, commercial, and regulatory sectors of DSM can mutually benefit from each other's expertise (as well as information and data, per the first recommendation). While the ISA and its responsibilities have been the focus of the policy-based recommendations of this thesis, DSM decision-making is broader than just the ISA. Contractors could share expertise, rather restricting it through the use of non-disclosure agreements. Before wading into unfamiliar DSM policy discussions, academics could do a better job of consulting outside of their existing research circles to better understand the bigger picture; e.g., the legalities (if they are not legal scholars), politics and sensitivities involved. Furthermore, as has been often commented upon, here and elsewhere, the LTC could designate a regular schedule to open up its meetings to observers and external input.

Were the above three 'rules of thumb' followed, this thesis posits that there would be an improved likelihood that data collected would be of good quality, and sampling would be sufficient, taking into account the unique ecological conditions of the deep sea; that DSM analyses would be statistically robust, leading to reliable results upon which decisions could be made; and that inclusive engagement in discussions (industry, academics, and civil society) would lead to fair decision-making and laws, durable policies and outcomes, benefiting humankind as a whole.

5.6 Concluding remarks

As was noted in Chapter 3, to be able to provide input into the drafting of DSM exploitation regulations has been, at a minimum, a once-in-a-generation opportunity. The two themes that run throughout the thesis (*transparency* and *statistically robust monitoring of environmental impacts*) have been identified here as critical to future good governance of DSM and could be readily incorporated into the drafting of the exploitation regulations. However, the current practices of the ISA are much less transparent than those in the international fisheries sector (Chapter 2) and its practices largely do not meet the expectations contained in recognised standards for terrestrial mining and other related resource management industries (Chapter 3). Regarding the monitoring of environmental impacts, while the ISA through published LTC guidance clearly recognises the need for statistical robustness, it currently lacks any guidance on how this should be assessed. DSM mortality modelling conducted in Chapter 4 is the first of its kind to begin to address this critical question. Simulations using benthic megafaunal data from the Clarion-Clipperton Zone suggest that impacts from neighbouring polymetallic nodule mining operations could be difficult to detect until it is 'too late'; i.e. only after serious harm has already occurred. To be able to detect early warnings of possible serious environmental harm, monitoring design will need to take into account statistical power from the outset, which will require both much larger sample areas and greater replication than was used in the three EIAs to date submitted to the ISA. To avoid missing critical signs of damage already occurring, Type II error will need to be minimised. In this context, Chapter 4 suggests using the same threshold Type II beta value as is typically used in determining Type I alpha values; i.e. 0.05. The difference in implementation between beta of ≤ 0.05 and ≤ 0.20 (a value sometimes used in other contexts) worked out in the simulations often to be just one more replicate site.

Based on the preceding research, this thesis has produced several policy and science-specific recommendations, 45 in all, which if taken up by the ISA, would improve the likelihood of statistically robust environmental monitoring and informed decision making. Additionally, three simply stated, overarching good practices have also been put forward, above, for consideration by all actors engaged in, and affected by, DSM governance.

A central question in 1967 that prompted Ambassador Pardo's UN speech (UNGA, 1967a; discussed in Chapter 1), though partially answered by UNCLOS and the Part XI Agreement, nevertheless remains partially open: *Who shall benefit from the mineral resources of the deep sea?* Ultimately, the common heritage of humankind principle adopted by States Parties suggests that these shared deep-seabed minerals are as much our children's and grandchildren's as they are our own. In order to resolve how any benefits gained from their exploitation will distributed, both geographically and intergenerationally, whilst the marine environment is still protected and preserved, will require best efforts from the ISA, and indeed each one of us, to achieve openness, inclusiveness, and scientific rigor.

5.7 Further research

As is typical of PhD studies, many avenues of fascinating research had to be abandoned in order to focus on a selected few. Below are some thoughts on topics that could further inform and benefit the governance of deep-seabed mining:

1. **Better understanding the 'resource curse' and how it can be avoided**: much of my first year of research was spent immersed in this topic, which is briefly outlined in Chapter 1. Despite more than three decades of quantitative research by resource economists and others, producing a voluminous literature, there is still a wide divergence of (strongly held) views, with no prevailing explanations.

2. **Better understanding the legal and policy implications of the 'common heritage of [hu]mankind' in the governance of deep-seabed mining**: unlike the above point, there is a relatively small literature associated with this topic with some convergence of legal opinions, but little guidance on how this principle operationally differentiates the governance of DSM. Does it indeed demand greater transparency than fisheries management, as has been posited in Chapter 2? And if so, what legal tests can be applied to ensure the principle is being met?

3. **Better understanding the impacts and limitations of transparency on (resource) governance**: the literature provides some tantalising suggestions of improvement, as well as disturbing findings of continued corruption. Why do some transparency initiatives work, while others fail? What other elements need to be in place for greater transparency to be helpful in furthering good governance of natural resources? How might these lessons apply to the ISA?

4. **Updating of Chapters 2 and 3**: these chapters' assessments are snapshots in time that will (hopefully) grow out of date in five years or so, requiring new assessments.

5. **Elaboration and expansion of Chapter 4's simulations**: this chapter has probably raised more questions than it answered! Key future research areas could include:

    - **Translating actual ecosystem effects into statistical effect sizes**. In Chapter 4, Cohen's *d* was already very large for most of the simulations and metrics –by standards used in other fields. What standards are appropriate for the deep sea? What will they mean in terms of actual ecological impacts?

    - **Developing bespoke ecological measures tailored for the unique statistical properties of deep-sea nodule-related communities**. Chapter 4 necessarily looked at existing, widely used and accepted biodiversity (and other) measures. However, might there be better, more sensitive variants that could be developed for measuring impacts in the deep sea? Furthermore, developing a variant Cohen's d (or another measure of statistical power) that did not vary according to sample size would greatly simplify the drafting of rules and regulations.

    - **Running similar simulations for other sizes of taxa**, sampled using other methods;

- **Simulating sub-lethal stress,** possible longer-term effects, and how these could be detected / measured;
- **Determining whether the use of indicator species is plausible** in deep sea nodule-related environments, and if so, identifying candidate species;
- **Running similar simulations for the other DSM environments**, noting the above research questions and limitations; i.e., detecting impacts on the ecological communities associated with vents, crusts, and perhaps also deep-sea muds.

Appendix A Environmental considerations for impact and preservation reference zones for deep-sea polymetallic nodule mining

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As the second author, I assisted with the conception and writing of the paper, which was led by Dr Daniel Jones (one of my supervisors). I contributed to: Introduction (A.2), Statistically robust monitoring (A.4.3), Replication of zones (A.4.4), PRZs and representativity (A.4.5), A proposed three-step adaptive approach (A.4.12), Box 1 (Conservation considerations), Figure 5-2: Summary of the considerations for monitoring of deep-sea mining impacts), and Table A-1: Examples of how the three different DSM resource types will require different monitoring regimes).

A.1 Abstract

Development of guidance for environmental management of the deep-sea mining industry is important as contractors plan to move from exploration to exploitation activities. Two priorities for environmental management are: A) mitigating the impacts and effects of activities where possible, and B) optimising approaches for monitoring of impacts. International regulation of deep-sea mining activities stipulates the creation of two types of zones for local monitoring within a claim, impact reference zones (IRZ) and preservation reference zones (PRZ). The approach used for allocating and assessing these zones will affect what DSM impacts can be measured, and hence taken into account and managed. This paper presents recommendations regarding key considerations to be made when establishing these reference zones for polymetallic nodule mining. It is recommended that zones should be suitably large (Recommendation 1) and have sufficient separation (R2) to allow for repeat monitoring of representative impacted and control sites. Zones should be objectively defined following best-practice and statistically robust approaches (R3). This will include the designation of multiple PRZ and IRZ (R4) for each claim to ensure statistically robust comparisons. PRZs should be representative of the mined area, and thus should contain high quality resource (R5) but PRZs in other habitats could also be valuable (R6). Sediment plumes should be considered in design of PRZ and may need additional IRZ to monitor their effects (R7). The impacts of mining may extend beyond the boundaries of a claim,

so transboundary effects should be considered (R8). The impacts of other activities and expected changes should be taken into account (R9). Sharing PRZ design, placement, and monitoring could be considered amongst contractors with adjacent claims (R10). The reliability of the results of monitoring are important for gaining public trust, and ultimately for maintaining the licence to operate; therefore, these should be independently verified (R11).

A.2 Introduction

Deep-sea mining activities are being proposed in national and international waters, focusing on three main resource types: polymetallic nodules (nodules), seafloor massive sulphides (SMS) and cobalt-rich crusts (crusts). Mining interest for nodules is mostly centred in the Clarion Clipperton Zone (CCZ) of the northern equatorial Pacific, SMS on active plate boundaries, and crust mining on seamounts, principally in the northwest Pacific. Whilst these three types of minerals will each require bespoke technology and approaches (**Table A-1**), they share in common the potential to cause serious harm to the marine environment (Levin et al., 2016). In the case of nodule mining, the footprint will be large, on the scale of hundreds of square kilometres of seafloor each year (Oebius et al., 2001; Smith et al., 2008). The spatial footprint of SMS and crust mining will be smaller but still ecologically significant (Boschen et al., 2013). Seabed mining activities for different mineral resources at shallower depths will not be covered here, but it is worth noting that some large operations exist (e.g. diamond sand mining in Namibia). Within national jurisdiction, some deep-sea SMS mining operations have been approved to date including in Papua New Guinea (Nautilus Minerals, 2008) and in Japan (Kyodo, 2017), though they have not yet gone into commercial production. No deep-seabed mining (DSM) in the legal “Area” beyond national jurisdiction has yet been approved, and the environmental regulations and approval process for commercial DSM exploitation are still under development by the International Seabed Authority (ISA). The detailed requirements for environmental monitoring of commercial DSM are likewise still in development.

The mining of deep-ocean minerals, like any form of human development, will impact the surrounding environment and biological communities. The mining vehicle is likely to disturb the sediment in wide tracks (Jones et al., 2017), which will likely remove most organisms. Noise and light pollution from the mining machinery and support vessels will impact biological communities from the sea surface to the deep-ocean floor (Peng et al., 2015). Sediment plumes created by the seabed mining operation will spread in the water column and eventually settle on the seafloor, smothering any fauna in both the directly disturbed area and surroundings (Oebius et al., 2001). Sediment plumes may also arise from the surface de-watering operation and will likely be discharged at depth (Miller et al., 2018). Models suggest that large sediment plumes will be created that spread over extensive areas, particularly in the case of nodule mining on fine-grained abyssal sediments (Aleynik et al., 2017). It is estimated that the sediment plume will cover at least twice the area of the operation (Gjerde et al., 2016).

As an input to the ongoing development of ISA environmental rules and regulations, this paper outlines key considerations relevant to the design and selection of sites to monitor impacts of DSM. Although many of these considerations will be of relevance to all types of seabed mining, here we focus on polymetallic nodule mining. Though good design principles remain relevant regardless of the effect being measured, not all possible effects are considered here (e.g. impacts from noise). This paper takes into account existing ISA guidance, where available, as well as some of the issues raised during workshops in 2015, 2016 and 2017 (see acknowledgments). For the purposes of this paper, environmental management of DSM shall be understood to be a mechanism to minimise direct and indirect damage of mining-related activities to the marine organisms, habitat, and ecology of the region. To achieve these ends (see **Table A-2**), it is necessary to avoid / minimise the negative impacts where possible, which in turn requires a level of monitoring such that impacts are readily detectable and assessable, before they cause serious harm. For those places where impacts have occurred, physical, biological and ecological recovery will also need to be monitored. Establishing an effective monitoring regime requires understanding the distribution of the parameters of interest in a region before mining commences, and hence detailed baseline surveys of the mining areas are first needed, before the monitoring and mitigation plans can be developed.

The underlying concepts for spatial management zones are similar for all types of mining. However, there are differences in considerations concerning the scale, spatial constraints, and ecology of these areas (**Table A-1**). The biological communities associated with active SMS deposits, for example, are very different from those in nodule fields, with the former being isolated areas with relatively high densities of fauna but relatively low diversities (Van Dover, 2000), whilst the latter are the opposite (Witman and Roy, 2009). Crusts and inactive SMS deposits are associated with typically diverse communities particularly of sessile suspension feeders (Schlacher et al., 2014), and unlike the other DSM resources, crusts may also be associated with commercial fish species (Levin et al., 2016). As a result of these and other critical differences, design of the monitoring regimes for each of the DSM resource types will necessarily differ in many aspects (**Table A-1**). We focus here on polymetallic nodule deposits. However, many of the underlying design criteria which shape decisions on monitoring, as discussed below, will be similar across all deposits.

Table A-1: Examples of how the three different DSM resource types will require different monitoring regimes
This table includes a simplified and general overview of the ecological considerations of particular importance to monitoring.

Mineral type	Expected direct footprint	Secondary impact plume dispersal considerations.	Ecological considerations particular to monitoring the mining resource	Expected time scale for recovery	Implications for monitoring
Nodules	Large (100s – 1000s km^2)	Generally low but variable currents at the deep seafloor suggest that plumes will be dispersed in all directions. Seafloor dominated by fine sediments – typically more so than either SMS or crusts.	Broad-scale regional stratification cause by a range of physical and biological factors, such as carbon flux from surface waters. Local communities influenced by habitat heterogeneity, including geomorphology and nodules as habitat. High biodiversity of most groups, but generally lower abundances than either SMS or crusts.	Very slow	Low abundances and high biodiversity suggest low statistical power to detect change in all but the most common species. Improving power requires large sample sizes and many replicates. Monitoring may need to be augmented with modelling to infer higher level changes (e.g. to species richness / biodiversity, respiration, re-mineralisation, etc.). Overall very slow recovery suggests very long term monitoring will be required.
SMS	Small (10s km^2)	Geomorphology of some vent areas can lead to prevailing current regimes (e.g. along ridges). Plumes from operations near active vents could become entrained in the vertical transport of heated water, prolonging their suspension throughout the water column, with increased dispersal distances.	Very highly stratified local communities, according to distance from active vent sites (i.e. local energy regimes). Active sites have high abundances, but lower biodiversity, whereas inactive neighbouring sites have much lower abundances but potentially higher biodiversity. Likely larger temporal variability than either nodules or crusts.	Highly variable	High stratification of ecology will need to be reflected in monitoring, with sample sizes, replicates, and time series matched to the each of the ecological communities. May be difficult to find representative control sites. High temporal variability of some sites suggests the need for additional replicates to insure against some of these changing their nature (e.g. from active to inactive venting, or vice versa), disqualifying them from detecting changes caused by mining. Possible pelagic (re-) suspension of plumes by nearby active sites will need to be factored in on a site-by-site basis.
Crusts	Medium (10s – 100s km^2)	In mining seamounts, much of the plume may be dispersed directly into the water column, higher above the surrounding seabed than for other mineral types.	Vertically stratified communities at a local scale, and by seamount groupings at a regional scale (with each seamount in a grouping still being unique in certain ways). Seamount biodiversity is often higher than surrounding areas, with the potential for	Slow and somewhat variable	Vertical stratification of communities suggests a need to vertically stratify monitoring as well –both benthic and pelagic. The quasi-uniqueness of each seamount suggests placement of PRZs on the same seamount, whenever possible. If not possible to find unaffected representative areas (for each stratum) on the seamount, statistical

	Sediments will be comprised of fewer fines than for either nodules or SMS. The heavier particles can be expected to accumulate and may lead to submarine sediment movements.	increased endemicity in some cases. Many pelagic animals are associated with seamounts including protected marine mammals and commercially important fish species.	power will need to be regained through increased number of replicates on a neighbouring one(s). Monitoring impacts upon endemic species will need to be designed on a case-by-case basis, dependent on their biology. Monitoring possible long-range pelagic effects will require widely dispersed sampling. Negative effects detected on fish species of commercial interest or on protected ‘red-listed’ species may necessitate management trade-offs, as well as additional legal responsibilities (outside the scope of this paper).

Table A-2: Specific management questions for deep-sea mining addressed by designation of appropriate PRZs and IRZs

Setting up a robust network of PRZs and IRZs can avoid costs through additional environmental work, delays or even cessation of activities associated with regulatory non-compliance.

Issue	Why important	How addressed
Characterising the impact of mining activities	The central question to be addressed, which will be legally required in the mining contract and associated monitoring plan.	Quantification of mining impact (specific impacts, magnitude, extent) by comparing PRZs and IRZs
Separating mining impacts from natural environmental change	Otherwise, mining activities may be held responsible for impacts that were caused by other factors.	Quantification of natural environmental change in long-term time-series at PRZs. PRZs must be large enough to have viable faunal populations over the term of the monitoring
Evaluation of the efficacy of management/mitigation measures	Build knowledge base and inform future management. Necessary for adaptive management.	Compare monitoring data from different mining projects PRZs and IRZs to evaluate the efficacy of their respective mitigation measures. Experiments could be established within and across mining blocks to more rigorously assess mitigation measures as part of active adaptive management.
Assessment of recovery from mining activities	Inform the timing of the release of future mining blocks. Reveal long-term trends in impacted and un-impacted communities	Long term time-series comparisons between PRZs and IRZs. Both zones need to be in place for long timeframes and not impacted by future activities.
Reduce uncertainty and necessary precautionary margin	Reducing uncertainty in ecosystem responses to mining will allow more effective and directed monitoring indicators to be selected, more meaningful environmental quality targets, and will clarify the amount of precaution needed (e.g. buffer zones to account for variability in plume dispersal). It may also require fewer measurements to be taken in subsequent monitoring programmes.	Evaluation of specific impacts across sites by comparing long-term data at PRZs and IRZs.
Ensure compliance with relevant regulations and best practices	It is vital to have robust data to demonstrate compliance; i.e. the environmental objectives of the approved work plan.	Compare impacts (as assessed from comparison of PRZs with IRZs) to protected species, habitats, policy targets or performance indicators.
Improve regional environmental management	Help integrate project-scale environmental management with regional and strategic approaches. A network of PRZs, if maintained as long-term monitoring sites, will enhance the role of larger areas designated for environmental protection, such as APEIs.	Results from project-specific monitoring of PRZs and IRZs would feed into strategic / regional assessments of cumulative and transboundary impacts

Ensure examples of representative habitat are locally preserved	Conserving habitat locally representative of mining areas is necessary to enhance the probability of recovery of impacted sites through local re-colonisation.	PRZs, if maintained as long-term monitoring sites, may act as partial conservation sites if large enough to sustain viable populations of some species (but outside the scope of this paper)

A.3 Interpretation of existing guidance on claim-scale spatial management areas

The legal and regulatory requirements for environmental monitoring of deep-sea mining will likely be the most important factor controlling what is done. The ISA provides some information on spatial management at two scales: at the scale of individual mining claims and at a regional scale. A regional environmental management plan has been developed for the CCZ (ISA, 2011b), which sets out a range of representative areas for the region to be protected from mining activities (known as 'areas of particular environmental interest', APEIs). The APEIs are important to regional-scale management (Wedding et al., 2013) but are not necessarily part of the claim-scale monitoring scheme and so are not covered in detail here. The ISA does provide guidance on claim-scale spatial management for all types of mining in the current "mining code" (ISA, 2000; ISA, 2012b), which provide an important approach for addressing several key monitoring objectives (**Table A-2**). In this context, the term "mining code" refers to the collection of rules, regulations and guidance concerning DSM. The mining code currently applies only to exploration activities, and sets out two types of spatial environmental management zones (subsequently referred to as 'zones') within the mining claim area for assessing mining activities: impact reference zones (IRZ) and preservation reference zones (PRZ). These are defined as follows:

> *IRZ are areas to be used for assessing the effect of each contractor's activities in the Area on the marine environment and which are representative of the environmental characteristics of the Area.*
>
> *PRZ means areas in which no mining shall occur to ensure representative and stable biota of the seabed in order to assess any changes in the flora and fauna of the marine environment.*

The draft exploitation code (ISA, 2016a) and environmental regulations (ISA, 2017b) do not yet provide guidance for the implementation of PRZ or IRZ. The environmental management plan for the CCZ (ISA, 2011b) provides some additional information (ISBA/17/LTC/WP.1 section VII.B.46.c and d):

> *Contractors will provide in their environmental management plans the designation of the required impact and preservation reference zones for the primary purposes of ensuring preservation and facilitating monitoring of biological communities impacted by mining activities.*
>
> *Impact reference zones should be designated to be within the seabed claim area actually mined.*

Preservation reference zones should be designated to include some occurrence of polymetallic nodules in order to be as ecologically similar as possible to the impact zone, and to be removed from potential mining impacts;

Contractors are required to minimize potential impacts on established preservation zones, and the Authority should consider the potential for impact on established preservation zones in evaluating any application for a mining licence

Figure 1 provides a plausible graphical representation of these zones within a nodule mining claim. The PRZ is principally a 'control' site for the IRZs, which measure impacts. However, being located closer to the claim area than the APEIs, the PRZs could also play important roles for conservation, for example providing connectivity as 'stepping stones' and sources for recolonization for impacted sites. However, to fulfil a conservation objective the PRZ would need to be in place for the long term and not mined. In both conservation and monitoring roles, PRZs will need to be representative of mined habitats and protected from the primary and secondary effects of mining activities. However, their contribution towards meeting conservation objectives, as part of a potential representative network of protected areas, is not the focus of this paper (see Box 1), which looks at monitoring.

Box 1: Conservation considerations

PRZ, being "areas in which no mining shall occur", are de facto marine conservation areas. Protected areas have been shown in other environments to be an effective mechanism for preserving biodiversity (Gray et al., 2016) and can increase density, biomass, size and diversity of shallow water marine organisms compared with areas outside the reserve (Halpern, 2003). The ability of protected areas to perform these roles hinges upon several factors, foremost of which is size (i.e. whether they are large enough to support viable populations of organisms affected by mining), and secondly their spacing, such that they can remain ecologically connected to each other and the impacted mining areas. Other important characteristics identified in shallower water environments are: (1) that reserves do not permit any exploitation activities, (2) they are ecologically contained (isolated) and (3) that they are well enforced and have a long duration of protection (Edgar et al., 2014). In the context of DSM and the current management regime, some conditions could be relatively easily met. However, determination of size and spacing will likely require further consideration. The interaction of claim-scale protected areas and the regional-scale APEIs will also likely be important for an effective conservation strategy.

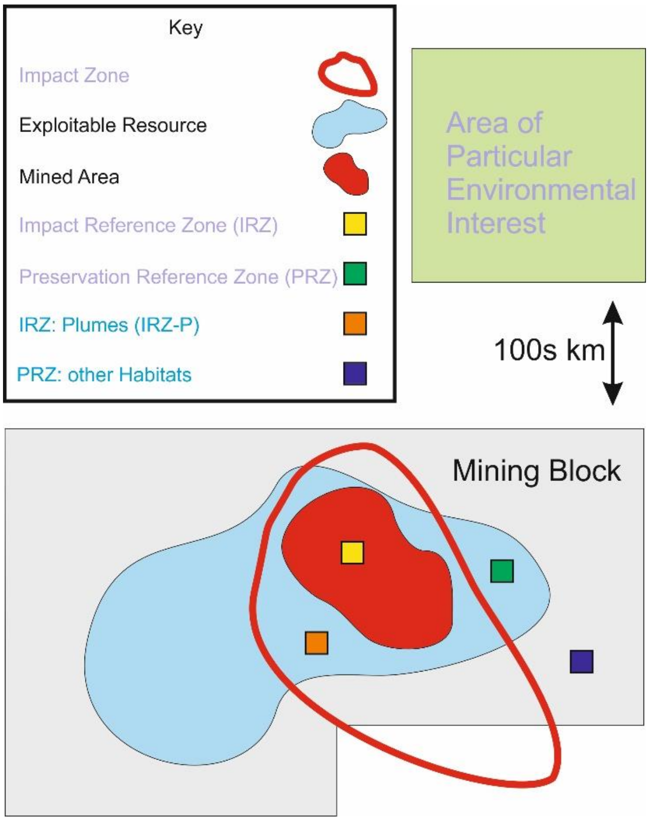

Figure 5-1: A graphical representation of PRZ and IRZ
as set out in the ISA mining code and in recommendations presented here. Text in purple refers to areas already defined under the Mining Code. Blue text refers to additional areas recommended here. We recommend multiple zones, but only single IRZ/PRZ are shown to improve clarity. The relative size of each area depicted was only chosen for clarity and is not intended as a recommendation.

A.4 Recommendations for claim-scale spatial management

There are many practical problems in the detection of anthropogenic impacts on biological communities (Underwood, 1994), particularly in the deep sea. Furthermore, deep-sea environments associated with DSM differ from shallower habitats in several important ways, which affect both statistical confidence and power, and will vary by resource type (**Table A-1**). Many communities have large natural temporal variances in the populations of many species (Smith et al., 2009). These populations often show a marked lack of concordance in their temporal trajectories from one species and one place to another (Gooday, 1988; Underwood, 1994). This problem is further exacerbated in many deep-sea areas by low densities of fauna and high diversities (Glover et al., 2002; Amon et al., 2016; Vanreusel et al., 2016), although this may not be the case in active venting systems (Van Dover, 2000) or seamounts (Clark et al., 2010). Sampling must therefore be of sufficient size and replication to identify unusual patterns of change in suites of interacting and variable measurements often spanning considerable distances

(Underwood, 1994; Thiault et al., 2016). Furthermore, the first monitoring samples should be completed prior to mining starting to provide an appropriate baseline. When these factors are taken into account and applied to mining a range of considerations become apparent, which are explored below and summarised in Figure 2.

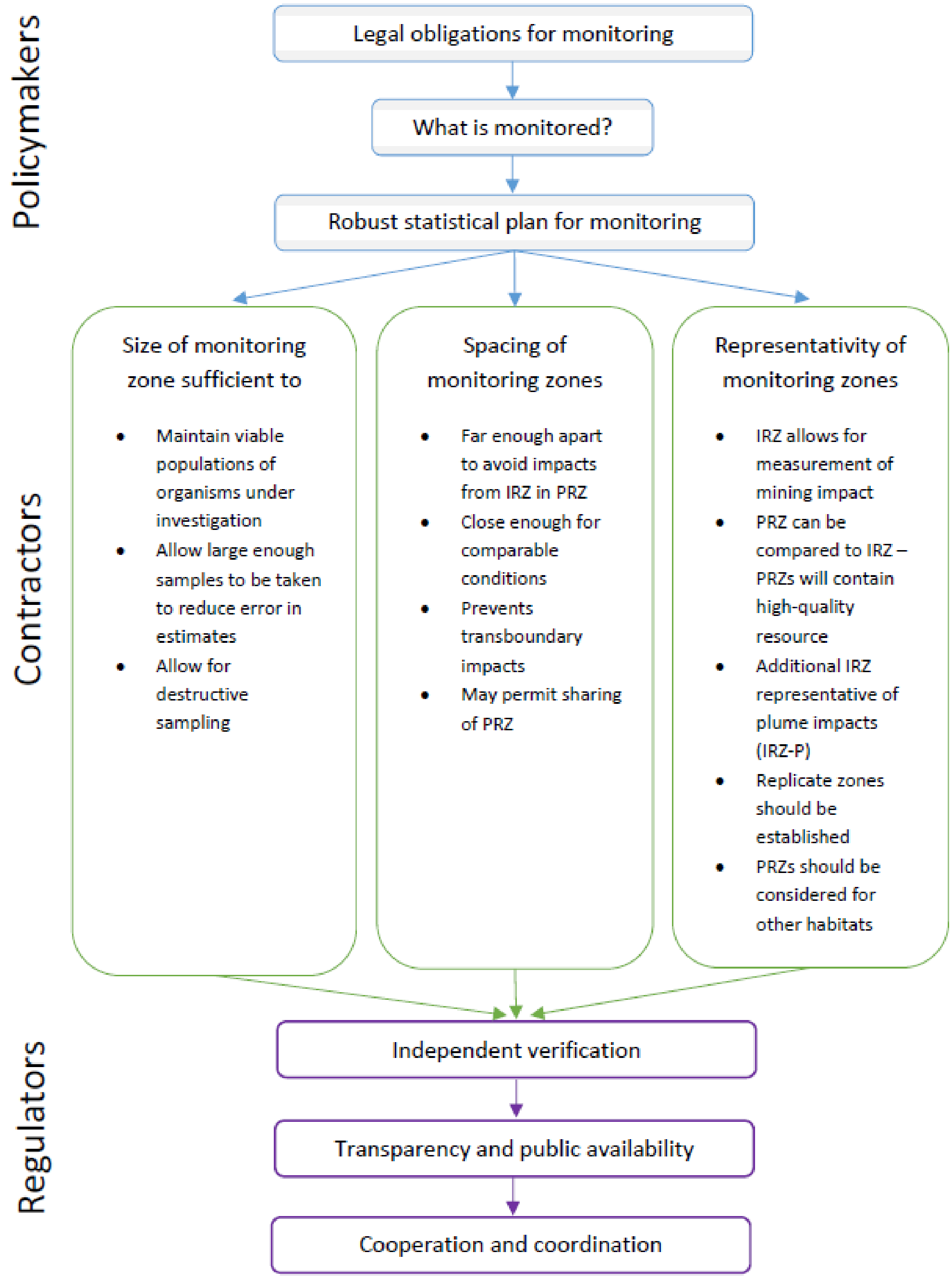

Figure 5-2: Summary of the considerations for monitoring of deep-sea mining impacts as presented in this paper. We focus on claim-scale monitoring in impact reference zones (IRZ) and preservation reference zones (PRZ).

A.4.1 Zone size

Size is a fundamental characteristic of spatial management zones. Conservation considerations aside, zones need to be sufficiently large to contain a representative subset of organisms sufficient for a statistically robust assessment of ecosystem integrity. Robust assessment of biological assemblages requires enumeration of hundreds of individuals from as many species as possible (Durden et al., 2016). Additionally, sites will need to be large enough to allow regular and repeated destructive sampling (e.g. box cores, trawls, and epibenthic sleds (Eleftheriou and McIntyre, 2013)) over a long period, likely decades, without any impact from sampling being detected. Densities of some organisms, particularly larger-sized animals (megafauna), are very low, especially in nodule areas. In the case of megafauna in nodule fields especially, representative sampling may require (photo / video) assessment of transects kilometres in length (Morris et al., 2014). Depending on the effect size being measured, the variances of the indicator under investigation and the statistical power desired, anywhere from 25 to >100 replicates may be necessary (Lan and Lian, 2010). These will need to be contained within the zone(s).

In line with the precautionary approach (Jaeckel, 2016b) it will be necessary to design zones based on precautionary assumptions. While default minimum sizes of protected areas are typically specified by the regulator, other more flexible science-based approaches for determining appropriate size could be taken, assuming the capacity exists to assemble the relevant local data and to assess local populations and their reproductive potential. While science-based local assessments increase the likelihood of effectiveness (Roberts et al., 2010), they do come with greater research costs. Thus, a management system could begin with a precautionary (i.e. likely too large) size of a PRZ as a default position, which could be modified (e.g. reduced in size) as more data become available suggesting what minimum dimensions might be required to achieve the objectives of viability, representability and resilience to sampling impact.

Finally, given the expected long duration of the monitoring (at least over the life of a 20 or 30-year contract, if not longer), PRZs will need to be large enough to self-support populations of the species being monitored. Otherwise, reductions in the populations of species in the PRZ (which is providing a representation of the natural environment not impacted by mining) because of insufficient recruitment could be confused with natural declines in the region that were caused by other factors, such as climate change.

A.4.2 Separation of zones

Spatial management zones will need to have sufficient geographical distance from mining to ensure that the PRZs are not impacted by mining activities, and the IRZs are affected by a meaningful range of affects. However, environmental heterogeneity tends to increase with spatial scale (Chesson, 2000), so zones closer together are likely to be more representative of each other. Thus, both types of zones will need to be close enough to each other and to the mining activities to ensure that they represent reasonable examples of impact and control treatments. Given the currently unknown behaviour of mining plumes, the question of appropriate spacing is particularly difficult, and will therefore require taking an adaptive approach for each of the resource types, to measure the varying impacts of the plumes over distance, and to control for them. It may be necessary to place IRZ at multiple distances away from the mining impact to evaluate the gradient of disturbance and its impacts.

A.4.3 Statistically robust monitoring

The monitoring design and schedule should be able to reliably detect the impacts of ongoing mining activities by comparing the state of the ecosystem subjected to mining with the state of the ecosystem that would have existed if mining had never occurred. This requires an approach that can reliably estimate the effect of mining activities amid the diverse sources of spatial and temporal variability in the deep sea, which in turn requires data to be collected before the mining has occurred (Stewart-Oaten et al., 1986; Osenberg et al., 1994), during, and at multiple points after the mining (Thiault et al., 2016). Spatiotemporal variation (i.e., unique spatial and temporal fluctuations at each site) is addressed, in part, by repeated sampling through time (Thiault et al., 2016) and at multiple sites (Underwood, 1994) (see below). Many impacts will lead to step-changes in the ecosystem after mining, which are easier to detect (Stewart-Oaten and Bence, 2001). However, some impacts from mining, particularly secondary impacts (such as from plumes), may not cause immediate or constant changes to a system. Indeed, complex ecological interactions may take time to propagate through the system, leading to time-dependent effects of disturbance (Thiault et al., 2016). Monitoring needs to be able to detect these changes. It should also be able to detect combined or cumulative effects of other environmental changes and attribute these to a cause or causes. Regular monitoring is also important to provide the information necessary for responsive adaptive management (Walters and Holling, 1990).

A statistically robust sampling programme should be implemented to consider the points raised here (e.g. Buckland et al., 2001). The robustness of the plan should be tested and scrutinised prior to sampling by statistical experts familiar with working in the deep sea. Baseline data collected at the claim sites should be sufficient to allow for estimations of population means and variance in the indicator of interest (e.g. species richness) required for a formal power analysis of a sampling plan. Three variables are of relevance here: significance (the error rate that you are willing to accept), power (the probability that the sampling plan will find a statistically significant difference in the indicator between the IRZ and PRZ when there is a difference), and effect size (the size of the difference in the indicator between the PRZ and IRZ). Typically, a significance level of 5% and a power of 80% are selected, but arbitrary convention may not be appropriate for some questions. Measuring smaller effect sizes will require more replicates than larger ones, and hence choosing an appropriate value beforehand is necessary. There are few conventions concerning effect levels to be measured, and will indeed be heavily dependent on the particular indicator. However, effect levels greater than one standard deviation (a change of ~68% of the measured value, if normally distributed data) are likely to already fall within the legal realm of 'serious harm' to the environment. Thus, it is expected that measuring an effect level less than one standard deviation (e.g. 0.5) will be necessary, where an effect size of 0.5 is that the mean value of the indicator in the PRZ is 0.5 standard deviations smaller (or larger) than that in the IRZ.

Given the multiple considerations and complexities involved, a system of peer-review or independent verification of sampling designs would help ensure that the design was robust prior to commencement of an expensive sampling programme. Marine data acquisition in other industries, such as oil and gas, has generally become formulaic and focused on the known impacts and effects of those industries, in part to meet existing legal and commercial drivers (Cordes et al., 2016). In moving into the deep-sea environment this approach has revealed problems in terms of robustness of data for understanding impacts to deep-sea ecosystems (Cordes et al., 2016). As a result, it will be insufficient to solely rely on shallower water protocols; rather, these will need to be revised for the deep-sea to provide the necessary statistical power for measuring the relevant deep-sea ecological indicators.

A.4.4 Replication of zones

Monitoring multiple examples of each type of zone enhances the statistical power to detect effects, and thus in the deep-sea where statistical power is usually an issue, it should be assumed that multiple replicates of PRZs and IRZs will need to be established. The comparison between a single impact and a single control location is confounded by any non-mining-related temporal ecological variation. For example, populations often have different temporal trajectories in different locations, and temporal interaction among places is also common (Underwood, 1994). Multiple control sites are also necessary to detect disturbances that do not affect long-term mean abundances of a population, but, instead, alter the temporal pattern of variance of abundance (Underwood, 1991).

To be effective, the location of zones should be defined as soon as possible in the mining process, at least in the preparation of the environmental impact assessment (Durden et al., 2018), but preferably in the initial planning stages (Durden et al., 2017). However, at the start of a mining project there will be some uncertainty in the exact spatial and temporal pattern of mining activities. This may lead to inappropriate zones being defined, for example if IRZs are unsuited to mining, or mine plans change around designated zones. Furthermore, it is likely that some areas defined as PRZs or IRZs may turn out, after further monitoring, to be unrepresentative. Also, some PRZs may turn out to be too close to mining activities and will become impacted. These could be re-designated as IRZs; others may have to be retired. These changes in status of designated areas could be particularly significant, both scientifically and economically, if unreplicated PRZs are impacted, as that this could require operational modifications or reductions in the planned mining area or movement of mining into less valuable resource areas. Finally, natural small-scale episodic events may occur in some areas reducing their value for monitoring, particularly in the case of highly dynamic SMS vent ecosystems. For all these reasons, increasing redundancy through designation of multiple sites is strongly suggested in order to mitigate a range of potential problems and allow for flexibility and adaptability in both the contractor's mining activities and the monitoring plan.

A.4.5 PRZs and representativity

Recent research (Amon et al., 2016; Vanreusel et al., 2016) illustrates the importance of nodules for abyssal biodiversity. Likewise, the minable resource may also be important for biodiversity associated with SMS (Boschen et al., 2013) and crust deposits (Schlacher et al., 2014). Ecological communities likely also respond to finer-scale environmental variation, such as variation in local geomorphology (Amon et al., 2016). Consequently, to fulfil the obligation of representativeness of the PRZ it will be necessary to demonstrate that the PRZs contain similar ecological and geomorphic features as the planned mining area, which in the case of nodule mining will mean a similar density and size of nodules. Thus, "including some occurrence of polymetallic nodules" (ISA, 2011b) is likely an insufficient criterion for a PRZ, which is "to be as ecologically similar as possible to the impact zone" (ibid.). Consideration should also be given to PRZs having other environmental traits that are the same as those sites suitable for mining, as these traits may also affect ecological community structure. For example, having limited slope and rugosity in the case of nodule mining, particularly as variation in seabed structure is known to affect communities in abyssal plains (Durden et al., 2015). Once suitable areas have been identified, the IRZs and PRZs should be selected at random within those areas for each habitat type (i.e. stratified random sampling) (Cochran, 1953).

A.4.6 Preservation reference zones for other habitats

Outside of the mined habitats, it is likely that other habitats, including ecologically or biologically significant areas may exist within the claim zones and that these may be impacted from mining activities through plume and other effects. These habitats could, for example, include areas unsuitable for mining because of geomorphological features (e.g. seamounts in a nodule mining area) or lack of resource (e.g. nodule free areas), and areas with significant aggregations of habitat-forming organisms (e.g. cold-water coral reefs near SMS deposits). To understand the full impacts of mining, it will be necessary to identify these ecologically important areas prior to mining and also include them in any monitoring programme. In addition, as discussed above, it will be necessary for statistical purposes to ensure that representative portions of all local habitats are spared from mining impacts. These may require an additional sub-class of PRZs to be recognised for each special feature and habitat type.

A.4.7 Consideration of the effects of plumes

Sediment and chemical plumes from mining disturbance are likely to be an important impact from DSM with potentially far-reaching (Jankowski et al., 1996; Ruhlemann and Knodt, 2015; Aleynik et al., 2017) and damaging impacts (Schaanning et al., 2008; Trannum et al., 2010) with expected negative consequences to both benthic and pelagic deep-water communities. The geographic location of plume impacts will almost certainly include the mined area, but may extend to be several times the spatial extent of the mining activities themselves (Sharma et al., 2001; Aleynik et al., 2017). Sediment plumes may also fall onto future mining blocks, where they will later become re-suspended and re-distributed further, thus amplifying their impacts.

The impact of plumes from DSM activities is poorly known, despite several experiments designed to simulate them (Fukushima, 1995; Desa and INDEX project group, 1997; Ozturgut et al., 1997; Kotlinski and Stoyanova, 1998). Environmental management of current and future activities will require that impacts from plumes are measured and understood. Thus, some impact reference zones will need to be designed specifically for the effects of plumes. Here, to differentiate these from other IRZs, we add a 'P' to the designation IRZ-P. IRZ-Ps would be situated in an area that is representative of the mined area that is not mined but is expected to receive significant impacts from the sediment plume. A gradient of plume-related impacts (e.g. settled sediment thickness) will need to be evaluated.

It will be necessary, but could prove to be difficult, for the contractor to provide evidence that the designated PRZs are not affected by the impacts of plumes and sediment deposition, bearing in mind that sub-lethal long-term effects of low levels of increased sedimentation are currently unknown. If a PRZ is found to be impacted, it will no longer be able to fulfil its role as defined in the mining code of being able to detect changes in the mined area (though it could become an IRZ-P). Initial modelling results (Aleynik et al., 2017) suggest that plume impacts will extend over areas several times larger than the mined area, particularly if the locations of low levels of additional suspended materials are assessed.

Whilst the direct impacts of mining are difficult to mitigate (avoidance: mine or don't mine), the secondary impacts caused by plumes, noise, etc., are mitigatable and should be the focus of management measures to minimise such disturbance. The spatial distribution of plume impacts is a function of four components: i) engineering: the type of mining machinery in use – how deeply it digs, how finely (if) it grinds up the raw ore, how it moves along the seabed, and how it discharges its "exhaust" of unwanted sediments (both in the deep-seafloor operations and on the surface discharge of additional water and fine particulate); ii) geology: the quantity and nature of the ore, as well as the associated seabed sediments, how long they stay in suspension and the amount of dissolution of elements; iii) hydrography: the strength, direction, and variability of local eddies and currents at the time of mining (Rye et al., 1998); and, iv) the duration of the mining activities. To effectively predict the spatial extent of the plume and hence set effective spatial management zones, models that use realistic data for all four components will be necessary. Likewise, mitigation measures to keep the extent of plumes to minimum could focus on these four components, exploring engineering solutions in concert with geological and hydrological site selection criteria, where they are least likely to have lasting impacts.

Research is required to determine the levels of suspended sediment or chemical concentrations that are not acceptable in a PRZ (based on smothering or toxicity). This will likely be set at a threshold where either sediment cannot be detected or where it has been shown to have negligible effects on deep-water organisms. This threshold could also be used for monitoring and enforcement, but may take several years of careful monitoring to establish. In the meantime, a precautionary value will need to be selected.

A.4.8 Transboundary effects

It is very possible that some of the impacts of mining will extend beyond the boundaries of the contractual / license area, particularly the impacts of plumes. This would require monitoring outside of what a contractor may be willing, obliged or allowed to provide. Alternatively, it could mean that the contractor could not mine up to the boundary of their area. These concerns are particularly relevant to mining activities generating large plumes, those at the edge of claim zones, and in small sized or irregularly shaped claims with a greater edge-to-area ratio and hence increased chances of edge-related effects spilling over into neighbouring areas. The likelihood of these concerns are increased if contractors give up parts of their exploration area when they move to exploitation. If it should happen that these impacts extended to a neighbouring contractual / license area held by another State Party, they may present diplomatic as well as liability challenges. Likewise, if plumes were to fall onto unclaimed areas there could be questions both concerning the liability and also who would pay to monitor these areas. Finally, plumes that fell within national jurisdiction would likely trigger environmental liability based on existing international environmental jurisprudence (e.g. Wirth, 1996), which again would need to be expanded to take into account the unique legal specifics of DSM. In all cases, to determine the legal ramifications, having a robust monitoring programme in place will be necessary to: i) detect such trans-boundary effects as they occur, and ii) to determine if these effects are likely to cause serious harm to the environment. The first point suggests that monitoring outside of claim blocks will be necessary when spillover is likely. The second point suggests that such monitoring would have to be factored in before mining commences; i.e. the appropriateness of trans-boundary monitoring should be a consideration in the monitoring plan from the outset.

A.4.9 Integration with other human activities

In an increasingly crowded ocean, the zoning of PRZs and IRZs will ultimately require integration into wider spatial planning and management. Maps and coordinates of zones should be made public (as has been the practice to date with the Pacific APEI). Additionally, they could be communicated to secretariats of other relevant international maritime bodies to better ensure they are taken into account. However, in cases where there are other potentially conflicting activities, it is unlikely that notification alone will be sufficient, and cooperative mechanisms will need to be developed (for example the International Cable Protection Committee and the International Maritime Organization) (Ardron et al., 2014b). Additionally, the PRZs should be included in international databases of protected areas (e.g. IUCN Protected Planet, http://www.protectedplanet.net/) and take into consideration other international designations (e.g. UN General Assembly *vulnerable marine ecosystems*,).

A.4.10 Sharing PRZs

It is conceivable that contractors may want to share PRZs along a common boundary of their claim areas. This offers the possibilities of cost and effort savings as well as a way to carry out more intensive monitoring. Combining the financial resources for monitoring by two contractors may allow for the installation of ambitious and novel monitoring equipment, such as seafloor observatories (Ruhl et al., 2011). Seafloor observatories could provide real-time data to enhance day-to-day environmental management, for example detecting peak current events, during which mining could be avoided because plumes generated would be widely dispersed. Combining PRZs also has the advantage of ensuring monitoring approaches are the same between two contractors, although coordination of monitoring activities around two independent mining developments may be difficult. A trans-boundary PRZ should be part of a wider array. Monitoring just one PRZ for two contract areas is not being suggested here, and would have several disadvantages: 1) it reduces replication, which would leave monitoring more vulnerable to the many possibilities of technical and ecological uncertainty; and, 2) it also reduces the overall spatial sampling carried out in the mining areas, with subsequent reductions in the amount of information available for the regulator for regional planning and understanding. Therefore, whilst cost-saving and cooperation among contractors should be encouraged, it should not be employed to replace rigorous sampling and replicates.

A.4.11 Verification of results

For mining using new and developing techniques, it should be advantageous for independent observers or verification agencies to be used to help ensure the independence and robustness of results. Transparency, particularly in the nascent stages of this new industry, will be important in developing shared good practices and building trust (Ardron, 2018; Ardron et al., 2018). Sampling plans would be made publicly available for external scrutiny, in addition to peer review, prior to sampling. Making subsequent data and metadata, analysis and interpretations publicly available will also help improve accountability and credibility of the results from this new and emerging industry.

A.4.12 A proposed three-step adaptive approach

When setting up a monitoring scheme for a given mining block within a contractual / lease area, three steps might be considered: 1) beginning with more PRZs than will ultimately be used in long-term monitoring to ensure statistical robustness as well as redundancy given various uncertainties; 2) re-designating some PRZs that are affected by mining into IRZs (while retiring others that are not helpful to the monitoring plan); and 3) learning from the current situation and the future plans for mining to set up a new array of PRZs/IRZs an appropriate time in advance (e.g. 3 years) in order to acquire the necessary baseline information. In this scheme, there would be three activities operating in parallel within a contractual area: i) active mining and monitoring; ii) baseline monitoring at the next block in anticipation of mining; and iii) surveying / selecting the subsequent mining block after the one currently being monitored for baseline information. Flexible iterative management, as suggested here, allows for learning and adapting through experience, and could prevent delays resulting from inadequate or unsuitable baseline or monitoring data, whilst providing the Contractor a stepwise investment strategy, rather than having to put in place a full monitoring system from the outset. However, such flexibility is only possible if the contractual / licensing scheme allows for regular review and revision of Plans of Work. The ISA contractual system currently in place for exploration has very limited flexibility of this sort, and Plans of Work for exploration have seldom been modified over the course of their 20-year life spans.

A.5 Conclusion

The latest draft of the exploitation regulations (ISA, 2016a) proposes separate Environmental Regulations, which are not yet completed. The ISA (July 2016; ISBA/22/C/CRP.1) states that guidelines are needed for establishment of IRZ and PRZ, which will feed into the Environmental Regulations. Establishing scientifically realistic and effective guidelines for spatial management zones should in turn inform the development of effective rules and regulations. Using existing experimental design guidance as a starting point, this paper has added considerations particularly relevant (or unique) to the deep sea and DSM, in order to formulate recommendations for establishment of PRZs and IRZs (Figure 2). Although focused on mining activities in areas beyond national jurisdiction, the recommendations presented here would be applicable and useful to the design of spatial environmental management zones in national waters. PRZ and IRZ in crust, SMS and pelagic environments present additional challenges to those presented here for nodule systems. Additional critical thinking in collaboration with a wide variety of experts is necessary for appropriate mechanisms for establishment to be developed.

Appendix B Supplementary materials to Chapter 3

Table B-1: Examples of good governance principles
If not named as a 'principle', then the given term is in the heading. Items have been re-ordered to facilitate comparisons. Wording is from the source documents (UNDP, 1997; G20/OECD, 2015; Kaufmann et al., 2008; Lockwood et al., 2010; and, Governance Institute of Australia, (n.d.)).

UNDP 'characteristics'	G20/OECD[140]	World Bank 'indicators'	Lockwood et al.	Governance Institute of Australia
Transparency	Disclosure and transparency; transparent and fair markets	Control of corruption	Transparency	Transparent
Accountability	(Not a principle, but throughout text.)	Voice and accountability	Accountability	Accountable
Participation			Inclusiveness	Participatory
Equity	Equitable treatment of shareholders	Regulatory quality	Fairness	Equitable and inclusive
Consensus orientation	Co-operation between corporations and stakeholders		Integration	
Responsiveness			Adaptability	Responsive
Strategic vision				
Effectiveness and efficiency	Effective supervision and enforcement	Government effectiveness	Capability	Effective and Efficient
Rule of law	Consistent with the rule of law	Rule of law	Legitimacy	Following the rule of law
		Political Stability and Absence of Violence		

[140] G20/OECD principles are for corporate good governance. Only those more broadly applicable have been excerpted.

Table B-2: Common components of transparency, cross-referenced to standards, with examples

Transparency component	Cross-references of this component to the reviewed standards	Examples
1. Access to Information	***Clearly specified disclosure requirements*** • **Extractive Industries Transparency Initiative [EITI] Standard 2016**, Requirements 2-7; • **Global Reporting Initiative [GRI] Reporting Standards GRI 102: General Disclosures 2016** (lists disclosure requirements), section 1, 2, 3, 4, 5 & 6 -; • **World Bank Environmental and Social Framework [World Bank ESF 2016]** section F, p.20 -Information Disclosure, Environmental and Social Framework [ESS] 1 (section 15, P. 27, section B (24), P. 30, section E (51-53), P. 36-37 - Stakeholder Engagement and Information Disclosure and section D, P. 42), ESS2, ESS4, ESS5, ESS7, ESS8, & ESS10 also provide for specific disclosures. The World Bank Access to Information Policy applies to the ESF and ESS; • **International Finance Cooperation [IFC] Performance Standards on Environmental Social Sustainability [PS-ESS], Performance Standard [PS]** 1 (Section 29, P. 8-Disclosure of Information), PS2 (section 9, P.2, section 14, P. 3, section 18, P.4), PS4 (Section, 11, P.3); • **Pacific-ACP States Legislative and Regional Framework for Deep Sea Mining [Pacific- ACP States LRF for DSM]**, Section 11, 12, 14; • **Initiative for Responsible Mining Assurance Standard for Responsible Mining IRMA-STD-001, Draft v2.0 [IRMA-STD-001-Draft v2.0]**, Principle 1 (Business Integrity), Chapter 1.1.4 (Disclosure and Reporting of Non-Compliance Response), Chapter 1.2 (Revenue and Payments Transparency); Principle 1 (Business Integrity), chapter 1.2.4. (Operating Company Transparency) - IRMA-STD-001-Draft v2.0. Contains requirements to make licenses and contracts publically	**IRMA-STD-001-Draft v2.0, Principle 1 (Business Integrity), Chapter 1 (Revenue and Payments Transparency), P. 24:** 1.2.1.1. The operating company shall comply with the requirements listed under this Criterion and Criterion 1.2.2, below, and/or demonstrate how it complies with equivalent reporting and disclosure requirements of the European Union Accounting Directive (Directive 2013/34/EU) and the European Union Transparency Directive (Directive 2013/50/EU) respectively, or an equivalent mandatory transparency regime.5 1.2.1.2. The operating company shall publish all material payments made by itself and its corporate owner, if relevant, to the government of the country in which the mining project is located. This information shall be updated on an annual basis, and publicly available on the company and/or on appropriate government website(s). **Ibid. P. 27-28:** a. Where these terms are negotiated, rather than governed by law, the company shall make the relevant agreements, licenses or contracts freely and publicly accessible. b. Where these terms are governed by law, free, public access to the relevant statutory documentation is deemed sufficient to meet the IRMA requirement. 1.2.4.2. The beneficial ownership of the operating company shall be publicly accessible. **Global Reporting Initiative [GRI] Standards - GRI 102: General Disclosures 2016; section 3.2, p. 24 - Reasons for omission:**

available. Note: relevant changes in draft IRMA-STD-001-Draft v2.0 include: Corporate owner not required to participate in EITI however participation is required by operating companies active in country with natural resource. Also, P. 19, Chapter 1.2 Revenue and Payments Transparency, "Removed requirement to make non-compliance information automatically publicly accessible (e.g., on a website). But for transparency purposes, retained ability for stakeholders to request and receive this information, with the exception of confidential information.)"

Information access in other standards

- **Madang Guidelines**, Guideline 17, P. 8;
- **Equator principles III**, P. 4 - (Approach - Information Sharing), Mandated Financial Institutions will share relevant non-confidential environmental and social information with other mandated financial institutions;
- **InterRidge statement of commitment to responsible research practices at deep-sea hydrothermal vents [InterRidge]**, Guideline 5, *commitment to sharing of data;*
- **OSPAR Code of Conduct for Responsible Marine Research in the Deep Seas and High Seas of the OSPAR Maritime Area [OSPAR],** Section 17 (Notification and research planning), section 23 (Data-sharing);
- **IRMA-STD-001-Draft v2.0**, Principle 2 (Social Responsibility) Chapter 2.4.5.1 (Reporting);
- **International Council on Mining & Metals [ICMM]** 10 principles do not contain a specific disclosure requirement.
- **Convention for the Prevention of Marine Pollution by Dumping of Wastes and Other Matter [MARPOL], and the London Protocol**, which are not intended to address information access per se, nonetheless have various requirements on labelling of dangerous cargo, development of garbage management plans, and reporting of spills, dumping and other related activities.

Availability of original data, aggregate data and metadata

If, in exceptional cases, an organization preparing a sustainability report in accordance with the GRI Standards cannot report a required disclosure, the organization shall provide in the report a reason for omission that:
3.2.1 describes the specific information that has been omitted; and
3.2.2 specifies one of the following reasons for omission including the required explanation for that reason.

Initiative for Responsible Mining Assurance [IRMA] STD-001-Draft v2.0, P 7:
…presently, many of the requirements specifically state that a company must post certain information on its website. IRMA is considering whether it might make more sense to have a central repository for IRMA disclosures (e.g., the IRMA website), rather than having each company create a place on its own website for IRMA-related information. IRMA recognizes, however, that web-based materials are not appropriate for all stakeholders.

International Seabed Authority [ISA] Nodule regulations, ISBA/19/C/17, 36(4):
Ten years after the date of submission of confidential data and information to the Authority or the expiration of the contract for exploration, whichever is the later, and every five years thereafter, the Secretary-General and the contractor shall review such data and information to determine whether they should remain confidential. Such data and information shall remain confidential if the contractor establishes that there would be a substantial risk of serious and unfair economic prejudice if the data and information were to be released.

	• **EITI** - information that countries and companies report on are compiled and reconciled into an EITI Report by an independent administrator, in addition countries also provide summary data. The reports and summary data are available on the EITI website: https://eiti.org/ and https://eiti.org/data • Some of the original reports that countries submit are also made available on local EITI websites. For example original Azerbaijan EITI reports are available here: http://www.eiti.az/index.php/en/reports . • The UK reports are available here: https://www.gov.uk/government/publications/extractive-industries-transparency-initiative-payments-report-2014 ***Delineating confidential information*** • **International Marine Mining Society Code for Environmental Management of Marine Mining [IMMS Code for EMMM]**, P. 9 - specifies that non-propriety information should be excluded from confidentiality requirements; • **ISA Zero Draft** exploitation regulations, Article 46; • **World Bank ESF ESS 8** (section 15–Confidentiality); • **IRMA-STD-001-Draft v2.0,** Principle 1 (Business Integrity), Chapter 1.1.6.2 (Record Keeping), Chapter 1.2.4. (Operating Company Transparency). • **Global Reporting Initiative [GRI] Standards - GRI 102: General Disclosures 2016; section 3.2** ***Embargoing information*** This aspect was not found in standards assessed, but is found in the ISA's Mining Code, regarding exploration contracts more than 10 years old (excerpted example text in column to the right).	
2. Reporting	***Clear reporting requirements*** • **EITI 2016 Standard**, Section 3 (Requirements for EITI implementing countries); • **GRI** 101 Foundation 2016 and GR1 102 General disclosures 2016 - GRI Standards – contain list of what sustainability report should contain including a list of disclosure requirements;	**GRI Standards: GRI 101 Foundation 2016, Section 1, Page 7 – Reporting Principles:** The Reporting Principles are fundamental to achieving high quality sustainability reporting. An organization is required to apply the Reporting Principles if it wants to claim that its sustainability report has been prepared in accordance with the GRI Standards [...] The Reporting Principles are divided into two groups: principles for

- Section 1, Page 7 (Reporting Principles) – GRI 101: Foundation 2016, GRI Standards;
- Section 2.5, P. 19 (Reporting on material topics), GRI 101: Foundation 2016 - GRI Standards;
- **IMMS Code for EMMM**, P. 8-9 (Reporting and Documentation);
- **Chinese Due Diligence Guidelines for Responsible Mineral Supply Chains,** Section 7.3, P. 28 (Design and implement a strategy to respond to identified risks), section 7.5, P. 31 (Report on process and results of supply chain risk management);
- **World Bank ESF**, Section D, P. 35-36 (Project Monitoring and Reporting), ESS1, ESS2& ESS10 also contain specific reporting elements;
- **IFC PS-ESS**, Section 36, P. 9 (Ongoing Reporting to Affected Communities);
- PS1 (section 36, P. 9), PS2, PS3 also contain specific reporting requirements - IFC PS-ESS
- **Pacific-ACP States LRF for DSM, Section 14.41-14.42, P. 29**;
- **Equator Principles**, Principle 9 (Independent Monitoring and Reporting) & 10 (Reporting and Transparency), P. 10 –
- **Equator Principles**, Annex B, P. 13, establishes Minimum Reporting Requirements;
- **IRMA-STD-001-Draft v2.0**, Principle 2 (Social Responsibility) Chapter 2.4.5. (Reporting).

Reporting of non-compliance:
IRMA-STD-001-Draft v2.0*:* records related to permit and legal non-compliance are to be disclosed to stakeholders upon request. Principle 1 (Business Integrity), Chapter 1.1.4. (Disclosure and Reporting of Non-Compliance).

defining report content and principles for defining report quality. The Reporting Principles for defining report content help organizations decide which content to include in the report. This involves considering the organization’s activities, impacts, and the substantive expectations and interests of its stakeholders […] Each of the Reporting Principles consists of a requirement and guidance on how to apply the principle, including tests.

IFC Performance Standards on Environmental and Social Sustainability, Section 36, P. 9 - Ongoing Reporting to Affected Communities:
The client will provide periodic reports to the Affected Communities that describe progress with implementation of the project Action Plans on issues that involve ongoing risk to or impacts on Affected Communities and on issues that the consultation process or grievance mechanism have identified as a concern to those Communities. If the management program results in material changes in or additions to the mitigation measures or actions described in the Action Plans on issues of concern to the Affected Communities, the updated relevant mitigation measures or actions will be communicated to them. The frequency of these reports will be proportionate to the concerns of Affected Communities but not less than annually.

IMMS Code for EMMM, P. 5:
Provide to the community non-proprietary technical information about potential effects and duration of operations, of waste products and their management, of rehabilitation procedures, and of socio-economic benefits and costs.

IRMA-STD-001-Draft v2.0, Principle 1 (Business Integrity), Chapter 1.1.4. (Disclosure and Reporting of Non-Compliance):
1.1.4.1. At minimum, the operating company shall disclose records relating to any legal and permit-related non-compliance to IRMA

		auditors, and shall disclose this information to stakeholders upon request. Records shall include those reasonably related to the non-compliance, including descriptions of non-compliance events and ongoing and final remedies. 2.4.5.1. The operating company shall periodically report publicly on the effectiveness of its due diligence activities. Reports shall include information on the potential and actual human rights impacts that have been identified, and account for how the operating company has prevented, mitigated and/or remediated those impacts. 2.4.5.2. Publicly available reports referred to in 2.4.2.7, 2.4.4.2.b and 2.4.5.1 may exclude information that is culturally inappropriate, politically sensitive, compromise the safety of any individual, or is legitimate confidential business information.
3. Quality Assurance	***Second party quality assurance***: • Section 7.3, P. 3 (Discrepancies and recommendations from EITI Reports), Section 4 (Validation Process) - EITI Standard 2016; • Section H, P. 21-22 ([Bank] Monitoring and Implementation Support), Section D, P. 35-36 ([Borrower] Project Monitoring and Reporting) - World Bank ESF; • **IRMA-STD-001-Draft v2.0 (each requirement accompanied by means of verification, IRMA's Verification Programme still under development but will include IRMA auditors).** • Section, 14.14, 14.19 (Due Diligence) - Pacific-ACP States LRF for DSM, also recommends that State entities undertake quality assurance. ***Standards that recommend/undertake external third party quality assurance***: • **London Protocol, 1996**, Article 9.5; • **Pacific-ACP States LRF for DSM**, Section 14.40, Section 11.5; • **IMMS Code for EMMM**, P. 9 (Performance Reviews). • **IRMA-STD-001-Draft v2.0, Pg 16 (Basis for Certification)** • **Chinese Due Diligence Guidelines for Responsible Mineral Supply Chains (CCCMMC)**	**GRI Standards: GRI 101 Foundation 2016, Section 1, Page 7 – Reporting Principles** The Reporting Principles for defining report quality guide choices on ensuring the quality of information in a sustainability report, including its proper presentation. The quality of information is important for enabling stakeholders to make sound and reasonable assessments of an organization, and to take appropriate actions. **Section 1.9, P. 15 - Reliability** 1.9 The reporting organization shall gather, record, compile, analyse, and report information and processes used in the preparation of the report in a way that they can be subject to examination, and that establishes the quality and materiality of the information. **Pacific-ACP States LRF for DSM, Section 14.19-Due Diligence:** To meet international obligations, before issuing a DSM exploration or mining licence or sponsorship agreement, States must conduct appropriate initial checks and analysis of the operator and its proposed work plan, to satisfy itself of the company's ability to perform the proposed activities in a timely, safe, environmentally

		responsible, and efficient manner. The legislation may therefore require certain pre-requisites from an operator before an application for DSM activity will be considered. These might include a minimum amount of operating capital, evidence of technical competence, appropriate insurance or other certification of financial responsibility, undertakings that relevant industry standards are adhered to by the DSM operator. Also, evidence or undertakings as to the seaworthiness, manning, equipment, and navigation of those vessels involved in DSM; perhaps also evidence as to energy efficiency and initiatives to reduce carbon footprint; and that adequate staff and operational performance policies and procedures are in place. **World Bank ESF, Section H, P. 21 - Monitoring and Implementation Support:** 56. The Bank will monitor the environmental and social performance of the project in accordance with the requirements of the legal agreement, including the ESCP and will review any revision of the ESCP including changes resulting from changes in the design of a project or project circumstances. The extent and mode of Bank monitoring with respect to environmental and social performance will be proportionate to the potential environmental and social risks and impacts of the project…A project will not be considered complete until the measures and actions set out in the legal agreement (including the ESCP) have been implemented. **International Marine Minerals Society Code for Environmental Management of Marine Mining, P. 9 - Performance Reviews:** Regularly (preferably every three years) evaluate company/entity performance under the Code by a team of qualified, externally accredited environmental auditors both from within and independent of the adopting company/entity.
4. Compliance	***Chinese Due Diligence Guidelines for Responsible Mineral Supply Chains,*** section 7.3.1, P. 28 and section 7.5, P.32	**Equator Principles, EPFI Reporting Requirements, P.10**

information / accreditation	**London Convention**; 1972, and the **London Protocol** (1996) Article 11 (Compliance Procedures), **Equator Principles**, Principle 8 (Covenants) P. 9, Principle 9 (Independent Monitoring and Reporting) P. 10, Annex B (Minimum Reporting Requirements, Implementation Reporting) P.14, **EITI**, accreditation through validation. Requirement 8, 8.3 Validation deadlines and consequences, P. 32-34 Information on the status of a country's validation process (showing compliance status) and accompanying documentation is available online on the EITI website https://eiti.org/document/validation-schedule **GRI Standards: GRI 101 Foundation 2016** Self-accreditation. Section 3.1, P.22 (Claims that a report has been prepared in accordance with the GRI Standards) **IRMA-STD-001-Draft v2.0** Section 1.1.4, Disclosure and Reporting of Non-Compliance, P. 20 **IFC PS-ESS** – The IFC's Access to Information Policy, provides for the disclosure and availability of project information, this includes financial, social and environmental information. This is publicly available on the IFC Project Information Portal https://disclosures.ifc.org/#/landing . In addition, an independent body known as The Office of the Compliance Advisor/Ombudsman (CAO), addresses complaints and conducts audits of IFC's financial, environmental and social performance. Information on CAO cases and the status of each is publicly available on the CAO website http://www.cao-ombudsman.org/cases/. **World Bank ESF,** ESS1, section C (36-37), Environmental and Social Commitment Plan, P. 34, section D (Project Monitoring and Reporting), P. 36	The EPFI will report publicly, at least annually, on transactions that have reached Financial Close and on its Equator Principles implementation processes and experience, taking into account appropriate confidentiality considerations. The EPFI will report according to the minimum reporting requirements. ***Annex B - Minimum Reporting Requirements, Implementation Reporting P.14,*** The EPFI will report on its implementation of the Equator Principles, including: • The mandate of the Equator Principles Reviewers (e.g. responsibilities and staffing); • The respective roles of the Equator Principles Reviewers, business lines, and senior management in the transaction review process; • The incorporation of the Equator Principles in its credit and risk management policies and procedures. For the first year of Equator Principles adoption, the EPFI will provide details of its internal preparation and staff training. After the first year, the EPFI may provide details on ongoing training of staff if considered relevant. **IRMA-STD-001-Draft v2.0 Section 1.1.4 Disclosure and Reporting of Non-Compliance, P. 20** 1.1.4.1. At minimum, the operating company shall disclose records relating to any legal and permit-related non-compliance to IRMA auditors, and shall disclose this information to stakeholders upon request. Records shall include those reasonably related to the non-compliance, including descriptions of non-compliance events and ongoing and final remedies.
5. Public participation	***Provisions for public participation*** • **GRI Standards**, section 1.1, P. 8 (Stakeholder Inclusiveness), GRI 101: Foundation 2016; • **World Bank ESF**, section G, P. 20 (Consultation and Participation), ESS1 (section E, P. 35 - Stakeholder Engagement and Information Disclosure),	**World Bank ESF, ESS 1. Assessment and Management of Environmental and Social Risks and Impacts, Section 15, P. 27 – Requirements:** The Borrower will:

ESS5 (Section 17, P. 81- Community Engagement), ESS7 (section 23, P.112- Meaningful Consultation Tailored to Indigenous Peoples/Sub-Saharan African Historically Underserved Traditional Local Communities, section B, P. 113-114 -Circumstances Requiring Free, Prior and Informed Consent (FPIC), ESS8 (section B, P. 121 - Stakeholder Consultation and Identification of Cultural Heritage) and ESS10 (section 6-8, P. 132 – Requirements, section 21, P.134 - Meaningful Consultation);

- **IFC PS on ESS**, PS1 (section 30, P.8 - Consultation, section 31, P.8 - Informed Consultation and Participation);
- **EITI Standard 2016**, Requirement 1, (Oversight by the multi-stakeholder group), Requirement 7;
- **Equator Principles**, Principle 5 (Stakeholder Engagement), P. 7;
- **IRMA-STD-001-Draft v2.0**, Principle 2 (Social Responsibility) specifically Chapter 2.8 (Community and Stakeholder Engagement), Chapter 2.9 (Obtaining Community Support and Delivering Benefits) and Chapter 2.10 (Free, Prior and Informed Consent (FPIC)); Principle 4 (Planning and Managing for Positive Legacies);
- **Pacific-ACP States LRF for DSM**, Guideline Section 16;
- **IMMS Code for EMMM,** Page 5 (Community Partnership);
- **Madang Guidelines**, 19, P. 8.

(b) Undertake stakeholder engagement and disclose appropriate information in accordance with ESS10

Section B (24), P. 30 - Environmental and Social Assessment:
The environmental and social assessment will include stakeholder engagement as an integral part of the assessment, in accordance with ESS10.

Section E (51-53), P. 36-37 - Stakeholder Engagement and Information Disclosure:
51. As set out in ESS10, the Borrower will continue to engage with, and provide sufficient information to stakeholders throughout the life-cycle of the project, in a manner appropriate to the nature of their interests and the potential environmental and social risks and impacts of the project.
52. For High Risk and Substantial Risk projects, the Borrower will provide to the Bank and disclose documentation, as agreed with the Bank, relating to the environmental and social risks and impacts of the project prior to project appraisal42. The documentation will address, in an adequate manner, the key risks and impacts of the project, and will provide sufficient detail to inform stakeholder engagement and Bank decision-making. The Borrower will provide to the Bank and disclose final or updated documentation as specified in the ESCP.
53. If there are significant changes to the project that result in additional risks and impacts, particularly where these will impact project-affected parties, the Borrower will provide information on such risks and impacts and consult with project-affected parties as to how these risks and impacts will be mitigated. The Borrower will disclose an updated ESCP, setting out the mitigation measures.

GRI Standards: GRI 101 Foundation 2016, Section 1.1, P. 8 - Stakeholder Inclusiveness
The reporting organization shall identify its stakeholders, and explain how it has responded to their reasonable expectations and interests…When making decisions about the content of its report,

		the organization is to consider the reasonable expectations and interests of stakeholders. This includes those who are unable to articulate their views and whose concerns are presented by proxies (for example, NGOs acting on their collective behalf); and those with whom the organization cannot be in constant or obvious dialogue. The organization is expected to identify a process for taking such views into account when determining whether a topic is material. **GRI Standards - GRI 102: General Disclosures 2016** **Disclosure 102-44, Page 32 - Key topics and concerns raised:** The reporting organization shall report the following information: a. Key topics and concerns that have been raised through stakeholder engagement, including: i. how the organization has responded to those key topics and concerns, including through its reporting; ii. the stakeholder groups that raised each of the key topics and concerns.
6. Review / appeal	***Requirement to address stakeholder grievances*** • **World Bank ESF**, Section I P. 22 (under Bank Requirements: Grievance Mechanism and Accountability), ESS1 (section 15, P. 27); ESS2; ESS7 (section C, P.118) and ESS 10 (section C (26-27), P.136); • **IFC Performance Standards on ESS**, PS1 (section 35, P. 9 - Grievance Mechanism for Affected Communities); PS2 (section 13, P. 3- Workers' Organizations, section 20, P. 4), PS4 (section 12, P.3), PS5 (section 11, P. 4); In addition, the independent Compliance Adviser Ombudsman addresses complaints and concerns raised by IFC project affected persons. • **GRI Standards**, Disclosure 102-44, Page 32 (Key topics and concerns raised) - GRI 102: General Disclosures 2016. • Section 1.8, P. 8 - GRI 103: Management Approach 2016, GRI Standards • **Equator principles**, Principle 6 (Grievance Mechanism), P. 8; • **IRMA-STD-001-Draft v2.0**, Principle 2 (Social Responsibility), Chapter 2.13 (Grievance Mechanism and Access to Other Remedies).	**Equator principles, Principle 6 (Grievance Mechanism), P. 8:** For all Category A and, as appropriate, Category B Projects, the EPFI will require the client, as part of the ESMS, to establish a grievance mechanism designed to receive and facilitate resolution of concerns and grievances about the Project's environmental and social performance […] It will seek to resolve concerns promptly, using an understandable and transparent consultative process that is culturally appropriate, readily accessible, at no cost, and without retribution to the party that originated the issue or concern. The mechanism should not impede access to judicial or administrative remedies […]

Appendix C Supplementary materials to Chapter 4

C.1 Data distribution and morphospecies detection

The rank abundance of the metazoan morpho-species (**mspp**) displays a log-linear relationship, with an inflection into the top decile of the rank, where mspp abundance rises noticeably (**Figure 5-3**). No single taxon dominates; the most abundant, a porifera (n=786), is followed by a polychaete (n=575) and an actinian (n=489), bryozoan (n=467), and an alcyonacean (n=367). In all, 132 mspp were identified in 10 052 photos (18 582 m^2), with a total of 6055 individuals (> 10mm). Despite the large area sampled, singletons, doubletons and tripletons still accounted for over one-third (35.6%) of the taxa in the dataset.

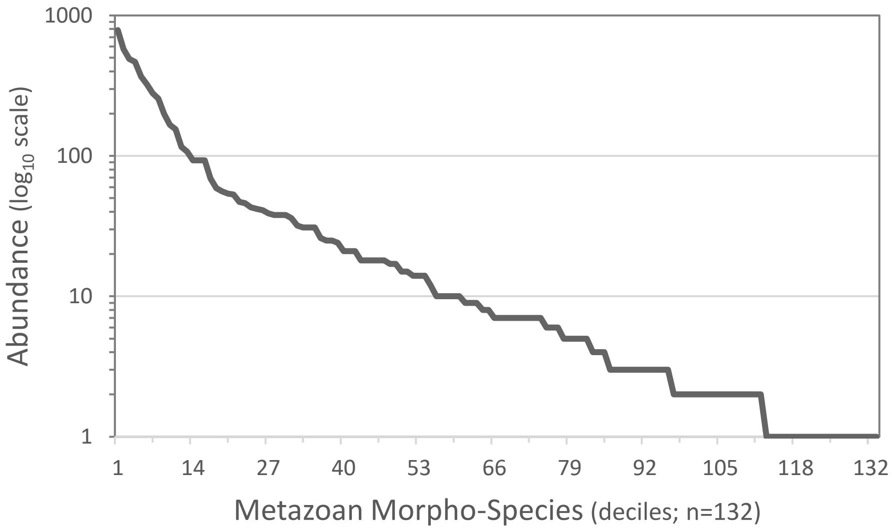

Figure 5-3: Rank abundance distribution of metazoan morphospecies
Abundance, the y-axis, is log-transformed. Note the inflection at about abundance = 90. The steps on the far right of the plot show the relatively large numbers of singletons (20), doubletons (16) and tripletons (11). Total area is 18 582.1 m^2 captured in 1052 photographs.

To check the detectability of organisms across all size classes, a histogram was plotted. More smaller animals were consistently detected than larger ones, suggesting that the detectability of organisms across the size range used in the analysis appears to be reliable (**Figure 5-4**).

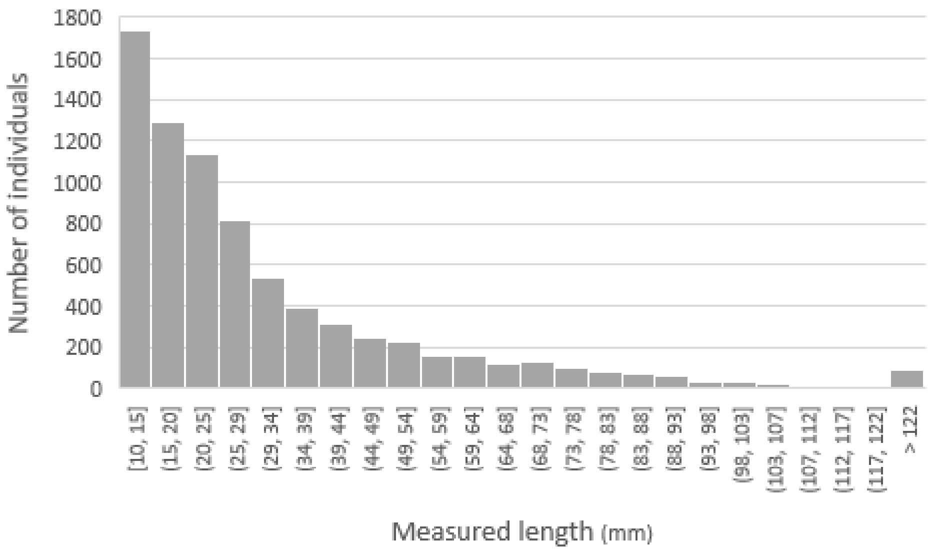

Figure 5-4: Size-frequency histogram of measured lengths of the metazoan data including higher order classifications, in 24 bins plus one overflow. The count of individuals, from large to smaller, steadily increases until the 10 mm cut-off.

C.2 Habitat classes

The No-Nodules class, defined by having 0-1% nodule coverage, accounts for only about 11% of the total area. The density of all metazoans (mspp and higher orders) in the Nodules class is nearly three (2.73) times greater than in the No-Nodules class. Within the Nodule class, Flats have the most nodules –about twice as many as the Troughs– and also the highest metazoan density, though the relationship is non-linear (Simon-Lledó et al., 2019a, 2019b).

Table C-3: Summary of the habitat classes including the three geomorphic sub-classes of nodules, and the unstratified data. Abbreviations: no.=number (count); m = metre; nod.= nodule; metaz.=metazoan; ind.=individuals observed (> 10 mm).

	Photos (no.)	Area (m^2)	Nod. Density (%)	Metaz. Density (ind.*m^{-2})
1. No-Nodules	1089	2028	0.53	0.128
2. Nodules	8963	16 554	7.34	0.350
2a. Troughs	2048	4360	4.99	0.315
2b. Flats	3481	5907	10.05	0.370
2c. Ridges	3434	6287	6.00	0.356
All (unstratified)	10 052	18 582	6.60	0.325

C.3 Additional treatment metrics and habitat classes

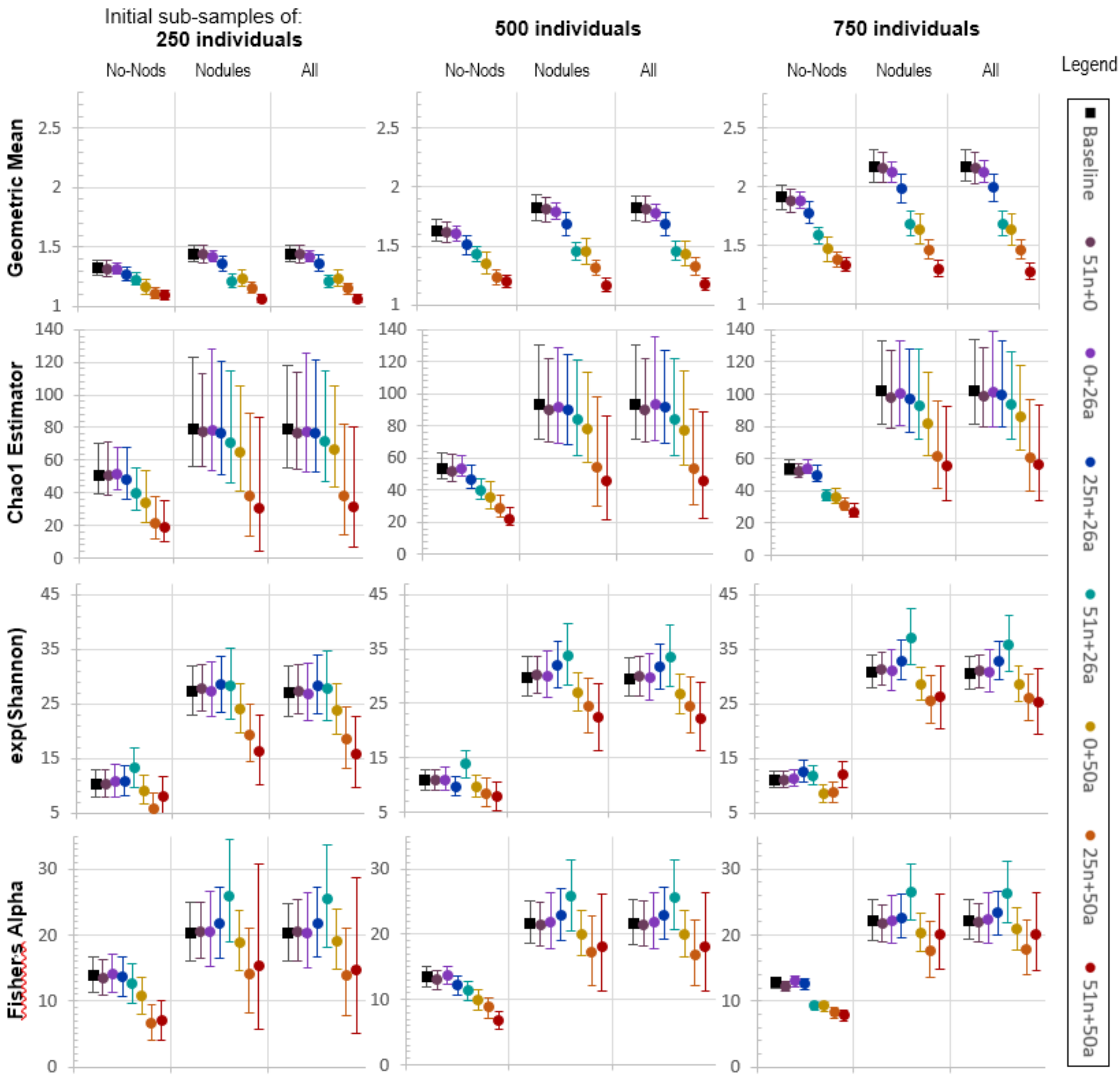

Figure 5-5: Additional panel of metrics to supplement Figure 4-2
across three sub-sample sizes (250, 500, 750 individuals). The treatment series' number codes that are in the rightmost legend (explained in **Table 4-3**'s central column) are ordered according to increasing combined impact, left to right, violet to red. Error bars depict the 95% range of results (a proxy for confidence) over 2000 simulations.

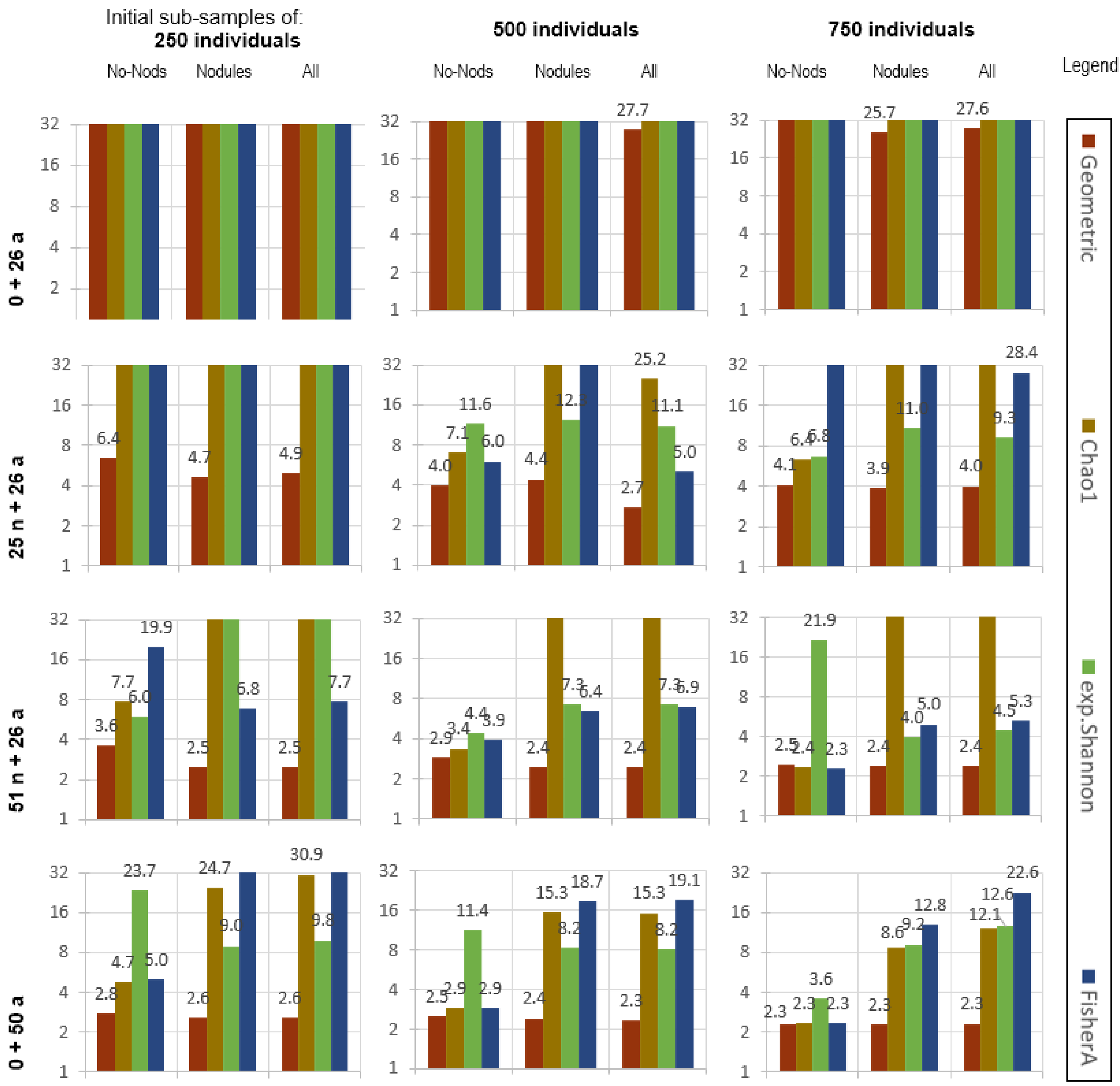

Figure 5-6: Power analysis of the four additional metrics in Figure 5-5 above (leftmost labels), across three initial sub-sample sizes (250, 500, 750), under the four middle degradation treatments (rightmost legend, explained in **Table 4-3**'s central column), increasing in severity from top to bottom. Two-tailed t-test error thresholds: significance ≤ 0.05; power (type II confidence) ≥ 95%. Note that the y-axis is logarithmic, depicting the theoretical number of sampling sites required to meet these error thresholds (≥ 2). Values greater than 32 are not fully displayed, as they would be impractical to implement.

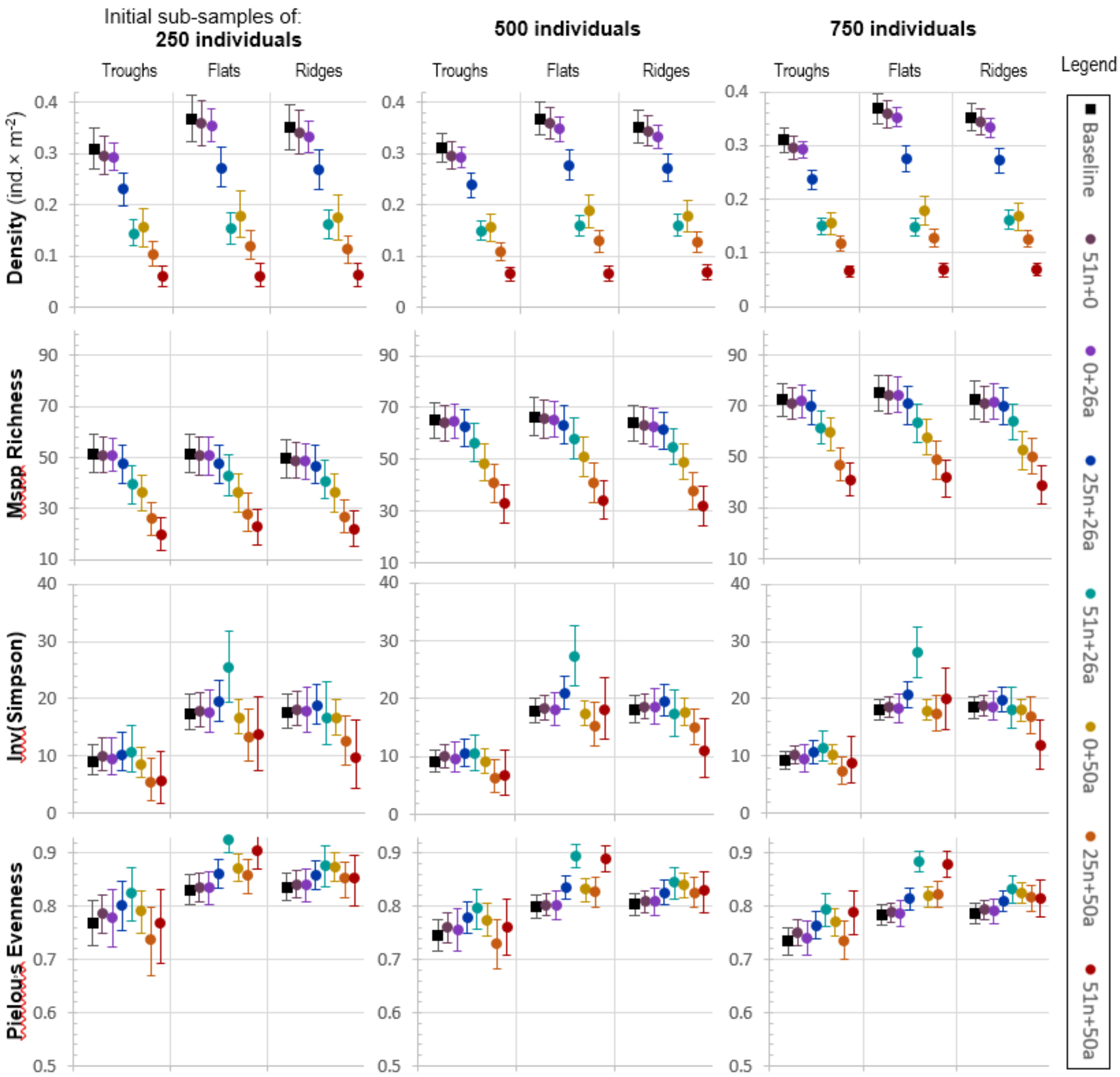

Figure 5-7: Seven degradation treatments on three nodule habitat sub-classes captured using the same four metrics per **Figure 4-2**, main text: density, mspp richness, inverse Simpson, and Pielou's evenness. The treatment codes in the rightmost legend are explained in **Table 4-3**'s central column (main text) ordered according to increasing combined impacts, left to right, violet to red. Error bars depict 95% range (a proxy for confidence) over 2000 simulations. Four additional metrics are displayed in **Figure 5-9**, below.

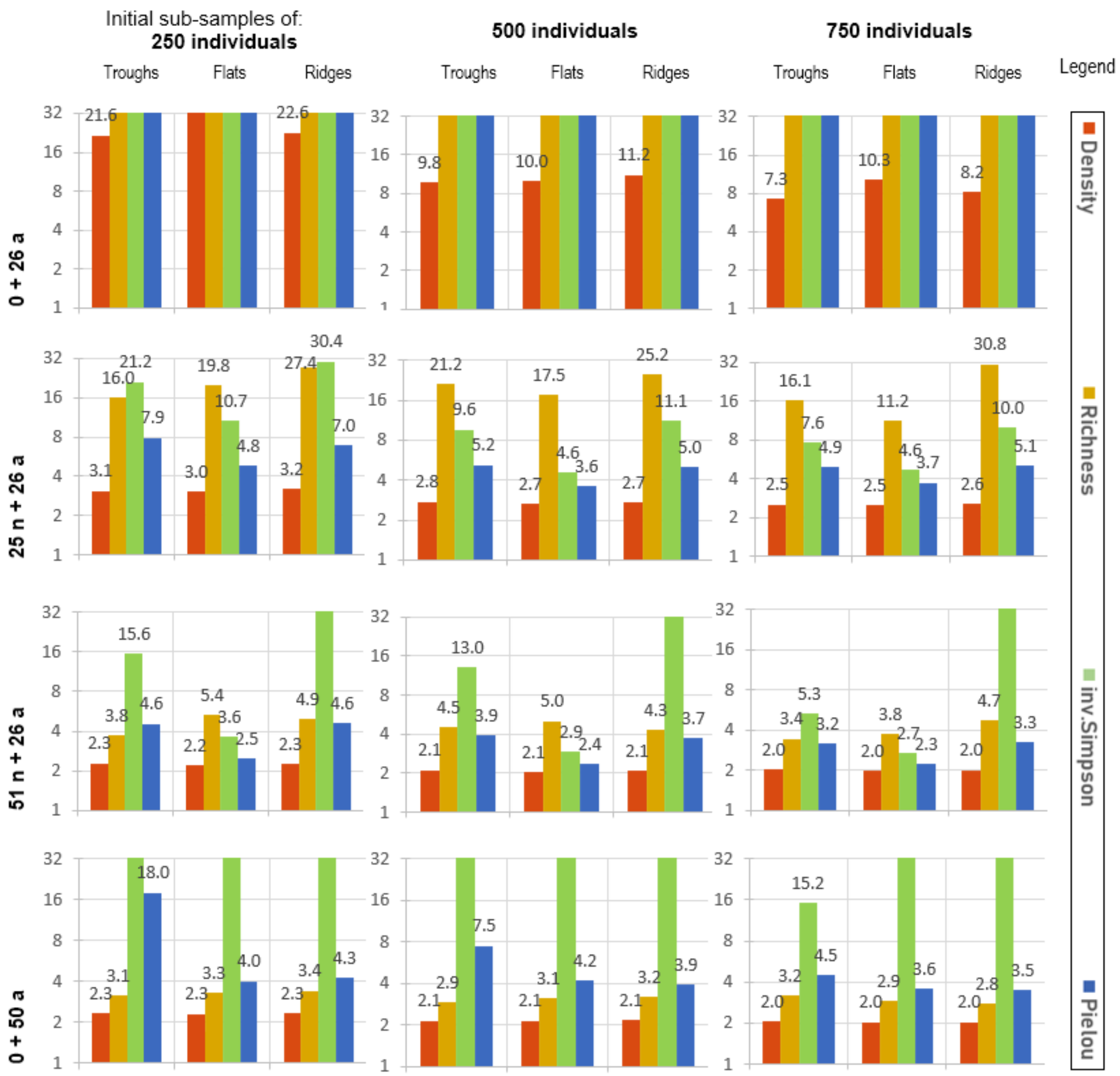

Figure 5-8: Power analysis of the four metrics in Figure 5-7 above
(rightmost legend), on three nodule habitat sub-classes (troughs, flats, ridges), across three initial sub-sample sizes (250, 500, 750 individuals), under the four middle degradation treatments (leftmost labels; explained in **Table 4-3**'s central column, main text), increasing in severity from top to bottom. Two-tailed t-test error thresholds: significance ≤ 0.05; power (type II confidence) ≥ 95%. The y-axis is logarithmic, depicting the theoretical number of sampling sites required to meet these error thresholds (≥ 2). Values greater than 32 are not fully displayed, as they would be impractical to implement. Four additional metrics are displayed below in **Figure 5-9** & **Figure 5-10**.

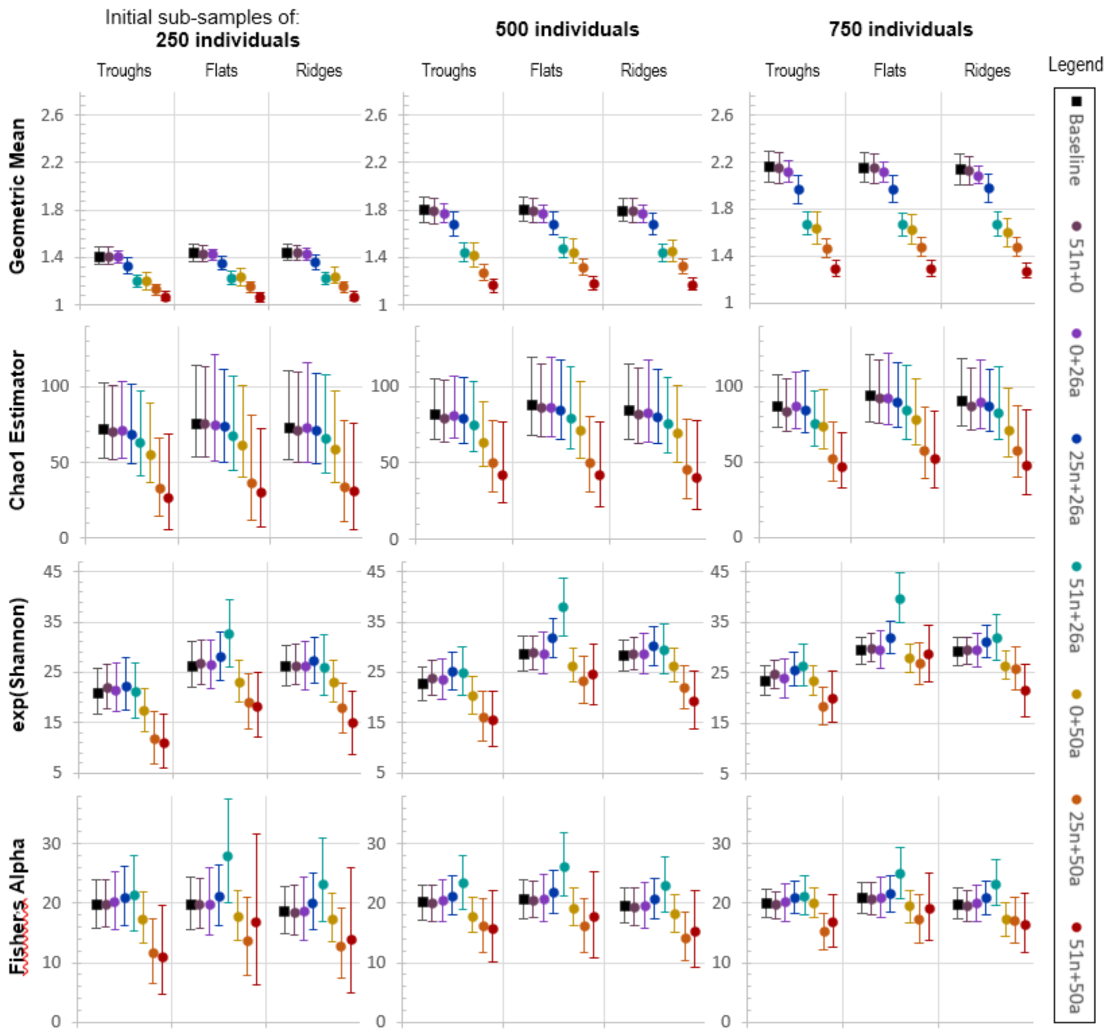

Figure 5-9: Additional panel of metrics to supplement Figure 5-7, above
The treatment codes in the rightmost legend are explained in **Table 4-3** (main text), ordered according to increasing combined impact, left to right, violet to red. Error bars depict the 95% range of results (a proxy for confidence) over 2000 simulations.

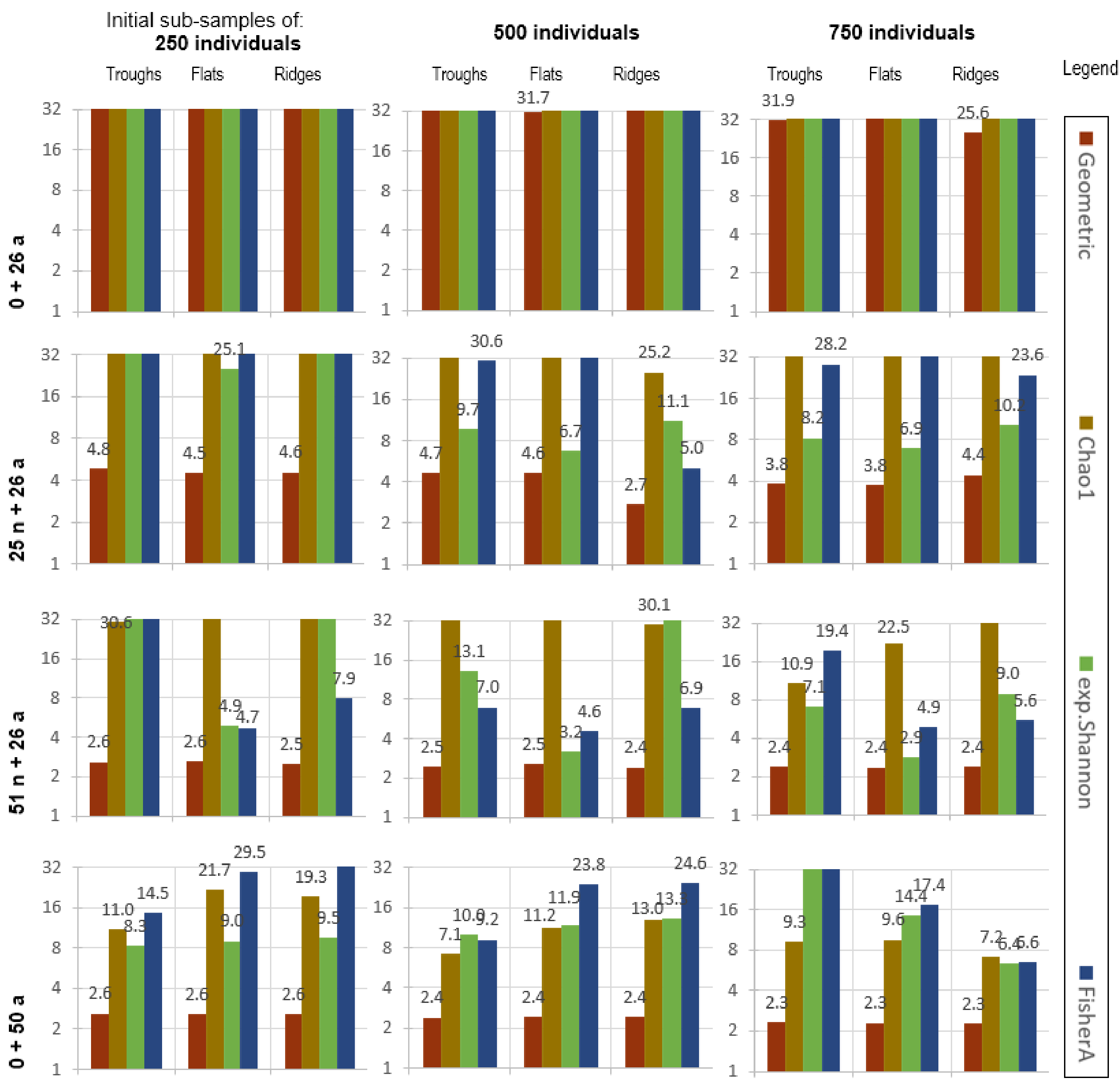

Figure 5-10: Power analysis of four metrics above, Figure 5-9
The four metrics (coloured columns), across three initial sub-sample sizes, under the four middle degradation treatments (leftmost labels, explained in **Table 4-3**, main text). Two-tailed t-test error thresholds: significance ≤ 0.05; power (type II confidence) ≥ 95%. The y-axis is logarithmic, depicting the theoretical number of sampling sites required to meet these error thresholds (≥ 2). Values greater than 32 are not displayed, as they would be impractical to implement.

C.4 R code: simulations and power analysis

C.4.1 R code to conduct simulations on data read in from a csv table.

This particular code is for a two-class analysis: ‘nodules’ and ‘no-nodules’. Code for the other classifications is shown but commented out. An output table from this code feeds into the power analysis code in the next section, below.

```
#####################################################################################
# Supporting code for:
# Detecting the effects of deep-seabed nodule mining:
# simulations using megafaunal data from the Clarion-Clipperton Zone
# Coded by Jeff A. Ardron and Erik Simon-Lledó, University of Southampton, UK
#
# This analysis applies disturbance simulations to data collected from APEI 6 in the Clarion-Clipperton
Fracture Zone.
# It is a stratified analysis that classifies first by binary nodule cover (where 0 or 1 percent nodules per
image = 'no'),
# then for areas with nodules, by geomorphic feature:
#   class 1: 0-1% nodules, 'no nodules'
#   class 2: >1%  nodules, 'nodules'
#
# Individuals that could not be placed into a morphospecies (msp) category are removed from the
degradation analysis
# because their generality adds noise to mspp degradations. In all, 22.7% of observed individuals (>1 cm)
were removed
# for this reason.
#
# Disturbance is first weighted according to the scenarios: i) by nodule affinity.
# The amount that nodule affinity affects degradation can be set; e.g. 51% and can accept negative
numbers
# (i.e. helps populations, e.g. -51%).
#
# Then, a second stochastic disturbance is applied within a given range, with a mean abundance
degradation of,
# for example:
# a) 17%; b) 33%; c) 50%.
#
# Finally, to pull out the signal in the stats, a constant may be optionally added to all non-zero msp totals on
each
# random sub-sample.
# This 'amplification' was found to be useful for exploration of the Chao statistics, but is not used here,
# and is commented out.
#
#####################################################################################

library(RVAideMemoire)
library(ggplot2)
library(plyr)
library(dplyr)
library(vegan)
library(Rmisc)
```

Appendix C: R code

```
rm(list=ls()) #clear all lists / variables

################ Global Variables and Functions ################################

SppColStart <- 18   #column number of first msp to be analysed (ordered from most abundant to least)
SppColEnd <- 149    #column number of last msp to be analysed (ordered from most abundant to least)
# Cutting off the table early can be done to discard singletons and/or orders at the very end.
# In this case, undifferentiated orders have been excluded, but singletons retained.

SppColNo = SppColEnd - SppColStart + 1  #Number of mspp being analysed

class_num <- 2   #number of classes (stratification)

n_randm <- 2000  #number of randomisations

############# area-based targets ###############

#area_scalar <- c(4)
area_scalar <- c(1,2,3,4) #sizes of subsample area * a base amount based on 250 individuals per sample per
class; ie 250, 500, 750, 1000
larea_scalar <- length(area_scalar)
#larea_scalar <- 1 #uncomment if the area-based targets are not being used. This sets the looping to 1
iteration only


TargetValue<- (678.641 * area_scalar)
# Total area needed before stopping a random selection.
# The value (in sq metres) came out of calibration runs for 'flat' class to achieve 250, 500, 750 individuals
mean
# sub-sample.
# Other classes are linearly scaled from this class's value (see scalars below).

StartValue<- as.integer(0.525 * TargetValue)
# How many records to randomly select in the first iteration, increasing by 1 each iteration until the
TargetValue is met.
# I have found that starting about half way to target generally works for these data; i.e. saves time.

nonod_scalar <- (2.88079)  # Derived from calibration runs. Note that the NoNodules class requires about
3x the area!
#trough_scalar <- (1.17908)
#flat_scalar <- (0.99447)
#ridge_scalar <- (1.04098)
nod_scalar <- (1.05694)


############# ...or individual-based targets ###############

#ind_scalar <- 1.0 #size of desired subsample * 500 (individuals, per Lledo et al. recommendation of 250-
500)

#indTargetValue<- as.integer(491  * ind_scalar) # set to less than 500 because of overshoots, averages out
to 500
#Total (mspp abundance) or (area), depending on analysis, needed before stopping a random selection

#indStartValue<- as.integer(537 * ind_scalar)
# How many records to randomly select in the first iteration, increasing by 1 each iteration until the
indTargetValue is met.
# 537 was derived from test runs to be a good place to begin, saving time.
```

```
#############

Nod_cat<-c("1.No-nodules","2.Nodules")


nodmod_factor <- c(0, 25, 51)
     # How much nodule affinity affects degradation, where affinity has a range from 0-100%,
     # and the factors are: 0-0 (not at all); 0-25%; 0-51% reduction --at 100% affinity.
     # Can also be set to a negative number to indicate that these mspp benefit from mining activities.
lnodmod_factor <- length(nodmod_factor)


areal_factor <- c(0, 26, 50)
     # How much random areal degradation with a stochastic range of +/- 100% of the factor,
     # where the factors are: 0 (not at all); 26% average reduction (0-52%); 50% average reduction (0-100%);
lareal_factor <- length(areal_factor)

amp_factor<- c(0)
#amp_factor<- c(0, 1, 2, 4)  # 'Amplification' constants to be cycled thru. These are added, not multiplied, to
non-zero
                      # occurrences.
                      # Unlike the degradation factors, these 'amplify' the (degraded) data for measurement
enhancement.
lamp_factor <- length(amp_factor)
amp_fn <- function(w) {as.integer((w+amp)*(trunc(w/(w+0.000001)+0.001)))} # Zero values get set to zero.
All others are increased by 'amp' amount.


geo_mean <- function(x, na.rm=TRUE){
  exp(sum(log(x[x > 0]), na.rm=na.rm) / length(x))}
# Geometric mean function that ignores zeros and NA, to be calculated in the loops below.
# (Zeros make the geometric mean zero. This special code has to be used because the degradations may
knock out
# some mspp to zero.)


skip_mds <- 1
#set to 1 to skip over the (time-consuming) MDS analyses; otherwise, any other value will trigger doing
them.


###### Generate 'sample_id' data frame for later use with MDS analyses #####

sample_id<-NULL

for (aa in 1:class_num) {
  cover_name <- paste0('N0', aa)
  strt <- 1 + ((aa - 1) * n_randm)
  ennd <- aa * n_randm
  sample_id[strt:ennd] <- cover_name
}

sample_id<-matrix(sample_id, nrow = class_num*n_randm, ncol = 1)
colnames(sample_id)<-c('Cover_cat')
sample_id<-as.data.frame(sample_id)
```

Appendix C: R code

```
############# Get data as csv files ###############

mzoa<-as.data.frame(read.table(filepath<-file.choose(),header=T,sep=','), stringsAsFactors=FALSE)
# metazoa data with images ordered vertically by increasing nodule coverage, and horizonatally by
decreasing mspp
# abundance, ending with singletons and then morpho-taxonomic orders.

mzoa_orig<-as.data.frame(mzoa)  #copy it for reuse.

nod_ass<-as.data.frame(read.table(filepath<-file.choose(),header=T,sep=','))
# file of nodule associations for each morphospecies.

#filename <- paste0("mzoa-orig", ".csv")
#write.csv(mzoa, filename)   #check the file looks OK, e.g. wrt to randomised degradation



#################### Looped Analysis #########################################

for (ddd in 1:larea_scalar) {

# Cycling through the differnet sample sizes...

for (aaa in 1:lnodmod_factor) {

# Cycling through the nodule affinity factors...

for (bbb in 1:lareal_factor) {

# Cycling through the areal factors...


# This is a bunch of temporary holders of variables not affected by the amp factor,
  # and thus not plotted and printed until after a full cycle of all amp factors.
  # Note that the 'amp factor' was not used in the published analysis, and is commented out here.
  den <- matrix(NA, nrow=lamp_factor, ncol = class_num)
  denmin <- matrix(NA, nrow=lamp_factor, ncol = class_num)
  denmax <- matrix(NA, nrow=lamp_factor, ncol = class_num)
  subsam <-matrix(NA, nrow=lamp_factor, ncol = class_num)
  subsammin <- matrix(NA, nrow=lamp_factor, ncol = class_num)
  subsammax <- matrix(NA, nrow=lamp_factor, ncol = class_num)
  vo <-matrix(NA, nrow=lamp_factor, ncol = class_num)
  vomin <- matrix(NA, nrow=lamp_factor, ncol = class_num)
  vomax <- matrix(NA, nrow=lamp_factor, ncol = class_num)
  are <-matrix(NA, nrow=lamp_factor, ncol = class_num)
  aremin <- matrix(NA, nrow=lamp_factor, ncol = class_num)
  aremax <- matrix(NA, nrow=lamp_factor, ncol = class_num)
  ric <-matrix(NA, nrow=lamp_factor, ncol = class_num)
  ricmin <- matrix(NA, nrow=lamp_factor, ncol = class_num)
  ricmax <- matrix(NA, nrow=lamp_factor, ncol = class_num)

for (ccc in 1:lamp_factor) {

# Cycling through the amp factors...


  ##### Set up file names and plot titles #####
```

```
#  FileEnding <- paste0("_", n_randm, "r", indTargetValue, "i_", nodmod_factor[aaa], "nod_",
areal_factor[bbb], "area_",amp_factor[ccc], "amp")
  FileEnding <- paste0("_", n_randm, "r", as.integer(TargetValue[ddd]+0.5), "m_", nodmod_factor[aaa],
"nod_", areal_factor[bbb], "area_", "_2class")
  #A name to be added to the end of all generated files, to help sort runs.

#  FileEndingSum <- paste0("_", n_randm, "r", indTargetValue, "i_", nodmod_factor[aaa], "nod_",
areal_factor[bbb], "area")
  FileEndingSum <- paste0("_", n_randm, "r", as.integer(TargetValue[ddd] +0.5), "m_", nodmod_factor[aaa],
"nod_", areal_factor[bbb], "area")
  #A name to be added to the end of all generated summary files, to help sort runs.

#  PlotTitle <- paste0(n_randm, "r", indTargetValue, "ind  ", nodmod_factor[aaa],  "NodDegr  ",
areal_factor[bbb], "ArealDegr  ",amp_factor[ccc], "Amp")
  PlotTitle <- paste0(n_randm, "r", as.integer(TargetValue[ddd] +0.5), "m  ", nodmod_factor[aaa],  "NodDegr
", areal_factor[bbb], "ArealDegr  ")
  #A title describing the general analysis, for when it is plotted, at the end

#  PlotTitleSum <- paste0(n_randm, "r", indTargetValue, "ind  ", nodmod_factor[aaa], "NodDegr  ",
areal_factor[bbb], "ArealDegr" )
  PlotTitleSum <- paste0(n_randm, "r", as.integer(TargetValue[ddd] +0.5), "m  ", nodmod_factor[aaa],
"NodDegr  ", areal_factor[bbb], "ArealDegr" )
  # A title describing the summary analysis, for when it is plotted, at the end

  ###### Set up 'amplification' function for non-zero data statistics #########

  amp <- amp_factor[ccc] # The amplification constant. If set to zero, no amplification. When setting the
amp, bear in mind:
  # Almost all observations are of single individuals.
  # Mspp totals in a given random sub-sample may range from 0-10, typically <5.


spp_table1 <- NULL  #Rotated mspp table 90 degrees counter-clockwise to join with nodule affinity table
spp_table2 <- NULL  #First treatment (nodule affinity)
spp_table3 <- NULL  #Table rotated back clockwise
spp_table4 <- NULL  #Second treatment (stochastic degradation)

###### Set up read-in tables for join ####################

spp_table1 <- mzoa_orig[SppColStart:SppColEnd]

rotate_counter_clockwise <- function(x) { apply(     t(x),2, rev)}
spp_table1 <- rotate_counter_clockwise (spp_table1)

colnames(spp_table1)<-NULL
Msp <- rownames(spp_table1)
rownames(spp_table1) <- NULL
spp_table1 <- cbind(Msp, spp_table1)
# These lines are a workaround to deal with column and row naming issues, and rebuilds them.

spp_table1 <- merge(spp_table1,  nod_ass, by = "Msp", all.x = TRUE, sort = FALSE)
# Join up with the nodule associations file so that we can later multiply a msp degradation factor based on
nodule
# affinity.  The merge command defaults to sorting which messes up things later on... ‘false’ keeps the
ordering as it was

#filename2 <- paste0("spp_table1", FileEnding, ".csv")
#write.csv(spp_table1, filename2)   #check the file looks OK
```

Appendix C: R code

```
############ First treatment: degradation due to affinity to nodules. #############

nod_mod<- spp_table1$xcent_onnod

num_cols <- length(spp_table1) - length(nod_ass) +1
spp_table2 <- as.matrix((spp_table1[,2:num_cols]))
# copy mspp over to a new table to preserve spp_table1, and to get rid of the labels and linked nod_ass
columns in
# the matrix

for (ii in 0:(SppColNo)) {
  # iterate thru each spp, which are now the rows in the rotated table

  xx <- as.numeric(as.matrix(spp_table2[ii,]))
  yy<- as.numeric(nod_mod[ii])
  zz <-   xx - ((xx * yy) /100 *nodmod_factor[aaa]/100) #This formula applies the weighting effect of nodule
affinity.
#   zz <- xx #if used, this line applies no nodule affinity effect

  spp_table2[ii,] <- zz

}
mspp <- as.matrix(spp_table1[1:SppColNo, 1])
spp_table2 <- cbind(mspp, spp_table2)


#filename2 <- paste0("spp_table2", FileEnding, ".csv")
#write.csv(spp_table2, filename2)   #check the file looks OK

####################################################################################
spp_table3 <- spp_table2

rotate_clockwise <- function(y) { t(     apply(y, 2, rev))}
spp_table3 <- rotate_clockwise (spp_table3)

#filename2 <- paste0("spp_table3", FileEnding, ".csv")
#write.csv(spp_table3, filename2)   #check the file looks OK


############ Second treatment: random degradation due to mining plumes etc. ############

spp_table4 <- ((spp_table3[2:(nrow(spp_table3)),])) #remove the top row of m-spp names
colnames(spp_table4)<-spp_table3[1,]
rownames(spp_table4) <- NULL
spp_table4 <-as.data.frame(spp_table4)
spp_table4 <- mutate_all(spp_table4, function(z) as.numeric(as.character(z)))
# This makes the dataframe numeric, which avoids R errors

#degrade_fn2 <- function(w) {w}  # If used, this line means there is no areal degradation effect,
                                   # and values from the earlier treatment are retained as fractions.
#degrade_fn2 <- function(w) {trunc (w +0.5)}  # If used, this line means there is no areal degradation effect,
                                   # but values from the earlier treatment are rounded.

degrade_fn2 <- function(w) {as.integer (w-(areal_factor[bbb] / 100 * (w * (1 + (sample(-100:100, 1,
replace=T)/100)))) +0.5)}
            #Areal degradation factor +/- random range of 50% of the factor, convert to integers, with
rounding
```

```
  # Note that the ends of the ranges could be adjusted to compensate for rounding effects on the long tail
  # (i.e. most observations = 1; indeed the non-zero observed mean is 1.0106 individuals)
  # This analysis was not adjusted, but earlier trial runs were, as follows:
  #   50% lost : 18-83 (from ideal of  17-83); 33% lost: 33-90 (from ideal of 33-100); 67% : 10-67 (from ideal 
0-67)

spp_table4 <- lapply (spp_table4, degrade_fn2)
#diminish by a random factor per photo (i.e. areal stochasticity)

#spp_table4 <- apply (spp_table4, MARGIN=c(1,2), degrade_fn2)
#diminish by a random factor, for each observation; i.e. no spatial pattern. (MARGIN= 1 for rows; 2 for cols; 
c(1,2) for cells.)

filename2 <- paste0("spp_table4", FileEnding, ".csv")
write.csv(spp_table4, filename2)   #check the file looks OK, and save the degraded data for future 
reference.


###################################################################################

mzoa[SppColStart:SppColEnd]<- spp_table4

mzoa$Total_abund <- rowSums (mzoa[SppColStart:SppColEnd]) #####Calculate (degraded) total abundance 
#####

mzoa$density<-mzoa$Total_abund/mzoa$Area_m2 ##### Calculate (degraded) density#####

#filename <- paste0("mzoa", FileEnding, ".csv")
#write.csv(mzoa, filename)   #check the file looks OK, e.g. wrt to randomised degradation


################################## Assign classes ##################################

n_class <- c(0,0)

mzoa$Cover_cat <- NA

for (i in 1:length(mzoa$Nod_cov)) {

 if (mzoa$Nod_cov[i]<=1)
   mzoa$Cover_cat[i]<-"N01"
 #n_class[1] <- n_class[1] + 1
   else
    if (mzoa$Nod_cov[i]>1)
     mzoa$Cover_cat[i]<-"N02"
    #     if (mzoa$Stratum[i] =="Trough")
#       mzoa$Cover_cat[i]<-"N02"
#     #n_class[2] <- n_class[2] + 1
#     else
#       if (mzoa$Stratum[i] =="Flat" )
#         mzoa$Cover_cat[i]<-"N03"
#       #n_class[3] = n_class[3] + 1
#       else
#         if (mzoa$Stratum[i] =="Ridge")
#           mzoa$Cover_cat[i]<-"N04"
#         #n_class[4] = n_class[4] + 1

}
```

Appendix C: R code

```
# n_class<-matrix(n_class, nrow = class_num, ncol = 1)

#N01 <- subset(mzoa, Cover_cat == "N01")
#N02 <- subset(mzoa, Cover_cat == "N02")
#N03 <- subset(mzoa, Cover_cat == "N03")
#N04 <- subset(mzoa, Cover_cat == "N04")

#group1<-mean(N01$Nod_cov)
#group2<-mean(N02$Nod_cov)
#group3<-mean(N03$Nod_cov)
#group4<-mean(N04$Nod_cov)

#nodcov<-c(group1,group2,group3,group4)

# The code below generalises the commented code above

nodc<-NULL
rows_named<-NULL

for (aa in 1:class_num) {

  rows_named[aa]<-paste0('N0', aa)
  N0x <- paste0('N0', aa)
  jaa<- subset(mzoa, Cover_cat == rows_named[aa])
  nodc[aa]<- mean(jaa$Nod_cov)
  assign(rows_named[aa], jaa)
}


filename <- paste0("mzoa-degr", FileEnding, ".csv")
write.csv(mzoa, filename)   #check the file looks OK, e.g. wrt to randomised degradation


###### Set up matrices for each indicator ######

suffix<-c('d','w','v','s','h','a','r','f','p','c','e','g', 'm' ) #keep 'm' at the end for special treatment
  # d=density; w=total individuals; v=volume per m2; s=inv.Simpson; h=exp.Shanon;
  # a=area; r=richness; f=Fisher alpha; p=Pielou eveness; c=Chao1; e=ACE; g=geometric mean; m=matrix of
msp column sums

suffixl<-length(suffix)

for (aa in 1:class_num) {
  for (bb in 1:suffixl-1) {
    NODx<-paste0('NOD',aa,suffix[bb])

    assign(NODx, matrix(NA, nrow=n_randm, ncol = 1)) #all the variables except the one ending in 'm' have
just 1 column
  }
  NODx<-paste0('NOD',aa,'m')
  assign(NODx, matrix(NA, nrow=n_randm, ncol = SppColNo)) #deal with 'm' which is a matrix of mspp
column sums

  itrx<-paste0('itr',aa)
  assign(itrx,matrix(NA, nrow=n_randm, ncol = 1)) #set up the iteration counter
}
#The above code generalises the commented out code below (which is easier to read and understand).
#NOD1d <- matrix(NA, nrow=n_randm, ncol = 1)
#NOD1w <- matrix(NA, nrow=n_randm, ncol = 1)
```

```
#NOD1v <- matrix(NA, nrow=n_randm, ncol = 1)
#NOD1s <- matrix(NA, nrow=n_randm, ncol = 1)
#NOD1h <- matrix(NA, nrow=n_randm, ncol = 1)
#NOD1a <- matrix(NA, nrow=n_randm, ncol = 1)
#NOD1r <- matrix(NA, nrow=n_randm, ncol = 1)
#NOD1f <- matrix(NA, nrow=n_randm, ncol = 1)
#NOD1p <- matrix(NA, nrow=n_randm, ncol = 1)
#NOD1c <- matrix(NA, nrow=n_randm, ncol = 1)
#NOD1e <- matrix(NA, nrow=n_randm, ncol = 1)
#NOD1g <- matrix(NA, nrow=n_randm, ncol = 1)
#NOD1m <- matrix(NA, nrow=n_randm, ncol = (SppColNo))

#NOD2d <- matrix(NA, nrow=n_randm, ncol = 1)
#NOD2w <- matrix(NA, nrow=n_randm, ncol = 1)
#NOD2v <- matrix(NA, nrow=n_randm, ncol = 1)
#NOD2s <- matrix(NA, nrow=n_randm, ncol = 1)
#NOD2h <- matrix(NA, nrow=n_randm, ncol = 1)
# ... and so forth


## Randomised assessment  stratified by the classes above. This version uses substitution. #####

##### First class is No Nodules #####

for (a in 1:n_randm) {

  acum_indiv <- 0
  acum_area <- 0

  itr1[a] <- 0 #counting iterations for quality control


  si<-as.integer(StartValue[ddd] * nonod_scalar)

  #si<-as.integer((indStartValue  * 3) + (indStartValue * (areal_factor[bbb] /2) *(nodmod_factor[aaa] +1)))
  # The second part of this formula adjusts per estimated degradation, thus saving some time. The first part
is the essential bit.
  # si<-StartValue[ddd]
  #si <- StartValue[ddd] * 3

 # while(acum_indiv<indTargetValue) {
 #   while (acum_area < TargetValue[ddd]) {

  while (acum_area < as.integer((TargetValue[ddd] * nonod_scalar) +0.5)) {
    sample1 <- sample_n (N01, si , replace = T)
    si = si + 2  #to speed up this very low density class, it is iterated +2
    itr1[a] = itr1[a] + 1
    acum_area = sum(sample1$Area_m2)
    acum_indiv = sum(sample1$Total_abund)
  }

  sample1_multi <- subset(sample1, select = c(SppColStart:SppColEnd))
  samp_m <- colSums(sample1_multi)
#  samp_m <- as.integer((colSums(sample1_multi) *0.5) +0.5) #if used, this applies a 2/3 degradation to
class1
                                # (also applied to class2, with 50% to class 3 and 33% to class4)

  samp_m <- amp_fn(samp_m)
```

```
  #if this line is uncommented, it applies a constant 'amplifier' value to all non-zero mspp columns --set up
above.

  ########### Start of stats that might be amplified ###########

  invsimp <- diversity(samp_m, "inv")
  expH <- exp(diversity(samp_m, "shannon"))
  rich <- specnumber(samp_m)
  fisha <- fisher.alpha(samp_m)
  pielou <- (diversity(samp_m, "shannon")) / log(rich)
  estimr <- estimateR(samp_m)
  chao <- estimr[2] #estimatoR in vegan: 1 is mspp count; 2 is chao1; 3 is se for that; 4 is ACE; 5 is se for that
#  ace <- estimr[4]
  geo <- geo_mean(samp_m)

  NOD1g[a] <- geo
#  NOD1e[a] <- ace
  NOD1c[a] <- chao
  NOD1p[a] <- pielou
  NOD1f[a] <- fisha
  NOD1r[a] <- rich
  NOD1s[a] <- invsimp
  NOD1h[a] <- expH

  NOD1m[a, ] <- samp_m

  ########### End of stats that might be amplified ###########

  NOD1w[a] <- sum(sample1$Total_abund)
  #how many individuals in each of the 'n_randm' iterations. Note that this is the actual value, not amplified.
  NOD1a[a] <- sum(sample1$Area_m2)

  NOD1d[a] <- NOD1w[a] / NOD1a[a]
        #density of individuals in each of the 'n_randm' iterations. Note that this is the actual value, not
amplified.
  NOD1v[a] <- sum(sample1$v_ml) / NOD1a[a]  #volume per area, not amplified

}

########### Next Class... Nodules ###########

for (a in 1:n_randm) {

  acum_indiv <- 0
  acum_area <- 0
  itr2[a] <- 0


  si<-as.integer(StartValue[ddd] *nod_scalar)

  #si<-as.integer((indStartValue) + (indStartValue * (areal_factor[bbb] /2) *(nodmod_factor[aaa] +1)))
  # The second part of this formula adjusts per estimated degradation, thus saving some time.
  # The first part is the essential bit.

#  while(acum_indiv<indTargetValue) {
  while(acum_area< as.integer((TargetValue[ddd]*nod_scalar)+0.5)) {
    sample1 <- sample_n (N02, si , replace =T) ; si=si+1
    itr2[a] = itr2[a] + 1; acum_area= sum(sample1$Area_m2)
    acum_indiv= sum(sample1$Total_abund) }
```

```
  sample1_multi<- subset(sample1, select = c(SppColStart:SppColEnd))
  samp_m<-colSums(sample1_multi)  #comment out if class-based degradatin is to be used (below).
#  samp_m <- as.integer((colSums(sample1_multi) *0.33) +0.5) #if used, this applies a 2/3 degradation to
class2
                                        # (also applied to class1, with 50% to class 3 and 33% to class4)

  samp_m <- amp_fn(samp_m)
  # If this line is uncommented, it applies a constant 'amplifier' value to all non-zero mspp columns --set up
above.

  ########### Start of stats that might be amplified ###########

  invsimp <- diversity(samp_m, "inv")
  expH <- exp(diversity(samp_m, "shannon"))
  rich <- specnumber(samp_m)
  fisha <- fisher.alpha(samp_m)
  pielou <- (diversity(samp_m, "shannon")) / log(rich)
  estimr <- estimateR(samp_m)
  chao <- estimr[2] #estimatoR in vegan: 1 is mspp count; 2 is chao1; 3 is se for that; 4 is ACE; 5 is se for that
#  ace <- estimr[4]
  geo <- geo_mean(samp_m)

  NOD2g[a] <- geo
#  NOD2e[a] <- ace
  NOD2c[a] <- chao
  NOD2p[a] <- pielou
  NOD2f[a] <- fisha
  NOD2r[a] <- rich
  NOD2s[a] <- invsimp
  NOD2h[a] <- expH
  NOD2m[a, ] <- samp_m

   ########### End of stats that might be amplified ###########

  NOD2w[a] <- sum(sample1$Total_abund)
  # How many individuals in each of the 'n_randm' iterations. Note that this is the actual value, not
amplified.
  NOD2a[a] <- sum(sample1$Area_m2)

  NOD2d[a] <- NOD2w[a] / NOD2a[a]
  #density of individuals in each of the 'n_randm' iterations. Note that this is the actual value, not amplified.
  NOD2v[a] <- sum(sample1$v_ml) / NOD2a[a]  #volume per area, not amplified

}


###########

all_samp_d<-cbind(NOD1d,NOD2d)
all_samp_w<-cbind(NOD1w,NOD2w)
all_samp_v<-cbind(NOD1v,NOD2v)
all_samp_a<-cbind(NOD1a,NOD2a)
all_samp_r<-cbind(NOD1r,NOD2r)
all_samp_s<-cbind(NOD1s,NOD2s)
all_samp_m<-rbind(NOD1m,NOD2m)
all_samp_h<-cbind(NOD1h,NOD2h)
all_samp_f<-cbind(NOD1f,NOD2f)
all_samp_p<-cbind(NOD1p,NOD2p)
```

Appendix C: R code

```
all_samp_c<-cbind(NOD1c,NOD2c)
#all_samp_e<-cbind(NOD1e,NOD2e,NOD3e,NOD4e)
all_samp_g<-cbind(NOD1g,NOD2g)

all_area_itr<-cbind(NOD1a,NOD1w,itr1,NOD2a,NOD2w,itr2)
colnames(all_area_itr) <- c('NoNodArea', 'NoNodAbund', 'iterations','NodsArea','NodsAbund','iterations')

filename <- paste0("SampleSize", FileEnding, ".csv")
write.csv(all_area_itr, filename) #check area targets and cycling OK


mean_dens<-colMeans(all_samp_d)
mean_subsamp<-colMeans(all_samp_w)
mean_vol<-colMeans(all_samp_v)
mean_area<-colMeans(all_samp_a)
mean_rich<-colMeans(all_samp_r)
mean_Simp<-colMeans(all_samp_s)
mean_expH<-colMeans(all_samp_h)
mean_fisha<-colMeans(all_samp_f)
mean_pielou<-colMeans(all_samp_p)
mean_chao<-colMeans(all_samp_c)
#mean_ace<-colMeans(all_samp_e)
mean_geo<-colMeans(all_samp_g)


dt1<-t(quantile(NOD1d, c(.025, .975), na.rm=TRUE) )
dql_1<-dt1[1]
dqh_1<-dt1[2]

dt2<-t(quantile(NOD2d, c(.025, .975), na.rm=TRUE) )
dql_2<-dt2[1]
dqh_2<-dt2[2]

#dt3<-t(quantile(NOD3d, c(.025, .975), na.rm=TRUE) )
#dql_3<-dt3[1]
#dqh_3<-dt3[2]

#dt4<-t(quantile(NOD4d, c(.025, .975), na.rm=TRUE) )
#dql_4<-dt4[1]
#dqh_4<-dt4[2]


wt1<-t(quantile(NOD1w, c(.025, .975), na.rm=TRUE) )
wql_1<-wt1[1]
wqh_1<-wt1[2]

wt2<-t(quantile(NOD2w, c(.025, .975), na.rm=TRUE) )
wql_2<-wt2[1]
wqh_2<-wt2[2]

#wt3<-t(quantile(NOD3w, c(.025, .975), na.rm=TRUE) )
#wql_3<-wt3[1]
#wqh_3<-wt3[2]

#wt4<-t(quantile(NOD4w, c(.025, .975), na.rm=TRUE) )
#wql_4<-wt4[1]
#wqh_4<-wt4[2]
```

```
vt1<-t(quantile(NOD1v, c(.025, .975), na.rm=TRUE) )
vql_1<-vt1[1]
vqh_1<-vt1[2]

vt2<-t(quantile(NOD2v, c(.025, .975), na.rm=TRUE) )
vql_2<-vt2[1]
vqh_2<-vt2[2]

#vt3<-t(quantile(NOD3v, c(.025, .975), na.rm=TRUE) )
#vql_3<-vt3[1]
#vqh_3<-vt3[2]

#vt4<-t(quantile(NOD4v, c(.025, .975), na.rm=TRUE) )
#vql_4<-vt4[1]
#vqh_4<-vt4[2]


rt1<-t(quantile(NOD1r, c(.025, .975), na.rm=TRUE) )
rql_1<-rt1[1]
rqh_1<-rt1[2]

rt2<-t(quantile(NOD2r, c(.025, .975), na.rm=TRUE) )
rql_2<-rt2[1]
rqh_2<-rt2[2]

#rt3<-t(quantile(NOD3r, c(.025, .975), na.rm=TRUE) )
#rql_3<-rt3[1]
#rqh_3<-rt3[2]

#rt4<-t(quantile(NOD4r, c(.025, .975), na.rm=TRUE) )
#rql_4<-rt4[1]
#rqh_4<-rt4[2]


st1<-t(quantile(NOD1s, c(.025, .975), na.rm=TRUE) )
sql_1<-st1[1]
sqh_1<-st1[2]

st2<-t(quantile(NOD2s, c(.025, .975), na.rm=TRUE) )
sql_2<-st2[1]
sqh_2<-st2[2]

#st3<-t(quantile(NOD3s, c(.025, .975), na.rm=TRUE) )
#sql_3<-st3[1]
#sqh_3<-st3[2]

#st4<-t(quantile(NOD4s, c(.025, .975), na.rm=TRUE) )
#sql_4<-st4[1]
#sqh_4<-st4[2]


ht1<-t(quantile(NOD1h, c(.025, .975), na.rm=TRUE) )
hql_1<-ht1[1]
hqh_1<-ht1[2]

ht2<-t(quantile(NOD2h, c(.025, .975), na.rm=TRUE) )
hql_2<-ht2[1]
hqh_2<-ht2[2]
```

```
#ht3<-t(quantile(NOD3h, c(.025, .975), na.rm=TRUE) )
#hql_3<-ht3[1]
#hqh_3<-ht3[2]

#ht4<-t(quantile(NOD4h, c(.025, .975), na.rm=TRUE) )
#hql_4<-ht4[1]
#hqh_4<-ht4[2]


at1<-t(quantile(NOD1a, c(.025, .975), na.rm=TRUE) )
aql_1<-at1[1]
aqh_1<-at1[2]

at2<-t(quantile(NOD2a, c(.025, .975), na.rm=TRUE) )
aql_2<-at2[1]
aqh_2<-at2[2]

#at3<-t(quantile(NOD3a, c(.025, .975), na.rm=TRUE) )
#aql_3<-at3[1]
#aqh_3<-at3[2]

#at4<-t(quantile(NOD4a, c(.025, .975), na.rm=TRUE) )
#aql_4<-at4[1]
#aqh_4<-at4[2]


ft1<-t(quantile(NOD1f, c(.025, .975), na.rm=TRUE) )
fql_1<-ft1[1]
fqh_1<-ft1[2]

ft2<-t(quantile(NOD2f, c(.025, .975), na.rm=TRUE) )
fql_2<-ft2[1]
fqh_2<-ft2[2]

#ft3<-t(quantile(NOD3f, c(.025, .975), na.rm=TRUE) )
#fql_3<-ft3[1]
#fqh_3<-ft3[2]

#ft4<-t(quantile(NOD4f, c(.025, .975), na.rm=TRUE) )
#fql_4<-ft4[1]
#fqh_4<-ft4[2]


pt1<-t(quantile(NOD1p, c(.025, .975), na.rm=TRUE) )
pql_1<-pt1[1]
pqh_1<-pt1[2]

pt2<-t(quantile(NOD2p, c(.025, .975), na.rm=TRUE) )
pql_2<-pt2[1]
pqh_2<-pt2[2]

#pt3<-t(quantile(NOD3p, c(.025, .975), na.rm=TRUE) )
#pql_3<-pt3[1]
#pqh_3<-pt3[2]

#pt4<-t(quantile(NOD4p, c(.025, .975), na.rm=TRUE) )
#pql_4<-pt4[1]
#pqh_4<-pt4[2]
```

```
ct1<-t(quantile(NOD1c, c(.025, .975), na.rm=TRUE) )
cql_1<-ct1[1]
cqh_1<-ct1[2]

ct2<-t(quantile(NOD2c, c(.025, .975), na.rm=TRUE) )
cql_2<-ct2[1]
cqh_2<-ct2[2]

#ct3<-t(quantile(NOD3c, c(.025, .975), na.rm=TRUE) )
#cql_3<-ct3[1]
#cqh_3<-ct3[2]

#ct4<-t(quantile(NOD4c, c(.025, .975), na.rm=TRUE) )
#cql_4<-ct4[1]
#cqh_4<-ct4[2]


#et1<-t(quantile(NOD1e, c(.025, .975), na.rm=TRUE) )
#eql_1<-et1[1]
#eqh_1<-et1[2]

#et2<-t(quantile(NOD2e, c(.025, .975), na.rm=TRUE) )
#eql_2<-et2[1]
#eqh_2<-et2[2]

#et3<-t(quantile(NOD3e, c(.025, .975), na.rm=TRUE) )
#eql_3<-et3[1]
#eqh_3<-et3[2]

#et4<-t(quantile(NOD4e, c(.025, .975), na.rm=TRUE) )
#eql_4<-et4[1]
#eqh_4<-et4[2]


gt1<-t(quantile(NOD1g, c(.025, .975), na.rm=TRUE) )
gql_1<-gt1[1]
gqh_1<-gt1[2]

gt2<-t(quantile(NOD2g, c(.025, .975), na.rm=TRUE) )
gql_2<-gt2[1]
gqh_2<-gt2[2]

#gt3<-t(quantile(NOD3g, c(.025, .975), na.rm=TRUE) )
#gql_3<-gt3[1]
#gqh_3<-gt3[2]

#gt4<-t(quantile(NOD4g, c(.025, .975), na.rm=TRUE) )
#gql_4<-gt4[1]
#gqh_4<-gt4[2]



dens_min<-c(dql_1,dql_2)
dens_max<-c(dqh_1,dqh_2)

w_min<-c(wql_1,wql_2)
w_max<-c(wqh_1,wqh_2)
```

Appendix C: R code

```
v_min<-c(vql_1,vql_2)
v_max<-c(vqh_1,vqh_2)

a_min<-c(aql_1,aql_2)
a_max<-c(aqh_1,aqh_2)

rich_min<-c(rql_1,rql_2)
rich_max<-c(rqh_1,rqh_2)

sim_min<-c(sql_1,sql_2)
sim_max<-c(sqh_1,sqh_2)

expH_min<-c(hql_1,hql_2)
expH_max<-c(hqh_1,hqh_2)

fisha_min<-c(fql_1,fql_2)
fisha_max<-c(fqh_1,fqh_2)

pielou_min<-c(pql_1,pql_2)
pielou_max<-c(pqh_1,pqh_2)

chao_min<-c(cql_1,cql_2)
chao_max<-c(cqh_1,cqh_2)

#ace_min<-c(eql_1,eql_2, eql_3, eql_4)
#ace_max<-c(eqh_1,eqh_2, eqh_3, eqh_4)

geo_min<-c(gql_1,gql_2)
geo_max<-c(gqh_1,gqh_2)


result<-t(rbind(mean_dens, dens_min,dens_max,
        mean_subsamp, w_min,w_max,
        mean_vol, v_min,v_max,
        mean_area, a_min,a_max,
        mean_rich,rich_min, rich_max,
        mean_Simp,sim_min, sim_max,
        mean_expH, expH_min, expH_max,
        mean_fisha,fisha_min, fisha_max,
        mean_pielou,pielou_min, pielou_max,
        mean_chao,chao_min, chao_max,
        mean_geo,geo_min, geo_max
#         mean_ace,ace_min, ace_max
))

result_df<-as.data.frame(result)
result_df$Cover_cat<-Nod_cat

# Hold off plotting and printing these variables until a full cycle of amp factors
den[ccc,] <- mean_dens
denmin[ccc,] <- dens_min
denmax[ccc,] <- dens_max
subsam[ccc,] <-mean_subsamp
subsammin[ccc,] <- w_min
subsammax[ccc,] <- w_max
vo[ccc,] <-mean_vol
vomin[ccc,] <- v_min
vomax[ccc,] <- v_max
are[ccc,] <-mean_area
```

```
aremin[ccc,] <- a_min
aremax[ccc,] <- a_max
ric[ccc,] <-mean_rich
ricmin[ccc,] <- rich_min
ricmax[ccc,] <- rich_max


##### plotting variables affected by amp factor, except MDS (below) #########

plotwidth <- 9 #in cm
plotheight <- 9

##########

fisha_p<-ggplot(data=result_df, aes(x=Cover_cat, y=mean_fisha)) +
 theme_bw()+
 labs(title = PlotTitle)+
 geom_errorbar(mapping=aes(ymin=fisha_min, ymax=fisha_max), width=0.4, size=1, color="black") +
 geom_point(shape=21, fill="white", size=3)+
 ylab("Mean Fisher Alpha")+
 xlab("")+
 theme(text = element_text(size=10),
      axis.text=element_text(size=9),
      plot.title = element_text(color="black", size=8, face="bold.italic"),
      axis.title=element_text(size=11),
      legend.position="none",
      #legend.title=element_text(size=9),
      axis.text.y = element_text(size=9),
      panel.grid.major = element_blank(),panel.grid.minor = element_blank() )

fisha_p
filename <- paste0("fish", FileEnding, ".pdf")
ggsave(filename, device = "pdf", path = NULL,
      scale = 1,
      width = plotwidth, height = plotheight, units = "cm",
      dpi = 300, limitsize = TRUE)


##########

pielou_p<-ggplot(data=result_df, aes(x=Cover_cat, y=mean_pielou)) +
 theme_bw()+
 labs(title = PlotTitle)+
 geom_errorbar(mapping=aes(ymin=pielou_min, ymax=pielou_max), width=0.4, size=1, color="black") +
 geom_point(shape=21, fill="white", size=3)+
 ylab("Mean Pielou Eveness")+
 xlab("")+
 theme(text = element_text(size=10),
      axis.text=element_text(size=9),
      plot.title = element_text(color="black", size=8, face="bold.italic"),
      axis.title=element_text(size=11),
      legend.position="none",
      #legend.title=element_text(size=9),
      axis.text.y = element_text(size=9),
      panel.grid.major = element_blank(),panel.grid.minor = element_blank() )

pielou_p
filename <- paste0("piel", FileEnding, ".pdf")
ggsave(filename, device = "pdf", path = NULL,
```

```
      scale = 1,
      width = plotwidth, height = plotheight, units = "cm",
      dpi = 300, limitsize = TRUE)


##########

simp_p<-ggplot(data=result_df, aes(x=Cover_cat, y=mean_Simp)) +
  theme_bw()+
  labs(title = PlotTitle)+
  geom_errorbar(mapping=aes(ymin=sim_min, ymax=sim_max), width=0.4, size=1, color="black") +
  geom_point(shape=21, fill="white", size=3)+
  ylab("Mean inverse Simpson (index)")+
  xlab("")+
  theme(text = element_text(size=10),
        axis.text=element_text(size=9),
        plot.title = element_text(color="black", size=8, face="bold.italic"),
        axis.title=element_text(size=11),
        legend.position="none",
        #legend.title=element_text(size=9),
        axis.text.y = element_text(size=9),
        panel.grid.major = element_blank(),panel.grid.minor = element_blank() )

simp_p
filename <- paste0("inv-simpson", FileEnding, ".pdf")
ggsave(filename, device = "pdf", path = NULL,
      scale = 1,
      width = plotwidth, height = plotheight, units = "cm",
      dpi = 300, limitsize = TRUE)


##########

expH_p<-ggplot(data=result_df, aes(x=Cover_cat, y=mean_expH)) +
  theme_bw()+
  labs(title = PlotTitle)+
  geom_errorbar(mapping=aes(ymin=expH_min, ymax=expH_max), width=0.4, size=1, color="black") +
  geom_point(shape=21, fill="white", size=3)+
  ylab("Mean exponential Shannon (index)")+
  xlab("")+
  theme(text = element_text(size=10),
        axis.text=element_text(size=9),
        plot.title = element_text(color="black", size=8, face="bold.italic"),
        axis.title=element_text(size=11),
        legend.position="none",
        #legend.title=element_text(size=9),
        axis.text.y = element_text(size=9),
        panel.grid.major = element_blank(),panel.grid.minor = element_blank() )

expH_p

filename <- paste0("expH", FileEnding, ".pdf")
ggsave(filename, device = "pdf", path = NULL,
      scale = 1,
      width = plotwidth, height = plotheight, units = "cm",
      dpi = 300, limitsize = TRUE)


##########
```

```
chao_p<-ggplot(data=result_df, aes(x=Cover_cat, y=mean_chao)) +
  theme_bw()+
  labs(title = PlotTitle)+
  geom_errorbar(mapping=aes(ymin=chao_min, ymax=chao_max), width=0.4, size=1, color="black") +
  geom_point(shape=21, fill="white", size=3)+
  ylab("Mean Chao1 Spp Estimater")+
  xlab("")+
  theme(text = element_text(size=10),
        axis.text=element_text(size=9),
        plot.title = element_text(color="black", size=8, face="bold.italic"),
        axis.title=element_text(size=11),
        legend.position="none",
        #legend.title=element_text(size=9),
        axis.text.y = element_text(size=9),
        panel.grid.major = element_blank(),panel.grid.minor = element_blank() )

chao_p

filename <- paste0("chao", FileEnding, ".pdf")
ggsave(filename, device = "pdf", path = NULL,
       scale = 1,
       width = plotwidth, height = plotheight, units = "cm",
       dpi = 300, limitsize = TRUE)

##########

geo_p<-ggplot(data=result_df, aes(x=Cover_cat, y=mean_geo)) +
  theme_bw()+
  labs(title = PlotTitle)+
  geom_errorbar(mapping=aes(ymin=geo_min, ymax=geo_max), width=0.4, size=1, color="black") +
  geom_point(shape=21, fill="white", size=3)+
  ylab("Mean Geometric Mean")+
  xlab("")+
  theme(text = element_text(size=10),
        axis.text=element_text(size=9),
        plot.title = element_text(color="black", size=8, face="bold.italic"),
        axis.title=element_text(size=11),
        legend.position="none",
        #legend.title=element_text(size=9),
        axis.text.y = element_text(size=9),
        panel.grid.major = element_blank(),panel.grid.minor = element_blank() )

geo_p
filename <- paste0("geo", FileEnding, ".pdf")
ggsave(filename, device = "pdf", path = NULL,
       scale = 1,
       width = plotwidth, height = plotheight, units = "cm",
       dpi = 300, limitsize = TRUE)



##########

#ace_p<-ggplot(data=result_df, aes(x=Cover_cat, y=mean_ace)) +
#  theme_bw()+
#  labs(title = PlotTitle)+
#  geom_errorbar(mapping=aes(ymin=ace_min, ymax=ace_max), width=0.4, size=1, color="black") +
#  geom_point(shape=21, fill="white", size=3)+
```

```
#  ylab("Mean ACE Spp Estimater")+
#  xlab("")+
#  theme(text = element_text(size=10),
#        axis.text=element_text(size=9),
#        plot.title = element_text(color="black", size=8, face="bold.italic"),
#        axis.title=element_text(size=11),
#        legend.position="none",
#        #legend.title=element_text(size=9),
#        axis.text.y = element_text(size=9),
#        panel.grid.major = element_blank(),panel.grid.minor = element_blank() )

#ace_p

#filename <- paste0("ACE", FileEnding, ".pdf")
#ggsave(filename, device = "pdf", path = NULL,
#       scale = 1,
#       width = plotwidth, height = plotheight, units = "cm",
#       dpi = 300, limitsize = TRUE)


#multiplot(dens_p,simp_p,mds1_p, wwt_p,vol_p, cols=2)



##################### MDS #######################

MDS_caps <- c("Bray-Curtis", "Chao")
MDS_type<-c("bray","chao")
lMDS_type <- length(MDS_type)


if (skip_mds != 1) {
# 'skip_mds' is a global variable set above to indicate whether to skip over time-consuming MDS analyses

for (dd in 1:lMDS_type) {

MDS_title<-paste0(MDS_caps[dd]," similarity with replacement")
#vegan offers several similarity options... These labels will affix to plots and filenames to help keep track.

similarity<-NULL
similarity<-vegdist(all_samp_m, method = MDS_type[dd])
attach(sample_id)
sol<-metaMDS(similarity)
NMDS = data.frame(MDS1 = sol$points[,1], MDS2 = sol$points[,2],Treatment=sample_id$Cover_cat)

NMDS1 <- subset(NMDS, Cover_cat == "N01")
NMDS2 <- subset(NMDS, Cover_cat == "N02")
#NMDS3 <- subset(NMDS, Cover_cat == "N03")
#NMDS4 <- subset(NMDS, Cover_cat == "N04")


N01_mult1<-mean(NMDS1$MDS1)
mt1_1<-t(quantile(NMDS1$MDS1, c(.025, .975), na.rm=TRUE) )
mqlo_1_1<-mt1_1[1]
mqhi_1_1<-mt1_1[2]
N01_mult2<-mean(NMDS1$MDS2)
mt1_2<-t(quantile(NMDS1$MDS2, c(.025, .975), na.rm=TRUE) )
mqlo_1_2<-mt1_2[1]
mqhi_1_2<-mt1_2[2]
```

```
N02_mult1<-mean(NMDS2$MDS1)
mt2_1<-t(quantile(NMDS2$MDS1, c(.025, .975), na.rm=TRUE) )
mqlo_2_1<-mt2_1[1]
mqhi_2_1<-mt2_1[2]
N02_mult2<-mean(NMDS2$MDS2)
mt2_2<-t(quantile(NMDS2$MDS2, c(.025, .975), na.rm=TRUE) )
mqlo_2_2<-mt2_2[1]
mqhi_2_2<-mt2_2[2]

#N03_mult1<-mean(NMDS3$MDS1)
#mt3_1<-t(quantile(NMDS3$MDS1, c(.025, .975), na.rm=TRUE) )
#mqlo_3_1<-mt3_1[1]
#mqhi_3_1<-mt3_1[2]
#N03_mult2<-mean(NMDS3$MDS2)
#mt3_2<-t(quantile(NMDS3$MDS2, c(.025, .975), na.rm=TRUE) )
#mqlo_3_2<-mt3_2[1]
#mqhi_3_2<-mt3_2[2]

#N04_mult1<-mean(NMDS4$MDS1)
#mt4_1<-t(quantile(NMDS4$MDS1, c(.025, .975), na.rm=TRUE) )
#mqlo_4_1<-mt4_1[1]
#mqhi_4_1<-mt4_1[2]
#N04_mult2<-mean(NMDS4$MDS2)
#mt4_2<-t(quantile(NMDS4$MDS2, c(.025, .975), na.rm=TRUE) )
#mqlo_4_2<-mt4_2[1]
#mqhi_4_2<-mt4_2[2]

mean_mds1<-c(N01_mult1,N02_mult1)
mean_mds2<-c(N01_mult2,N02_mult2)

mds1_min<-c(mqlo_1_1,mqlo_2_1)
mds1_max<-c(mqhi_1_1,mqhi_2_1)

mds2_min<-c(mqlo_1_2,mqlo_2_2)
mds2_max<-c(mqhi_1_2,mqhi_2_2)


################### Plot MDS #################################

plotwidth <- 9 #in cm
plotheight <- 9


mdsplt<-ggplot(data = NMDS, aes(x=MDS1,y= MDS2,group=Cover_cat, colour=Cover_cat)) +
  labs(title = PlotTitle)+
  xlab(MDS_title)+
  ylab("")+


  geom_point(aes(color = Cover_cat),size=1) +  theme_bw() + theme(panel.grid.major =
element_blank(),panel.grid.minor = element_blank())+
  scale_color_manual(values=c("#0000AA", "#0055FF", "#00AAFF", "#40FFFF",
                     "#80FFBF", "#BFFF80", "#FFFF40", "#FFAA00", "#FF5500", "#AA0000"))+
  theme(text = element_text(size=8),
     axis.text=element_text(size=8),
     plot.title = element_text(color="black", size=8, face="bold.italic"),
     axis.title=element_text(color="black", size=8, face="bold.italic"),
     #legend.position="none",
```

```
      legend.title=element_text(size=8),
      panel.grid.major = element_blank(),panel.grid.minor = element_blank() )

mdsplt

filename <- paste0("MDS_all-", MDS_type[dd], FileEnding, ".pdf")
ggsave(filename,  device = "pdf", path = NULL,
     scale = 1,
     width = plotwidth, height = plotheight, units = "cm",
     dpi = 300, limitsize = TRUE)



mds1_p<-ggplot(data=result_df, aes(x=Cover_cat, y=mean_mds1)) +
 theme_bw()+
 labs(title = PlotTitle)+
 geom_errorbar(mapping=aes(ymin=mds1_min, ymax=mds1_max), width=0.4, size=1, color="black") +
 geom_point(shape=21, fill="white", size=3)+
 ylab("Mean MDS-D1")+
 xlab(MDS_title)+
 theme(text = element_text(size=10),
      axis.text=element_text(size=9),
      plot.title = element_text(color="black", size=8, face="bold.italic"),
      axis.title=element_text(size=11),
      legend.position="none",
      #legend.title=element_text(size=9),
      axis.text.y = element_text(size=9),
      panel.grid.major = element_blank(),panel.grid.minor = element_blank() )

mds1_p

#filename <- paste0("mds1-", MDS_type[dd], FileEnding, ".pdf")
#ggsave(filename, device = "pdf", path = NULL,
#      scale = 1,
#      width = plotwidth, height = plotheight, units = "cm",
#      dpi = 300, limitsize = TRUE)




mds2_p<-ggplot(data=result_df, aes(x=Cover_cat, y=mean_mds2)) +
 theme_bw()+
 labs(title = PlotTitle)+
 geom_errorbar(mapping=aes(ymin=mds2_min, ymax=mds2_max), width=0.4, size=1, color="black") +
 geom_point(shape=21, fill="white", size=3)+
 ylab("Mean MDS-D2")+
 xlab(MDS_title)+
 theme(text = element_text(size=10),
      axis.text=element_text(size=9),
      plot.title = element_text(color="black", size=8, face="bold.italic"),
      axis.title=element_text(size=11),
      legend.position="none",
      #legend.title=element_text(size=9),
      axis.text.y = element_text(size=9),
      panel.grid.major = element_blank(),panel.grid.minor = element_blank() )

mds2_p

#filename <- paste0("mds2-", MDS_type[dd], FileEnding, ".pdf")
```

```
#ggsave(filename, device = "pdf", path = NULL,
#       scale = 1,
#       width = plotwidth, height = plotheight, units = "cm",
#       dpi = 300, limitsize = TRUE)

### Store the first set of results before starting the second run ###
mean_mds1_1 <- mean_mds1
mean_mds2_1 <- mean_mds2

mds1_min_1 <- mds1_min
mds1_max_1 <- mds1_max

mds2_min_1 <- mds2_min
mds2_max_1 <- mds2_max

}

############### Write summary file ##########################

result <- NULL

result<-t(rbind(mean_dens, dens_min,dens_max,
              mean_subsamp, w_min,w_max,
              mean_vol, v_min,v_max,
              mean_area, a_min,a_max,
              mean_rich,rich_min, rich_max,
              mean_Simp,sim_min, sim_max,
              mean_expH, expH_min, expH_max,
              mean_fisha,fisha_min, fisha_max,
              mean_pielou,pielou_min, pielou_max,
              mean_chao,chao_min, chao_max,
              mean_geo,geo_min, geo_max,
#               mean_ace,ace_min, ace_max,
              mean_mds1_1,mds1_min_1, mds1_max_1,
              mean_mds2_1,mds2_min_1, mds2_max_1,
              mean_mds1,mds1_min, mds1_max,
              mean_mds2,mds2_min, mds2_max
))

}

# else is used for skipping over MDS
else {
  result <- NULL

result<-t(rbind(mean_dens, dens_min,dens_max,
              mean_subsamp, w_min,w_max,
              mean_vol, v_min,v_max,
              mean_area, a_min,a_max,
              mean_rich,rich_min, rich_max,
              mean_Simp,sim_min, sim_max,
              mean_expH, expH_min, expH_max,
              mean_fisha,fisha_min, fisha_max,
              mean_pielou,pielou_min, pielou_max,
              mean_chao,chao_min, chao_max,
              mean_geo,geo_min, geo_max
              #             mean_ace,ace_min, ace_max,

))
```

```
}

filename <- paste0("results", FileEnding, ".csv")
write.csv(result, filename)


}  ###### end of amp cycles

######## Plot and print the means of those variables not affected by the amp factor, that were set aside
above ########

 mean_dens<-colMeans(den)
 dens_min<-colMeans(denmin)
 dens_max<-colMeans(denmax)
 mean_subsamp<-colMeans(subsam)
 w_min <- colMeans(subsammin)
 w_max <- colMeans(subsammax)
 mean_vol<-colMeans(vo)
 v_min <- colMeans(vomin)
 v_max <- colMeans(vomax)
 mean_area<-colMeans(are)
 a_min <- colMeans(aremin)
 a_max <- colMeans(aremax)
 mean_rich<-colMeans(ric)
 rich_min<-colMeans(ricmin)
 rich_max<-colMeans(ricmax)

 result<-t(rbind(mean_dens, dens_min,dens_max,
            mean_subsamp, w_min,w_max,
            mean_vol, v_min,v_max,
            mean_area, a_min,a_max,
            mean_rich,rich_min, rich_max
 ))

 result_df<-as.data.frame(result)
 result_df$Cover_cat<-Nod_cat

 ###################################

 plotwidth <- 9 #in cm
 plotheight <- 9

 ##########


 dens_p<-ggplot(data=result_df, aes(x=Cover_cat, y=mean_dens)) +
  theme_bw()+
  labs(title = PlotTitleSum)+
  geom_errorbar(mapping=aes(ymin=dens_min, ymax=dens_max), width=0.4, size=1, color="black") +
  geom_point(shape=21, fill="white", size=3, position="identity")+
  ylab(expression(paste("Mean fauna density (indiv  ",  m^-2,")")))+
  xlab("")+

  theme(text = element_text(size=10),
     axis.text=element_text(size=9),
     plot.title = element_text(color="black", size=8, face="bold.italic"),
     axis.title=element_text(size=11),
     legend.position="none",
     #legend.title=element_text(size=9),
```

```
      axis.text.y = element_text(size=9),
      panel.grid.major = element_blank(),panel.grid.minor = element_blank() )

dens_p

filename <- paste0("density", FileEndingSum, ".pdf")
ggsave(filename, device = "pdf", path = NULL,
     scale = 1,
     width = plotwidth, height = (plotheight), units = "cm",
     dpi = 300, limitsize = TRUE)


##########

ssmp_p<-ggplot(data=result_df, aes(x=Cover_cat, y=((mean_subsamp)))) +
  theme_bw()+
  labs(title = PlotTitleSum)+
  geom_errorbar(mapping=aes(ymin=w_min, ymax=w_max), width=0.4, size=1, color="black") +
  geom_point(shape=21, fill="white", size=3)+
  ylab(expression(paste("Mean no. of individuals")))+
  xlab("")+


  theme(text = element_text(size=10),
      axis.text=element_text(size=9),
      plot.title = element_text(color="black", size=8, face="bold.italic"),
      axis.title=element_text(size=11),
      legend.position="none",
      #legend.title=element_text(size=9),
      axis.text.y = element_text(size=9),
      panel.grid.major = element_blank(),panel.grid.minor = element_blank() )

ssmp_p

filename <- paste0("subsamp", FileEndingSum, ".pdf")

ggsave(filename, device = "pdf", path = NULL,
     scale = 1,
     width = plotwidth, height = plotheight, units = "cm",
     dpi = 300, limitsize = TRUE)


##########

sarea_p<-ggplot(data=result_df, aes(x=Cover_cat, y=((mean_area)))) +
  theme_bw()+
  labs(title = PlotTitleSum)+
  geom_errorbar(mapping=aes(ymin=a_min, ymax=a_max), width=0.4, size=1, color="black") +
  geom_point(shape=21, fill="white", size=3)+
  ylab(expression(paste("Mean sub-sample area")))+
  xlab("")+

  theme(text = element_text(size=10),
      axis.text=element_text(size=9),
      plot.title = element_text(color="black", size=8, face="bold.italic"),
      axis.title=element_text(size=11),
      legend.position="none",
      #legend.title=element_text(size=9),
      axis.text.y = element_text(size=9),
```

```
      panel.grid.major = element_blank(),panel.grid.minor = element_blank() )

sarea_p

filename <- paste0("subarea", FileEndingSum, ".pdf")

ggsave(filename, device = "pdf", path = NULL,
     scale = 1,
     width = plotwidth, height = plotheight, units = "cm",
     dpi = 300, limitsize = TRUE)


##########

vol_p<-ggplot(data=result_df, aes(x=Cover_cat, y=mean_vol)) +
  theme_bw()+
  labs(title = PlotTitleSum)+
  geom_errorbar(mapping=aes(ymin=v_min, ymax=v_max), width=0.4, size=1, color="black") +
  geom_point(shape=21, fill="white", size=3)+
  ylab(expression(paste("Mean biovolume (mL  ",  m^-2,")")))+
  xlab("")+

  theme(text = element_text(size=10),
      axis.text=element_text(size=9),
      plot.title = element_text(color="black", size=8, face="bold.italic"),
      axis.title=element_text(size=11),
      legend.position="none",
      #legend.title=element_text(size=9),
      axis.text.y = element_text(size=9),
      panel.grid.major = element_blank(),panel.grid.minor = element_blank() )

vol_p

filename <- paste0("v_ml", FileEndingSum, ".pdf")
ggsave(filename, device = "pdf", path = NULL,
     scale = 1,
     width = plotwidth, height = plotheight, units = "cm",
     dpi = 300, limitsize = TRUE)


##########

rich_p<-ggplot(data=result_df, aes(x=Cover_cat, y=mean_rich)) +
  theme_bw()+
  labs(title = PlotTitleSum)+
  geom_errorbar(mapping=aes(ymin=rich_min, ymax=rich_max), width=0.4, size=1, color="black") +
  geom_point(shape=21, fill="white", size=3)+
  ylab("Mean morpho-spp richness")+
  xlab("")+
  theme(text = element_text(size=10),
      axis.text=element_text(size=9),
      plot.title = element_text(color="black", size=8, face="bold.italic"),
      axis.title=element_text(size=11),
      legend.position="none",
      #legend.title=element_text(size=9),
      axis.text.y = element_text(size=9),
      panel.grid.major = element_blank(),panel.grid.minor = element_blank() )

rich_p
```

```
  filename <- paste0("rich", FileEndingSum, ".pdf")
  ggsave(filename, device = "pdf", path = NULL,
       scale = 1,
       width = plotwidth, height = plotheight, units = "cm",
       dpi = 300, limitsize = TRUE)


##########

} }

########### End of cycling through the two degradation factors ###########

### calculate and print mean number of nodules per image per category
nodc<-matrix(nodc, nrow = class_num, ncol = 1)
nod_sum <- cbind(nodc, n_class)
rownames(nod_sum)<- rows_named
colnames(nod_sum)<- c('mean_nods', 'class_n')

filename <- paste0("zz_NodCoverByClass", ".csv")
write.csv(nod_sum, filename)

}
########### end of area cycles ###########

########### End of Code ########### End of Code ########### End of Code ###########
```

C.4.2 R code to conduct power analysis on results created by the above code

```
#################################################################################
# Supporting code for:
# Detecting the effects of deep-seabed nodule mining: simulations using megafaunal data
# from the Clarion-Clipperton Zone
# Coded by Jeff A. Ardron, University of Southampton, UK
#
# This analysis applies power analyses to previously calculated disturbance simulations on data collected
# from APEI 6 in the Clarion-Clipperton Fracture Zone.
#
# It assumes a specific ordering of variables in the input table, as reflected in column names list, below.
#
#####################################################################################

library(RVAideMemoire)
library(scales)
library(plyr)
library(dplyr)
library(vegan)
library(Rmisc)
library(pwr)

rm(list=ls()) #clear all lists / variables

######################## Global Variables and Functions #######################

ntreat <- 9

newcolnames <- c("dens_mean", "dens_var", "dens_coh", "dens_p05-80", "dens_p05-90", "dens_p05-95",
        "rich_mean", "rich_var", "rich_coh", "rich_p05-80", "rich_p05-90", "rich_p05-95",
        "simp_mean", "simp_var", "simp_coh", "simp_p05-80", "simp_p05-90", "simp_p05-95",
        "expH_mean", "expH_var", "expH_coh", "expH_p05-80", "expH_p05-90", "expH_p05-95",
        "fish_mean", "fish_var", "fish_coh", "fish_p05-80", "fish_p05-90", "fish_p05-95",
        "piel_mean", "piel_var", "piel_coh", "piel_p05-80", "piel_p05-90", "piel_p05-95",
        "chao_mean", "chao_var", "chao_coh", "chao_p05-80", "chao_p05-90", "chao_p05-95",
        "geom_mean", "geom_var", "geom_coh", "geom_p05-80", "geom_p05-90", "geom_p05-95")


########################## Power Analysis #########################

# The R pwr analysis cannot handle any n less than 2, and will send an error.
# To get around this, the 'try' function is used as a wrapper, and will return 2 if there is an error.

n05_80 <- function(dd) {
  nnn <- try(pwr.t.test(n=NULL, d=dd, sig.level=.05,power = 0.8, type= "one.sample",
alternative="two.sided")
  ,silent=TRUE)
  if (inherits(nnn,"try-error")) return(2)
  else return(nnn$n)}

n05_90 <- function(dd) {
  nnn <- try(pwr.t.test(n=NULL, d=dd, sig.level=.05,power = 0.9, type= "one.sample",
alternative="two.sided")
  ,silent=TRUE)
  if (inherits(nnn,"try-error")) return(2)
  else return(nnn$n)}
```

```
n05_95 <- function(dd) {
  nnn <- try(pwr.t.test(n=NULL, d=dd, sig.level=.05,power = 0.95, type= "one.sample",
alternative="two.sided")
  ,silent=TRUE)
  if (inherits(nnn,"try-error")) return(2)
  else return(nnn$n)}

############# Get data from analyses as csv file ###############

result_v_compiled<-as.data.frame(read.table(filepath<-file.choose(),row.names=1, header = T, sep=','),
stringsAsFactors=FALSE)

iiimax <- nrow(result_v_compiled)
jjjmax <- (ncol(result_v_compiled))/2 #stepping across the matrix to get each mean

newtable <- matrix(0, nrow=(nrow(result_v_compiled)), ncol = (ncol(result_v_compiled))*3)
#cols are mean, variance, cohenD, p05-80, p05-90, p05-95; i.e. 3x as many as in the above table of variance

colnames(newtable) <- newcolnames
rownames(newtable) <- rownames(result_v_compiled)

### Populate the new table with the values from the compiled table, leaving gaps for the new variables

for (fff in 1:iiimax) {
ggg <- 1
eee <- 1
for (hhh in 1:jjjmax) {
newtable[fff,ggg] <- result_v_compiled[fff,eee]
ggg <- ggg+1
eee <- eee+1
newtable[fff,ggg] <- result_v_compiled[fff,eee]
ggg<- ggg+5
eee <- eee+1
}}

deltamean <- 0
poolsd <- 0
cohend <- 0

for (iii in 1:iiimax) {
  eee <- 1
  kkk <- 1
  baserow <- (as.integer((iii-1)/ntreat)*ntreat) + 1 #for each of the (ntreat = 9) treatments per sub-sample
size
for (jjj in 1:jjjmax) {

  baseline <- result_v_compiled[baserow,eee]
  deltamean <- baseline - result_v_compiled[iii,eee]
  poolsd <- sqrt((result_v_compiled[baserow,(eee+1)] + result_v_compiled[iii,(eee+1)])/2)
  cohend <- deltamean/poolsd


  newtable[iii,(kkk+2)] <- cohend
  newtable[iii,(kkk+3)] <- n05_80(cohend)
  newtable[iii,(kkk+4)] <- n05_90(cohend)
  newtable[iii,(kkk+5)] <- n05_95(cohend)


kkk <- kkk+6
```

```
eee <- eee + 2 #skip the variance column in the compiled table

}
}
rn<- rownames(newtable)
classname <- substr(rn[1], 1, 3) #extract the first three letters to identify what class this is

filename <- paste0("zzz_", classname,"_CompiledPWR", ".csv")
write.csv(newtable, filename)

########### End of Code ########### End of Code ########### End of Code ###########
```

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