The application of Adaptive Management to deep sea mining projects

Crossouard, N., and Matthewson, T.

HR Wallingford, Howbery Park, Wallingford, OX10 8BA, UK.

Abstract

This paper provides a summary of some of the main principles of Adaptive Management and how these may be applied to the development of environmentally responsible deep sea mining. It draws on real and hypothetical examples of project activities in coastal and deep waters.

A. Introduction

Deep sea mining (DSM), the extraction of seabed deposits in water depths of as much as 6,500m, is an emerging sector. It is a potential means of meeting the increasing demand for metals such as Ni, Co and rare earth metals required for high-technology devices and the equipment needed for renewable energy generation and consumption such as electric vehicles.

However it poses a number of challenges for those involved in the responsible Environmental Management of deep sea mining activities. These include:

- The deep sea environment within which mining will operate is poorly understood relative to coastal environments, in almost all respects: from the physical oceanographic regime to the ecology found there[1];
- As a new industry, there is limited direct practical experience with monitoring to draw upon that can guide understanding on the environmental effects of DSM and how these can be managed; and
- The policy and regulatory regime, in at least as far as international seas are concerned, is still evolving within an incomplete understanding of the appropriate environmental risk management approach.

At the same time, in the context of the climate emergency, major projects are coming forward in international and national seas that are seeking to exploit the deep sea deposits of, for example, the Clarion Clipperton Zone (CCZ), in a responsible way.

B. Concerns over the environmental impacts of deep sea mining

For many years, there have been widespread concerns over the potential environmental impacts of deep sea mining[2] including physical impacts on the seafloor, the creation of sediment plumes and underwater noise as a result of seabed operations, and the release of waste materials following pre-processing of the minerals at the sea surface. These concerns are understandable in this context of a novel industry working in an environment where understanding of processes and effects is limited.

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[1] Amon, Diva J.; et.al. 2022 Assessment of scientific gaps related to the effective environmental management of deep-seabed mining. Marine Policy, 138.

[2] MIDAS, 2016. Managing Impacts of Deep Sea Resource Exploitation Research Highlights. www.eu-midas.net.

As we learn more about the impacts of working in the deep oceans, some of the effects may be less severe than previously thought – for example in relation to sediment plumes[3]. Nonetheless, as more projects come forward for development, environmental management professionals are having to grapple with these residual uncertainties.

C. What is adaptive management and why is it so relevant to deep sea mining?

Adaptive management (AM) is an approach used in Environmental Impact Assessment (EIA) to manage such uncertainties and also the changes that may occur during a project's implementation. It involves a structured and iterative process of monitoring, evaluating, and adjusting management strategies and mitigation measures to ensure that environmental impacts are within agreed limits.

Given it is well-suited to situations where there remains uncertainty about effects, AM is seen as a means to reconcile the significant uncertainties about the environmental impacts of deep sea mining[4], with the increasing urgency to find a responsible way of obtaining the natural resources needed for a low carbon future.

D. The main principles of adaptive management in the context of deep sea mining

Given that all marine systems are dynamic and complex, AM is an approach that is already adopted in the environmental management of projects and activities in coastal waters. The main steps in applying this approach are outlined below, with particular implications for the use of this approach in deep oceans:

1) **Establishing a baseline:** The first step is to establish a baseline of environmental conditions before the project begins. In marine systems, and especially in the oceans, this is a particular challenge owing to the practical challenges of monitoring in remote and very deep waters.

2) **Developing a management plan:** A management plan is developed with recognition of sources of uncertainty and is based on the anticipated impacts identified during the EIA process. The EIA process may also have developed thresholds to be used in the monitoring stage for triggering intervention. These thresholds are typically based on the precautionary principle of preventing significant adverse effects, however the thresholds also need to be measurable reliably and robustly with the technology available. An issue facing DSM is that there is minimal experience upon which to base these thresholds, although there is practice and guidance starting to emerge in this area[5].

3) **Monitoring:** The next step is to monitor the project's activities to identify whether effects are in line with expectations and any modelling undertaken. Here again there are major challenges with the application of this approach to DSM, in that exploration and exploitation activities in the deep sea will require at least some monitoring technology to operate autonomously and reliably in remote areas under extreme

[3] Elerian, M., Huang, Z., van Rhee, C. Helmons, R., 2023. Flocculation effect on turbidity flows generated by deep-sea mining: A numerical study. Ocean Engineering, Volume 277, 2023.

[4] International Seabed Authority, 2023. Report of the Chair of the Legal and Technical Commission on the work of the Commission at the first part of its twenty-eighth session. Development of standards and guidelines (environmental threshold values). Twenty-eighth session Council session, part I. Kingston, 16–31 March 2023

[5] B. Hitchin, S. Smith, K. Kröger, DOB Jones, A. Jaeckel, NC Mestre, J. Ardron, E. Escobar, J. van der Grient, T. Amaro, 2023. Thresholds in deep-seabed mining: A primer for their development, Marine Policy, Volume 149, 2023.

conditions. That said, valuable lessons are already being learned from the observation of pilot studies called “collector tests” being conducted by the DSM sector[6] [7] [8].

4) **Evaluation:** The data collected during monitoring is evaluated to determine if the current management plan is effective in mitigating the anticipated impacts. For DSM mining, it is envisaged that this will be implemented by the use of thresholds, derived from the EIA, above which there is an unacceptable risk of environmental impacts. The approach will also rely upon the monitoring methods being capable of resolving parameters to the same level as the specified trigger thresholds.

5) **Adjustment:** If the management plan is not effective, adjustments are made to the plan to address any unexpected impacts or changes. As certain effects arising from DSM, such as sediment plume creation and noise emissions, are highly dynamic, the evaluate-and-adjust approach needs to be in near real-time. Thus, the additional mitigation measures need to be pre-planned with a scale of escalation depending on the threshold exceedance. This requirement for pre-planning is also important from a stakeholder and regulatory perspective to provide confidence and transparency in the approach applied. It is also important to note that given a precautionary approach is typically applied, sometimes monitoring can reveal that effects are less than anticipated and in this instance AM may allow some relaxation of the mitigation applied.

6) **Review**: The process is then reviewed periodically to ensure that the management plan remains effective and that environmental impacts are in line with predictions.

E. Case studies

With a view to providing tangible examples of the implementation of AM, two case studies are presented here; one which shows how AM can be implemented in the coastal zone and another which then considers how certain aspects of AM could be applied for a (hypothetical, but with a real-world setting) DSM project.

Adaptive management in the coastal zone (London Gateway Port, UK)[9] [10]

London Gateway Port (LGP) in the Thames estuary is a major deep-sea container port. Construction of the port in 2013 involved dredging of 30.5 million m^3 of sediment and use of this for the building of a reclamation.

In the immediate vicinity of the port and also further afield along the navigation channel for the Port of London are various sites of importance considering environmental aspects but

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[6] Sabine Haalboom, Henko C. de Stigter, Christian Mohn, Thomas Vandorpe, Marck Smit, Laurens de Jonge, Gert-Jan Reichart, 2023. Monitoring of a sediment plume produced by a deep-sea mining test in shallow water, Málaga Bight, Alboran Sea (southwestern Mediterranean Sea), Marine Geology, Volume 456, 2023.

[7] GSR, 2023. Touchdown: The Story of Patania II. Accessed at: https://deme-gsr.com/touchdown/. Date accessed: 01 May 2023.

[8] TMC, 2023. Frequently Asked Questions. Accessed at: https://metals.co/frequently-asked-questions/ Date Accessed: 01 May 2023.

[9] Central Dredging Association (CEDA) (2015) Environmental Monitoring Procedures. Information paper.

[10] Lee, M.W., Taylor, J.A. and Crossouard, N. A. “Principles into Practice: Monitoring of Dredging Projects”, Proceedings of the Twenty-Second World Dredging Congress, WODCON XXII, Shanghai, CHINA, April 22-26. 2019.

also commercial and infrastructure perspectives (Figure 1). These sites are referred to as sensitive receptors.

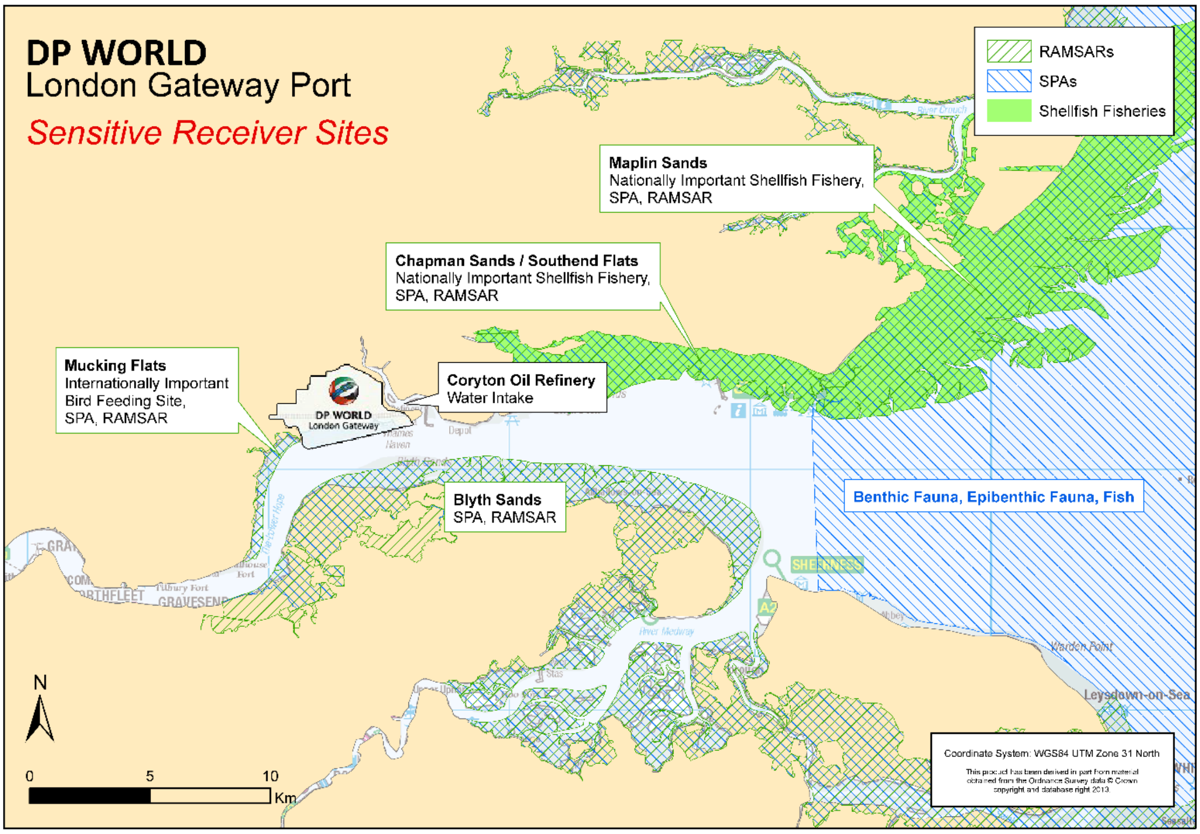

Figure 1: LGP sensitive receptor sites[11]

With respect to the process for informing and implementing AM during the project, the following steps were followed:

1) Sensitive receptor sites were identified.
2) A **baseline dataset** was collected prior to construction during which key sediment and water quality and physical oceanographic parameters were measured along with the health of the ecology of the sensitive receptors. Importantly, the baseline dataset was sufficiently long to capture seasonal variation in the estuary but also allow quantification of the health of the key sensitive receptors (data was collected for multiple years in advance for certain sensitive receptors such as fish to capture variability between years).
3) **Modelling** was undertaken to predict the extent and magnitude of the increases in (for example) suspended sediment concentration (SSC) arising from the works.
4) Arising from the **EIA process** environmental **thresholds** (or triggers) for key parameters (SSC and dissolved oxygen concentration) were established for management of the works in the short-term (e.g. day to day or even shorter timescales in some cases).
    a. These were applied in a **tiered approach** with “caution” and “stop” thresholds established. Figure 2 shows an example of exceedance of these thresholds for SSC over a tidal cycle.
    b. The purpose of the “caution” threshold was to act as an indicator for the potential for higher than acceptable conditions (e.g. SSC) occurring, giving

[11] CEDA (2015) Environmental Monitoring Procedures. Information paper. © Central Dredging Association

the opportunity for pre-planned mitigation measures to be put in place having considered the situation that resulted in the caution threshold being reached. Such measures could for example have been a reduction in the dredging production rate. If a “stop” threshold was reached the dredging was required to cease (at that location) until the parameter which had exceeded the threshold had returned below threshold limits.

   c. Aspects considered in the development of the thresholds were the levels that could be sustained by the receptors (magnitude and duration) and the locations at which the parameters should be measured (considering both spatial (X/Y) location and also vertical distribution in the water column). Consideration of the variation in both space and time of the natural conditions at the site was also required when assessing the implementation of the thresholds.

Figure 2: Example of the exceedance of caution and stop thresholds for SSC

5) **Management and mitigation responses** (what to do in the event of a trigger being breached) were defined, documented and agreed with regulators well in advance of the works.
6) A **plan for monitoring** during the AM regime around the works and how the data were to be analysed was established.
   a. This involved the monitoring of SSC, dissolved oxygen, salinity, temperature, currents, waves, water and sediment quality, bathymetry/topography and key indicators for the health of fauna at the sensitive receptor sites.
   b. To allow the short-term management of the works necessitated a requirement for **real-time telemetry** of the data and development of a data **platform to visualise data** from the range of monitoring sites established (Figure 3). Data for each site could be interrogated further and plotted graphically along with thresholds in near real-time.

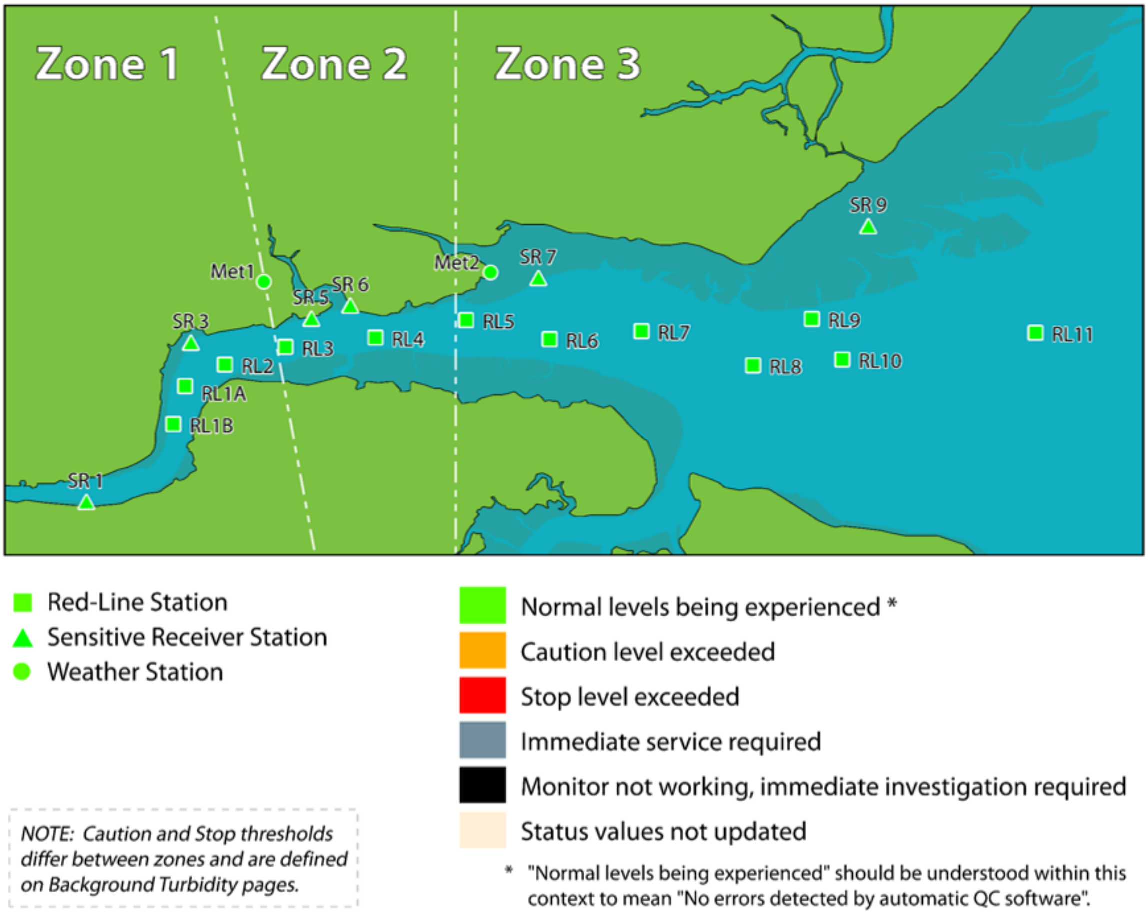

Figure 3: Real-time monitoring data visualisation platform developed for LGP project[12]

7) The above (monitoring plan, thresholds developed and responses should those thresholds be breached) were all captured as part of an **Environmental Monitoring and Mitigation Plan** for the works which was agreed with UK regulators.
8) An **independent advisory panel** was established to advise on the environmental monitoring.
9) The monitoring was regularly **reviewed and adapted** (again with agreement from the regulators) based on the monitoring results. To enable this it was key to have some flexibility in the approach documented and agreed (this also has important implications for contractual arrangements between parties).
10) **Stakeholders** (such as fisheries) were **engaged** with before and during the project to benefit from their knowledge and experience at the site, to try to address concerns and to keep them accurately informed.

Adaptive Management in a (hypothetical) DSM project

Here a seamount location with ferromanganese crusts was selected to consider how certain principles of AM in the context of DSM set out above could be implemented if exploitation of the crusts were to take place at this location. This location was selected because studies have already been conducted at this location that may, in theory, inform future mining in the

[12] After Laboyrie, H. P., Van Konigsveld, M., Aarninkof, S. G. J., Van Parys, M., Lee, M., Jensen, A., Csiti, A. and Kolman, R. (2018). "Dredging for Sustainable Infrastructure". CEDA / IADC, The Hague, the Netherlands.

area. However it must be noted that to the authors' knowledge there are no active plans to mine at this site.

The location selected is the Tropic Seamount with water depths of approximately 1000m at its crest and up to 4000m at its base (300 nautical miles SSW of the Canary Islands). Monitoring already conducted at the seamount included the collection of a range of datasets which would be relevant in the context of planning environmental management of mining crusts at the seamount[13] (Figure 4).

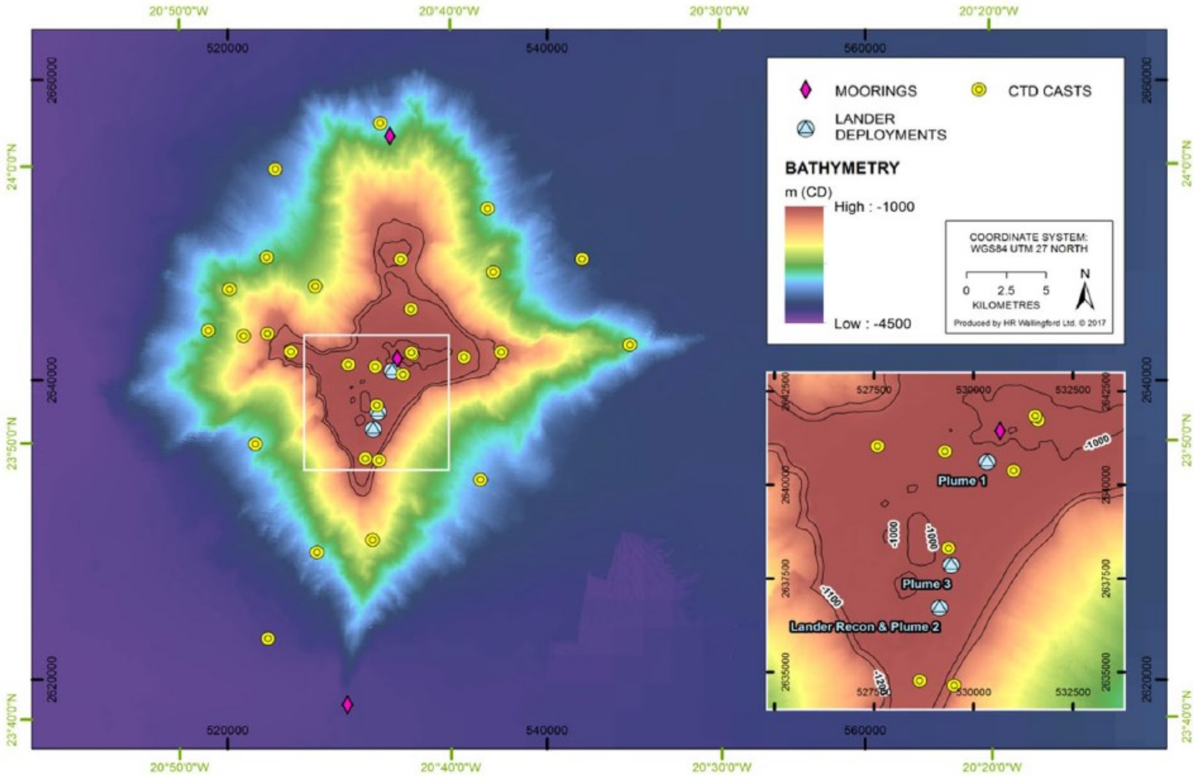

Figure 4: Bathymetry at Tropic Seamount with selected locations of previous monitoring sites[14]

Considerations on the implementation of AM with reference to the key principles set out in Section D are provided below, with a focus on certain site-specific aspects that would feed into the **Development of the Management Plan** and the planning of the **Environmental Monitoring**, however this paper only considers aspects of this project that may be of interest to the reader in relation to AM.

Development of the Management Plan

Key to the **Development of the Management Plan** will be the development of environmental thresholds for key parameters. In this case, we can expect SSC to be the primary parameter monitored. In seamount environments where internal tides exert a key control on the currents there may be some potential for natural suspension of sediments. Such natural variability would be of importance to establishing thresholds for (in this case) SSC and was captured as part of the previous monitoring. Evidence of elevated SSC at times of peak current flows was found as part of the previous monitoring undertaken at the

[13] Spearman, J., Taylor, J., Crossouard, N. et al. Measurement and modelling of deep sea sediment plumes and implications for deep sea mining. Sci Rep 10, 5075 (2020). https://doi.org/10.1038/s41598-020-61837-y
[14] See reference 13 above.

site (Figure 5). This natural phenomenon (baseline SSC variability) would need to be built into the threshold setting and may result in a time-varying threshold.

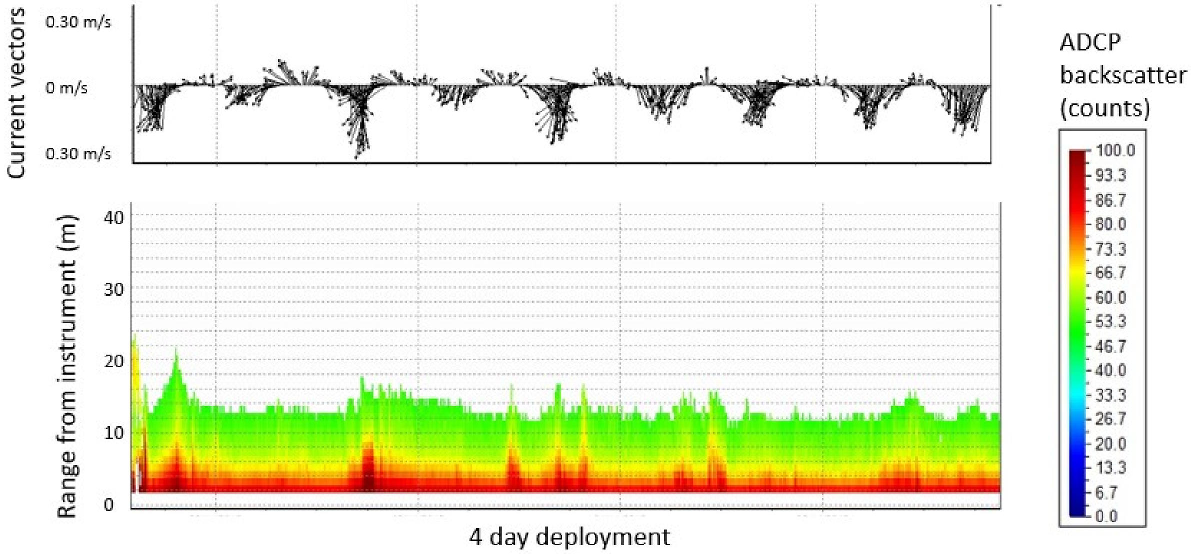

Figure 5: Example current vectors and ADCP backscatter at a site on the seamount crest, with some correlation between times of peak current flow and increased ADCP backscatter

The use of a tiered threshold approach as often used in coastal settings could also be practically employed here, with lower threshold limits likely triggering additional monitoring or scrutiny of monitoring as a minimum but potentially also a lowering of the rate of mining production.

One can envisage that the mining itself could also be carried out in a staged manner, with low production rates at first increasing to higher rates on the basis of minimal or no exceedances of certain thresholds. Mining production rates to use on an initial basis could be informed by small-scale experiments or tests which could have taken place immediately following the baseline monitoring period, much the same as has been seen with the "collector tests" being conducted in the CCZ presently.

The nature of the currents at the site (as shown in Figure 5) would have a bearing on the extents of sediment plumes arising from the mining operation. Understanding the interaction between currents and the created plumes would also have a bearing on the AM regime. For example, might mining be timed to coincide with periods when currents were less prone to take sediments towards sensitive receptors?

A detailed understanding of the ecological receptors and their sensitivities is key to an AM approach. Achieving this understanding is one of the fundamental challenges for DSM, and tropical seamounts are no exception. Seamounts have been shown to support a diversity of benthic fauna, for example, sponges, fans and corals[15] that may need to be better understood before an AM approach could be applied here.

[15] Cornwall, W., 2019. Mountains hidden in the deep sea are biological hot spots. Will mining ruin them? Accessed at: https://www.science.org/content/article/mountains-hidden-deep-sea-are-biological-hot-spots-will-mining-ruin-them Date accessed: 02 May 2023.

That said, the location of key receptors on the seamount such as deep sea sponges have also been modelled to be (most probably) distributed on the flanks of the seamount[16] (Figure 6). The location of such receptors relative to the potential resource (Figure 7) and the predicted extents of sediment plume releases (Figure 8) would all form key inputs into the development of the environmental management plan.

The use of predictive models would also give the ability to test and refine monitoring and mining scenarios.

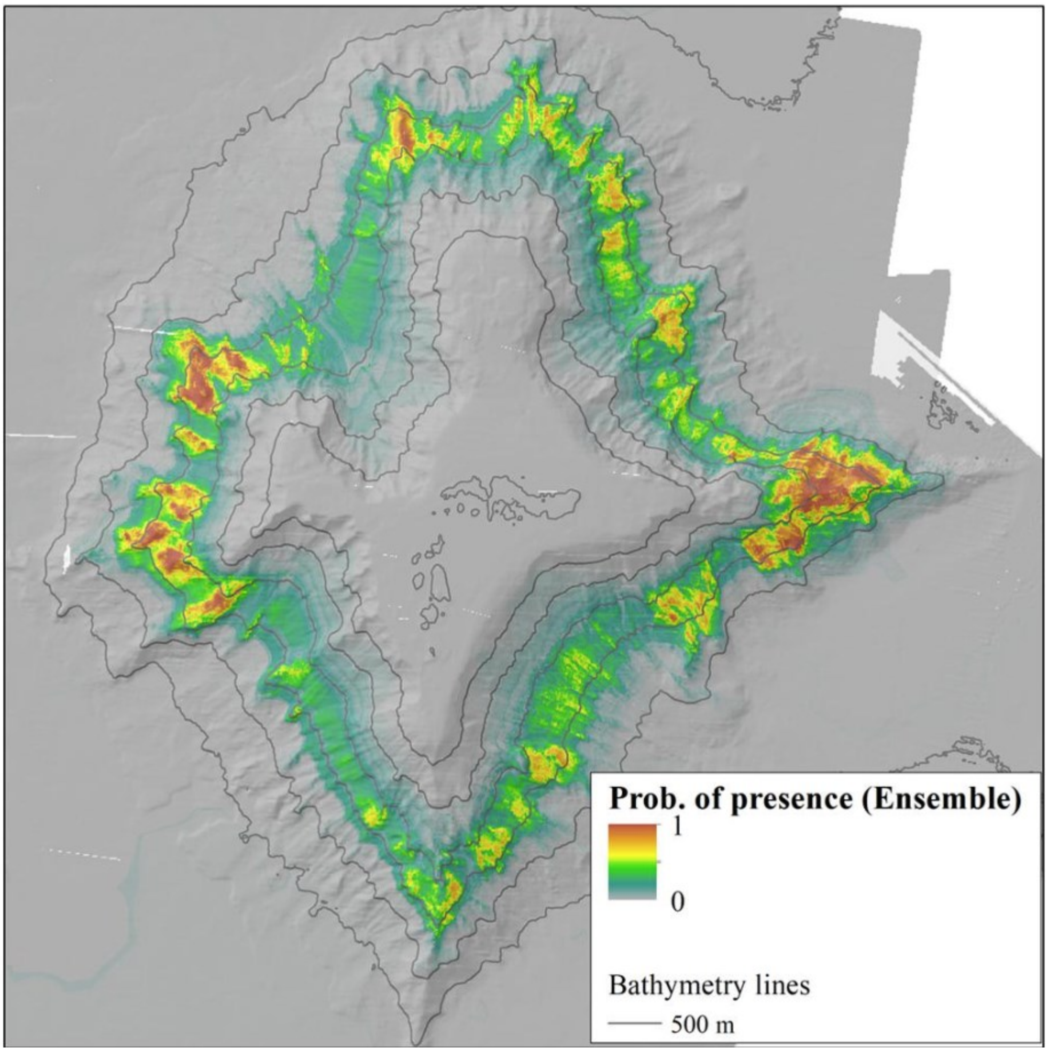

Figure 6: Prediction of deep sea sponge presence on Tropic Seamount[17]

[16] Ramiro-Sánchez B, González-Irusta JM, Henry L-A, Cleland J, Yeo I, Xavier JR, Carreiro-Silva M, Sampaio Í, Spearman J, Victorero L, Messing CG, Kazanidis G, Roberts JM and Murton B (2019) Characterization and Mapping of a Deep-Sea Sponge Ground on the Tropic Seamount (Northeast Tropical Atlantic): Implications for Spatial Management in the High Seas. Front. Mar. Sci. 6:278. doi: 10.3389/fmars.2019.00278

[17] See reference 16 above.

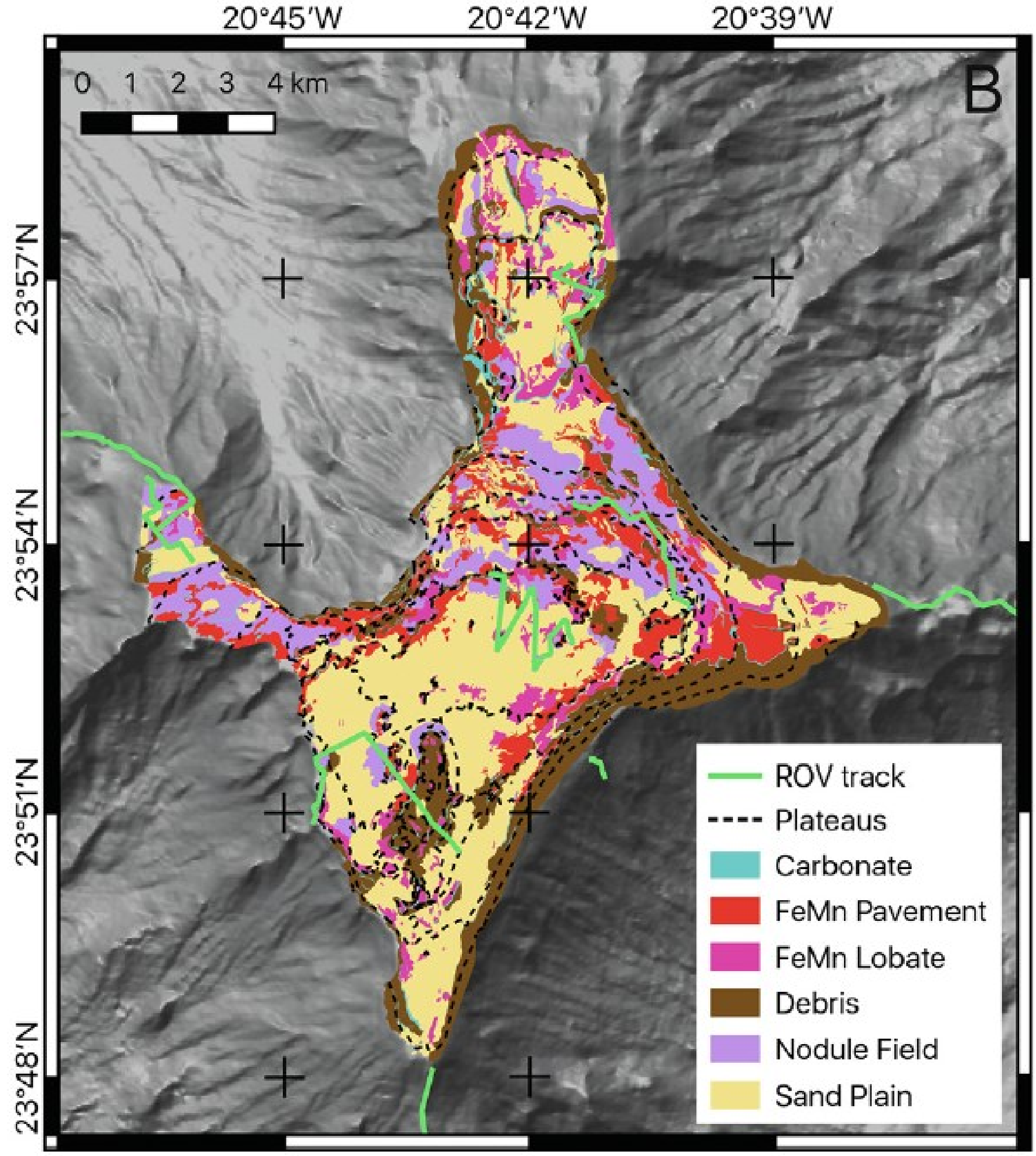

Figure 7: Geological map of the surface outcrop at Tropic Seamount[18]

[18] I.A. Yeo, S.A. Howarth, J. Spearman, A. Cooper, N. Crossouard, J. Taylor, M. Turnbull, B.J. Murton, Distribution of and hydrographic controls on ferromanganese crusts: Tropic Seamount, Atlantic, Ore Geology Reviews, Volume 114, 2019.

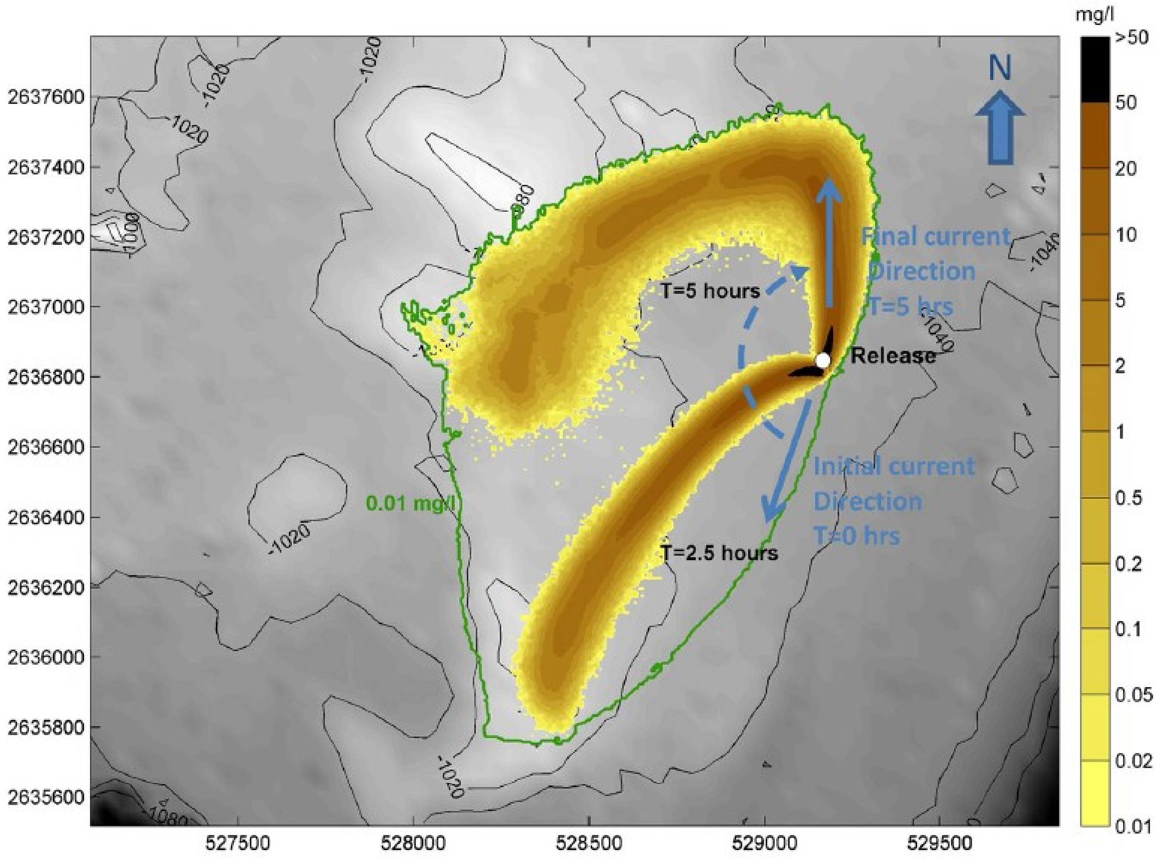

Figure 8: Snapshot of predicted increases in SSC averaged over bottom 10m of water column with envelope of increases greater than 0.01mg/l within the green line[19]

Environmental Monitoring

Monitoring of the environmental impact of the mining would be likely to include the measurement of SSC and sediment deposition, light measurements and sound measurements amongst a range of other water quality, oceanographic and bathymetric parameters. Monitoring of the health of the receptors identified in the EIA would also naturally be required.

Monitoring is likely to be required in both the near and far field with monitoring sites in the far field being located based on the location of sensitive receptors and the predicted pathways of sediment plume releases from the mining activity.

Instruments would be expected to be deployed on a range of platforms which are both mobile (e.g. ROVs and AUVs) and fixed (frames on the seabed or instruments mounted in moorings). Key to the management of the mining activity would be the requirement to telemeter the data in near real-time from the array of instrumentation using acoustic data telemetry methods.

Routine ROV video and photographic monitoring would be required to assess the receptors for indications of stress and also the level of sediment deposition.

[19] See reference 13 above.

G. Concluding comments on adaptive management for deep sea mining and the EIA process

Adaptive Management approaches have been developed to address uncertainties about the environmental impacts of coastal projects. The framework therefore also has potential to apply to deep sea mining, where greater uncertainty over effects inevitably exists.

The key inputs to an Adaptive Management approach include a robust baseline that recognises the temporal and spatial variation in key parameters (and receptors), the sensitivities of known receptors, the ability to predict, reliably track and record these variables in near real-time, planned, documented and agreed interventions to respond to exceedances in these variables, and a feedback loop of monitoring.

It will be obvious to EIA practitioners that the foundations of this approach are based on robust and well-established EIA good practice. It will also be evident that an Adaptive Management approach is not a quick and simple "short cut". Rather, done properly it offers a means to undertake environmentally responsible deep sea mining, built on sound science.