PREDICTING THE IMPACTS OF MINING DEEP SEA POLYMETALLIC NODULES IN THE PACIFIC OCEAN

A Review of Scientific Literature

May 2020

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FRONT COVER: A SPERM WHALE AND FREEDIVER. IF NODULE MINING DEVELOPS DEEP-DIVING WHALES LIKE THE VULNERABLE SPERM WHALE COULD BE ADVERSELY IMPACTED. IMAGE: WILLYAM

OPPOSITE PAGE: A POLYMETALLIC NODULE FROM THE PACIFIC OCEAN. IMAGE: VELIZAR GORDEEV

TRIBUTE TO STEVEN LEE

We would like to acknowledge the contribution of Steven Lee. A talented young marine biologist with a passion for conservation, Steven had so much to offer our oceans. His presence will be missed by the seas and by the people he loved. His research towards this report is much appreciated.

MAY 2020

Predicting the impacts of mining deep sea polymetallic nodules in the Pacific Ocean

A Review of Scientific Literature

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ABBREVIATIONS

ABNJ	Areas Beyond National Jurisdiction
APEI	Area of Particular Environmental Interest
CCZ	Clarion Clipperton Zone
DISCOL	Disturbance and recolonization experiment
DSM	Deep sea/seabed mining
EEZ	Exclusive Economic Zone
EPO	Eastern Pacific Ocean
GSR	Global Sea Mineral Resources
IATTC	Inter-American Tropical Tuna Commission
ISA	International Seabed Authority
IUCN	International Union for the Conservation of Nature
MIDAS	Managing impacts of deep sea resource exploitation
MPA	Marine Protected Area
NORI	Nauru Ocean Resources Inc
PNG	Papua New Guinea
ROV	Remotely Operated Vehicle
UNCLOS	United Nations Convention on the Law of the Sea
WCPFC	Western and Central Pacific Fisheries Commission
WCPO	Western and Central Pacific Ocean
WPO	Western Pacific Ocean

EXECUTIVE SUMMARY

Deep sea mining (DSM) in the Pacific is of growing interest to frontier investors, mining companies and some island economies. To date no commercial operations have been established, but much seabed mineral exploration is occurring. The focus is on polymetallic nodules in the Clarion Clipperton Zone (CCZ) in the north-eastern equatorial Pacific, and in the exclusive economic zones (EEZs) of several nations.

Some stakeholders promote DSM as essential to supply the metals required for a global transition to renewable energy. However, existing terrestrial mineral stocks, progress towards mining of electronic waste, advances towards the development of circular economies, and alternative sources of metals, challenge assertions that the seabed must be mined.

Some companies and governments maintain that future DSM within EEZs will support national prosperity and the development goals of Pacific island economies with little or no negative impact. At the same time, many Pacific islanders express concern about the social, economic and environmental impacts they anticipate deep sea mining would have on their lives. The body of knowledge validating these concerns is slowly growing.

The feasibility and economic benefits of DSM are unsubstantiated. The world's first licenced deep sea mining project, Solwara 1 in Papua New Guinea (PNG), has had a significant negative economic outcome for that nation. When Nautilus Inc declared bankruptcy, PNG was left burdened by debt, having been persuaded by that company to invest in its failed project. Civil society there and across the Pacific are vocal in their opposition to DSM with calls for a ban in PNG and a moratorium elsewhere in the region.

In 2019, the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) reported on the unparalleled rate of extinction of the world's biodiversity, with implications for human health, prosperity and long-term survival. The Intergovernmental Panel on Climate Change (IPCC) Special Report on the Ocean and Cryosphere in a Changing Climate has since described the precarious state of marine ecosystems. Yet neither report takes into account the predicted impacts and risks of DSM.

Deep sea habitats are rich in biodiversity of which only a fraction is known to science. In the Pacific, the little information available on deep seabed habitats relates to the CCZ. Almost nothing is known about the species and diversity of deep sea environments across the rest of the region.

This review represents an analysis of literature addressing the predicted and potential impacts of mining deep sea nodules in the Southwest, Central, and Northeast Pacific. More than 250 scientific and other articles were examined to explore what is known — and what remains unknown — about the risks of nodule mining to Pacific Ocean habitats, species, ecosystems and the people who rely on them. The report details scientifically established risks, including those related to the lack of knowledge surrounding this emerging industry.

> **The accumulated scientific evidence indicates that the impacts of nodule mining in the Pacific Ocean would be extensive, severe and last for generations, causing essentially irreversible damage. Expectations that nodule mining would generate social and economic gains for Pacific island economies are based on conjecture. The impacts of mining on communities and people's health are uncertain and require rigorous independent studies.**

Environmental impacts of deep sea mining

Many deep sea habitats are highly diverse with very little known about the biology and ecology of the wide range of species they support. Recently discovered deep sea species are typically highly specialised, relatively slow growing, and long lived. These traits make them particularly vulnerable to environmental change.

Small-scale experiments and trials of remotely operated vehicles (ROVs)[1] have shown that nodule mining would alter the composition of deep sea communities for millennia. The hard surface habitats provided by nodules would be removed along with the organisms that grow on them. Because nodules take millions of years to form, the loss of such habitats would essentially be permanent: thus animals that live or rely on them — like deep sea octopus and many immobile species — would be lost. Scientists have stated that species losses would be unavoidable if deep sea mining proceeds and most of these species have not yet been studied.

DSM exploration leaseholds already cover millions of square kilometres of ocean floor. If only a small portion of exploration areas are fully exploited, mining would cover tens of thousands of square kilometres, with the impacts of these operations extending even further. The impact of a single mine, let alone the cumulative impacts of many mines, is unknown.

Mining companies have not disclosed details of their proposed operating systems or waste management processes — both being key determinants of the scale and range of potential impacts. Companies indicate that various depths are under consideration for discharge of mine waste back into the sea, after initial processing on board surface support vessels.

There is little understanding about the characteristics of the waste plumes that would result — how far such plumes would travel vertically and horizontally, what metals and processing agents they would contain, how toxic these would be, and the effects of sedimentation on little-studied deep sea habitats and species when plumes settle. A range of animals including whales, turtles and tuna are known to routinely make extended deep dives to 1,000 metres below the surface and deeper. Such species could be exposed to mine waste discharged at any point in the water column.

The limited information available on plume behaviour focuses on near-surface waters. There are no empirical studies of the impacts of waste disposal in deeper waters. Studies indicate that plumes resulting from waste discharged near the surface , whether deliberately or accidentally, may be toxic to species living there. Near-surface plumes may also cause plankton blooms.

1. ROVs include 'seabed collectors' which move over the seabed, collecting nodules that are then pumped to the surface.

These could cause bioaccumulation of toxic metals in marine food webs and affect the movement and migration of species that feed on plankton and fishes, such as birds, sharks and cetaceans. Near-surface plumes could also affect small pelagic fishes, shrimps and squids that make vertical migrations from deep waters to the surface, and are important sources of food for many species including tuna. Mine waste could also trigger blooms of cyanobacteria.

If mine waste was discharged in mid or deep waters, it is possible that upwelling could result in plumes at higher levels of the water column with similar impacts. Detailed oceanographic assessments of each proposed mine site are required to determine the degree of such risks. Studies are yet to be conducted on mine waste toxicity to deep sea species.

Surface support vessels, DSM equipment and infrastructure would meanwhile create noise and light pollution at the surface, seabed and — depending on the operating system — possibly at mid-water depths. Such pollution would affect a wide range of species.

While the range and scale of predicted and potential environmental impacts would be significant, scientists have concluded that it is highly unlikely that remediation of impacts would be possible. Compensation for impacts by biodiversity offsetting is likewise viewed as unrealistic.

Social and economic dimensions of deep sea mining

Pacific peoples have deep cultural and spiritual connections to their ocean born from sailing, fishing and trading over hundreds of generations. As societies and individuals, their identities are intertwined with the ocean including sites that are deep under water and far from human habitation. Studies are yet to explore the full scope of socio-cultural effects of nodule mining.

The most severe economic impacts of DSM are likely in fisheries. Many Pacific island economies depend on fisheries for national wealth and employment, local livelihoods, cultural practices, and food security. In 2018, the Pacific tuna fishery was worth more than more than USD 6 billion and accounted for a significant share of the GDP of many economies.

A single DSM risk assessment for fisheries has been carried out. It focused on tuna and suggested the risk might be low due to depth separation between mining activities and tuna habitats. However, it highlighted numerous knowledge gaps, stating that extensive site specific studies would be needed to determine the risks. In addition, mining and waste discharge methods are unknowns that would greatly influence the scale and scope of impacts on fisheries.

Risks to tuna fisheries and other open-ocean species would be greatly increased by mine waste released in surface layers as well as noise and light pollution from DSM infrastructure. Yellowfin and bigeye tuna would be exposed to waste discharges at depths of up to 1,000 metres or more, as these species make extended deep dives. Climate change research predicts that tropical tuna stocks will move eastwards in future years, shifting their populations into habitats where nodule deposits occur. If plumes from nodule mining affected seamounts, deep sea snapper fisheries would be at risk.

The contiguous and interconnected nature of ocean ecosystems means that mining impacts would not be contained to any one area or jurisdiction (i.e. they would be transboundary). Cumulative impacts from multiple operations are particularly important considerations. It is not possible at this point to predict the reach and scope of impacts of any individual project let alone the cumulative impacts of the many projects proposed throughout the Pacific.

Cumulative and transboundary impacts are especially important given the economic value and migratory nature of tuna and other fish stocks that straddle maritime jurisdictions. Recent evidence suggests that deep sea fishes also migrate.

Even before any commercial operations have been established, DSM is causing deep social divisions. Many Pacific islanders prioritize preserving habitats, their way of life, livelihoods and food security over the unconfirmed benefits that DSM may bring. They are aware of the destruction caused by many land-based mines and other terrestrial natural resource projects — and the lack of lasting benefits for affected communities that have accrued from these.

While some governments and community members support deep sea mining for economic development, many Pacific island economies remain underdeveloped after decades of resource extraction. Even if commercially successful, DSM may not provide sufficient revenues to be an economic panacea for Pacific islanders, or to offset predicted and potential losses in current uses of the ocean (e.g. fisheries).

From a global perspective, concerns have been raised about the damage DSM would do to species and habitats that are part of common human heritage.

Insufficient information, risks and need for caution

The potential impacts of mining deep sea nodules are poorly understood. As a result it is not possible to adequately assess and manage the risks. In particular:

- Studies of deep sea biodiversity and habitats in nodule grounds are few. The available information is dominated by research in the CCZ with very little publicly available scientific information about the diversity, biology, ecology, and population dynamics of deep sea species and habitats in the wider Pacific, their ecological roles, and their ability to withstand or recover from deep sea nodule mining.
- Most of the nodule mining technology and methods is proprietary information, or has yet to be developed. The scale and period of proposed operations are not clear. Thus, it is not possible to predict the extent of physical damage to seafloor habitats and biota, plumes generated and their spread, or sedimentation.
- Also unknown are the impacts on surface, mid-water and deep sea species of noise and light pollution.
- Nodule mining will create cumulative pressures on species, habitats, and ecosystems including species in shallower waters that may be exposed to waste. Global oceans are already experiencing stress from numerous sources including acidification, land-based pollutants such as plastics, and climate change. DSM's contribution to the cumulative

impacts of multiple stressors is unknown.

- The extent of impacts across jurisdictional boundaries is also unknown. The migratory nature of many marine organisms and the interconnected nature of oceans means that DSM at one site would affect marine life and fish stocks at another. Migrations of deep sea fishes have been demonstrated in the Atlantic Ocean and could occur in Pacific. Transboundary impacts of nodule mining may become a source of conflict.
- Social and economic costs and benefits for Pacific island economies are unknown. The economic feasibility of nodule mining, distribution of earnings, duration of benefits, liabilities for companies and governments, and social impacts are yet to be independently examined. In PNG, the distribution of wealth from resource extraction projects has been at the heart of several armed conflicts, notably the Bougainville Civil War (leading to a referendum on independence in 2019) and recent conflicts over royalties from natural gas in the highlands.
- No information exists in the public domain on the potential impacts on human health through bioaccumulation of metals that would be contained in plumes generated by nodule mining. This is a highly significant knowledge gap as seafood forms a major component of the diet of Pacific islanders, and commercial fisheries are major contributors to the GDP of many Pacific economies.
- No studies are available on the full scope of social, cultural and economic effects.
- There is no evidence that it is possible to develop spatial management arrangements to ensure the protection of deep sea species and ecosystems, especially in view of the transboundary and cumulative nature of DSM related impacts. It is also unclear whether such arrangements could protect species moving through waters above the seabed.
- The carbon sequestration functions of deep sea ecosystems are recognised but poorly understood. How these and global carbon balance might be affected by nodule mining is unknown.

This review concludes that mining deep sea polymetallic nodules in the Pacific will have severe and long-lasting impacts on the seabeds mined and the species they support and may pose significant risks to marine ecosystems more broadly. The potential impacts on fisheries, communities and human health are largely unknown and thus pose risks. The review finds that the relationship of Pacific islanders to the ocean is not well integrated into discussions about nodule mining and that social and cultural impacts are yet to be meaningfully explored. Lastly, the social and economic benefits are questionable. We conclude that a precautionary approach to nodule mining is warranted.

1 | OVERVIEW

Covering 30 per cent of the earth's surface, the Pacific Ocean is vital to millions of people. For many Pacific island economies, fishing and tourism are important activities. The ocean also holds important and irreplaceable social and cultural values. The peoples of the Pacific are "ocean peoples" who view the Pacific as a large, interconnected system of land and sea where resources flow between their communities across artificial boundaries (4).

There is increasing pressure on the Pacific Ocean for metals. Increased demand attributed to emerging markets, population growth, urbanisation, and a growing global middle class is often used to justify a need for deep sea mining (5).

The Pacific seabed contains valuable minerals (6). These minerals exist as cobalt-rich crusts, massive sulphide deposits of hydrothermal vents and fields of polymetallic nodules (6, 7). Polymetallic nodules are lumps deposited over millions of years and typically comprise several minerals including nickel, cobalt, copper and manganese. They may also contain zinc, zirconium, lithium, platinum, titanium and other valuable elements (8).

Nodules form extremely slowly, with growth estimated at between several millimetres and several centimetres every million years (6). They have been found on several deep seabed plains known as abyssal plains. Many deposits lie in "high seas" areas beyond national jurisdictions, outside the exclusive economic zone of any country (Fig. 1) (9).

The Clarion Clipperton Zone (CCZ) is a vast abyssal plain in the Eastern Pacific at a depth of more than 3,000 metres. Its high concentration of nodules has made it a focus for mining exploration (1, 10). There are also nodules on the seabed in the North Pacific and within the EEZs of several countries including the Cook Islands, Kiribati, Palau and Tuvalu (Fig. 1). In the Cook Islands, exploration has recently begun (11) and there is growing interest especially in the Penrhyn Basin within its EEZ (1). For exploration in the CCZ, the Cook Islands, Kiribati, Nauru and Tonga have partnered with foreign mining interests (1).

Speculation about the commercial value of mineral-rich polymetallic nodules has resulted in a high level of interest in DSM exploration and in developing mining technology and processes (e.g. 12, 13). As highlighted in Section 3, the progress made by companies is unclear.

Companies from Asia, the Pacific, North and South America, and Europe have secured DSM exploration licences, largely focused on the CCZ (1, 14). Some companies and governments promote DSM as a viable and environmentally preferable alternative to terrestrial mining to address projected shortages of minerals, particularly for technology required to reduce global carbon emissions (2, 13). However, there are credible alternatives to DSM including urban mining and circular economies that focus on reducing, reusing and recycling metals, and a "cradle-to-cradle" approach in the sustainable design of all products (15).

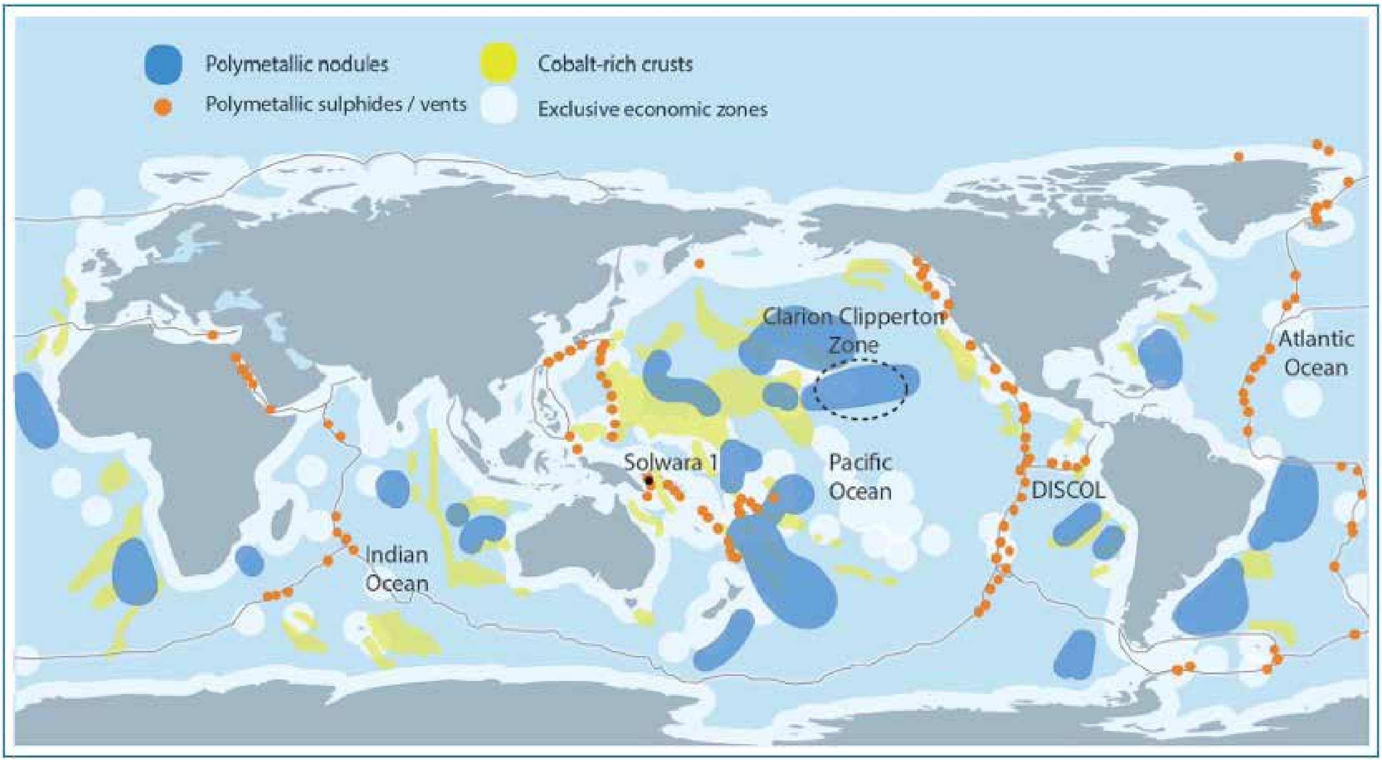


Figure 1: WORLD MAP SHOWING THE LOCATION OF SEABED MINERAL DEPOSITS

There are three main seabed mineral deposits: polymetallic nodules (blue), polymetallic or seafloor massive sulphides (orange) and cobalt-rich ferromanganese crusts (yellow). Solwara 1 was the first DSM project in the world to be granted a licence to mine seafloor massive sulphides in the Bismarck Sea of Papua New Guinea. The company has been declared bankrupt and the PNG Government describes it as a failed project that is unlikely to proceed (3). DISCOL was an *insitu* disturbance and recolonization experiment established in 1989 to examine the effects of nodule mining in the deep Peru Basin.

FIGURE REPRODUCED FROM MILLER (*ET AL.*) 2018 (9) UNDER CREATIVE COMMONS ATTRIBUTION LICENSE CC

It is argued that "a transition towards a 100 per cent renewable energy supply — often referred to as the 'energy revolution' — can take place without deep sea mining" (16).

Deep sea mining is often promoted as delivering benefits to local peoples and developing states. However, its costs and benefits are not possible to determine. A key issue is the lack of knowledge about the habitats, ecosystems and biodiversity of the deep sea. Given this knowledge gap, there is poor understanding of the potential impacts of DSM (2, 9, 17-19). In addition, the technology is untested and mining methods are not described — hence impacts cannot be assessed.

DSM remains financially unproven and the commercial viability of mining nodules has yet to be established (8). Past attempts to develop DSM have not delivered expected benefits due to technical problems, poor metal prices, competition from terrestrial sources and low profitability (20, 21). The Solwara 1 hydrothermal vent project in Papua New Guinea failed before becoming operational. It left the PNG government with a debt of USD 125 million — one third of the country's health budget in 2018 (3, 22). Furthermore, resource extraction such as mining and logging has a history of social unrest in the Pacific, including violent conflict and civil war (23). Experience indicates that DSM needs to be carefully considered.

If commercial scale nodule mining were to occur, the economic benefits for Pacific islands may be limited due to the economic structure of DSM activities and the technology required (24). Cost-benefit analyses by industry consultants suggest that DSM may be viable in some situations but not others (25).

A number of scientific reviews have raised concerns over critical knowledge gaps and potential impacts (e.g. 17, 18). Others have called for greater scrutiny and caution in financing DSM projects and improved accountability and management in assessing DSM exploration permits and leases (24, 26).

Pacific communities value deep sea habitats and their protection even if they are unable to directly experience them (27). Opposition to DSM has been expressed by regional non-governmental organisations, local communities and religious institutions (26, 28). After more than a decade of petitions and other representations in Papua New Guinea, an open letter from the PNG Council of Churches and civil society organisations requested that the Government cancel all seabed mining licences (29).

Pacific peoples have strong traditional ties to ocean resources that provide food security, livelihoods and social cohesion (30). These links are integral to Pacific cultures and identities and are central to policies and approaches. At the United Nations Oceans Conference in 2018, Pacific leaders reaffirmed these ties and their dependence on the ocean — and the need to commit to a strong regional approach for ocean governance, sustainable management and conservation.

This report provides a comprehensive review of available information with a focus on peer-reviewed scientific literature. It presents the current state of knowledge about the predicted and potential impacts of nodule mining in the Pacific. It also draws conclusions about the risks associated with this emerging industry.

> ***"The Ocean is our cultural identity. It is a cornerstone of our social cohesion. It is also the foundation of our economy and it is our road to prosperity. But the ocean is deeply threatened and endangered by humankind due to inconsiderate activities and behaviour. Climate change, overexploitation of natural resources, marine pollution from land and ocean based sources are putting our livelihoods on borrowed time."***

President of French Polynesia, HE Mr. Edourd Fritch, stated at the UN Ocean Conference in 2017.

1.1 Review approach

With its scope set as to examine predicted and potential impacts of deep sea nodule mining in the Pacific Ocean, this study employed a standard approach to reviewing scientific literature, focusing on peer-reviewed articles. It also explored "grey literature"- publications by organisations such as the World Bank, the Secretariat of the Pacific Community and non-governmental organisations. These were typically also peer reviewed. Sources such as public statements and media articles were used to describe context or events.

Key words were used to search for specific topics including the effects of deep seabed mining, deep sea mining technologies and methods, deep sea mining case studies, deep sea mining and carbon cycling and climate change, biodiversity, fisheries, and threatened species. The primary search was conducted using Google Scholar™, the preferred search engine for records and scholarly articles from both scientific and grey literature. Once references were collected, bibliographies of articles were examined to identify further relevant literature.

The review used 18 key words and word combinations to search for information within topics. The search terms are indicated below. The first 100 articles from each search were examined, and all relevant articles — those directly related to the subject of the search — were compiled into an Endnote™ library. These information sources were used to develop this report.

More than 250 scientific articles, reports and industry sources were examined to produce this review. Articles published in scientific journals were considered the most reliable, especially those that used data collected from deep sea experiments or surveys. Where data from the deep sea was not available, the review presents substantiated case studies to illustrate potential impacts.

A second process was used to source information describing the context of DSM in the Pacific. A general Google search was used for information about mining technology and operations, government statements or policies, commentary from civil society and accounts of specific events.

The draft report was sent to seven independent experts for peer review. The final report reflects the assessment, input and additional references provided by those experts.

SPECIFIC SEARCH TERMS USED

Deep sea mining effect
Deep sea mining methods
Deep sea mining apparatus
Deep sea mining techniques
Deep sea mining technology
DeepGreen mining process
Global Sea Mineral Resources mining process
UK Seabed Resources mining process
Patania I and Patania II
Polymetallic nodules
Clarion Clipperton zone
Deep sea mining fisheries
Deep sea mining climate change
Deep sea mining carbon cycle
Species migration through Eastern Pacific
Eastern Pacific turtle tagging and tracking
Eastern Pacific manta tagging and tracking
Eastern Pacific seabird tagging and tracking

2 | DEEP SEA MINING IN THE PACIFIC

2.1 Current interests

Interest in the potential of DSM goes back to at least 1965, with the publication of J.L. Mero's *Mineral Resources of the Sea*. This interest drove a rush of speculation, expeditions and trials from Germany, the United States, the United Kingdom, Japan and France that were largely unsuccessful.

According to Glasby, "more than USD 650 million (in 1982 dollars) had been spent on developing technologies and exploring for deep sea manganese nodules with little return … 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" (20).

Renewed interest in seabed mining has resulted in companies acquiring exploration licences and developing technologies to mine nodules especially in international waters. Mining activities encompass three types of operations (1):

- **Prospecting:** searching for deposits within a designated licence area in international waters, or within a nation's exclusive economic zone. Prospecting aims to determine the composition, size and distribution of deposits and their economic value.
- **Exploration:** searching for and measuring deposits (grade and tonnage) with exclusive rights. Exploration analyses the deposits as well as the use and testing of mining, processing and transport equipment. Social, economic, technical, environmental and commercial studies should provide information at this stage about up-scaling to commercial mining.
- **Exploitation:** commercial mining of seabed deposits would include mineral extraction as well as the construction and operation of processing and transport systems to produce and sell minerals and derived products or metals.

In the Pacific, deep sea mining activities are currently limited to prospecting and exploration. The International Seabed Authority (ISA) has granted contracts to 18 companies to explore for nodules and almost all are for the Clarion Clipperton Zone (CCZ) (Table 1, Figure 2). The contracts permit each contractor exclusive rights to explore an initial area of up to 150,000 square kilometres outside national jurisdictions.

2.1.1 International Seabed Authority

Given that many of the zones rich in seafloor minerals lie outside of national jurisdictions, coordination and management of DSM in these areas falls to a multilateral body. The International Seabed Authority (ISA) was established in 1982 under the United Nations Convention on the Law of the Sea (UNCLOS) (5). The ISA is a small autonomous UN body based in Jamaica charged with managing activities on the seabed and subsoil in areas beyond

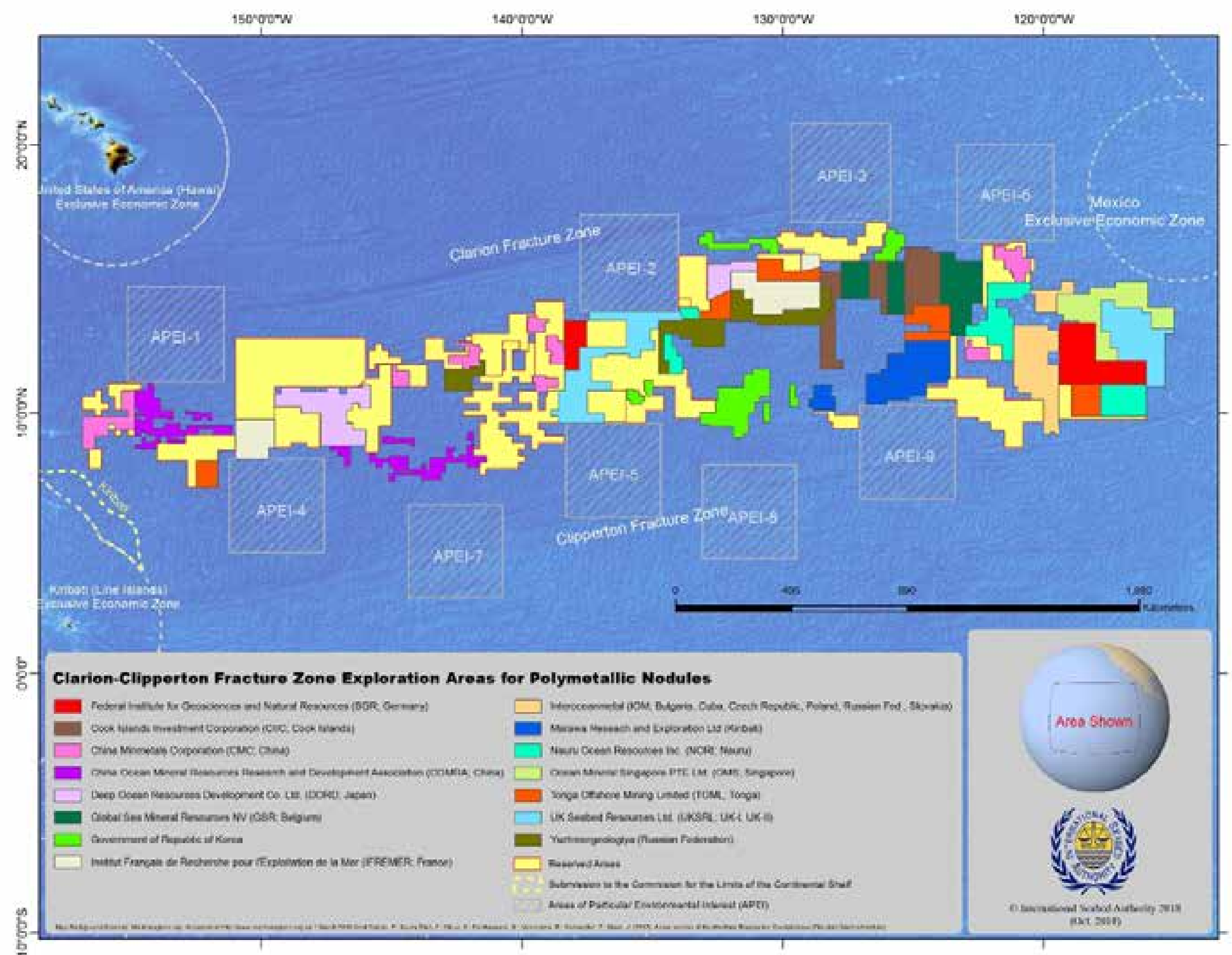


Figure 2: LICENCE AREAS GRANTED FOR EXPLORATION OF POLYMETALLIC NODULES IN THE CCZ
The areas are located between the Kiribati EEZ and the Mexican EEZ, a distance of more than 4,500 kilometres, and include nine Areas of Particular Environmental Interest
Map sourced from: https://www.isa.org.jm/maps

national jurisdiction (2). It is responsible for developing regulations for exploitation of sea floor minerals, having already completed regulations for exploration under which it has issued 29 exploration licences. Regulations for exploitation were scheduled to be finalised in 2020, and are expected to open the high seas up to a high level of DSM activity.

Concerns have been raised about the lack of transparency and lack of independent scrutiny in ISA processes, conflicts of interest between the ISA and the mining companies they are mandated to regulate, and the haste with which regulations are being developed with little consideration of the precautionary principle and the absence of wide public debate (22). There are concerns that monitoring plans have not been made publicly available or are not detailed enough to detect change (31). There is also a need to clarify the roles and responsibilities of the ISA, sponsoring states and other parties so that mining activities can be effectively supervised and compliance with regulations enforced (32).

COMPANY	START OF CONTRACT	END OF CONTRACT	SPONSORING STATE	LICENCE LOCATION
Beijing Pioneer Hi-Tech Development Corporation	October 18, 2019	October 17, 2034	China	WPO
China Minmetals Corporation	May 12, 2017	May 11, 2032	China	CCZ
Cook Islands Investment Corporation	July 15, 2016	July 14, 2031	Cook Islands	CCZ
UK Seabed Resources Ltd	March 29, 2016	March 28, 2031	United Kingdom	CCZ (II)
Ocean Mineral Singapore Pte Ltd	January 22, 2015	January 21, 2030	Singapore	CCZ
UK Seabed Resources Ltd	February 8, 2013	February 7, 2028	United Kingdom	CCZ (I)
Global Sea Mineral Resources NV (GSR)	January 14, 2013	January 13, 2028	Belgium	CCZ
Marawa Research and Exploration Ltd	January 19, 2015	January 18, 2030	Kiribati	CCZ
Tonga Offshore Mining Ltd	January 11, 2012	January 10, 2027	Tonga	CCZ
Nauru Ocean Resources Inc	July 22, 2011	July 21, 2026	Nauru	CCZ
Federal Institute Geoscience and Natural Resources of Germany	July 19, 2006	July 18, 2021	Germany	CCZ
Government of India*	March 25, 2002 March 25, 2017*	March 24, 2017 March 24, 2022*	India	Indian Ocean
Institut français de recherche pour l'exploitation de la mer*	June 20, 2001 June 20, 2016*	June 19 2016 June 19, 2021*	France	CCZ
Deep Ocean Resources Development Co. Ltd*	June 20, 2001 June 20, 2016*	June 19, 2016 June 19, 2021*	Japan	CCZ
China Ocean Mineral Resources Research and Development Association*	May 22, 2001 May 22, 2016*	May 21, 2016 May 21, 2021*	China	CCZ
Government of the Republic of Korea*	April 27, 2001 April 27, 2016*	April 26, 2016 April 26, 2021*	Republic of Korea	CCZ
JSC Yuzhmorgeologiya*	March 29, 2001 March 29, 2016*	March 28, 2016 March 28, 2021*	Russian Federation	CCZ
Interoceanmetal Joint Organization*	March 29, 2001 March 29, 2016*	March 28, 2016 March 28, 2021*	Bulgaria, Cuba, Czech Republic, Poland, Russian Federation and Slovakia	CCZ

Table 1: LIST OF ALL COMPANIES HOLDING ISA LICENCES to conduct deep sea exploration for polymetallic nodules, in order of the newest to oldest licences.

See: https://www.isa.org.jm/deep seabed-minerals-contractors

*Indicates the companies/governments that have been granted extensions.
WPO – Western Pacific Ocean. CCZ – Clarion Clipperton Zone.

2.1.2 Pacific island economies

In addition to ISA licences in areas beyond national jurisdiction, several Pacific countries have licenced exploration within their EEZs (Table 2). The Cook Islands, Kiribati, New Zealand, Palau and Tuvalu have nodules within their zones (1, 9). The Cook Islands, Kiribati and Nauru are also pursuing deep sea nodule mining in the CCZ (Table 2).

Foreign mining companies such as Nautilus Minerals and DeepGreen Metals have partnered with national governments to mine nodules. The Cook Islands and Nauru strongly support DSM with the aim of attracting investment (1). The Cook Island Government developed a regulatory framework to manage deep sea mining within its waters and established a National Seabed Minerals Authority in 2013. Prospecting and exploration regulations were passed in 2015. The drive for mining has raised concerns for Marae Moana Marine Park — which covers the entire EEZ of the Cook Islands (33) — and tourism which accounts for 70 per cent of the nation's GDP (see Section 5).

COUNTRY	EEZ MINING INTERESTS	ADDITIONAL ACTIVITIES
Cook Islands	Abundant manganese nodules with high cobalt content. A DSM exploration licence has been issued.	Strong political interest in DSM. In 2016, the Cook Islands secured an ISA contract to conduct DSM exploration in the CCZ.
Kiribati	Has the largest EEZ in the region with potential for nodule mining. No DSM licences issued.	State-owned Marawa Research and Exploration Ltd holds an ISA contract for nodule mining in the CCZ. Mining company DeepGreen Metals helped prepare and fund the application
Nauru	No data on the presence of nodules within the EEZ.	Nauru Offshore Resources Inc (NORI), a subsidiary of DeepGreen Metals, holds an ISA contract for nodule exploration in the CCZ. DeepGreen prepared and funded the application, and sits on NORI's board of directors
Palau	Nodule occurrence in the EEZ considered 'possible'. No DSM licences issued.	Palau has been a strong proponent of marine conservation with 80 percent of its EEZ zoned as a marine protected area.
Tonga	No nodules noted within the EEZ.	Tonga Offshore Mining Ltd holds an ISA contract for nodule exploration in the CCZ. The company is a subsidiary of mining company DeepGreen
Tuvalu	Prospecting has shown nodules in the EEZ, but at lower abundance and grade than elsewhere. No DSM licences issued.	Has expressed interest in sponsoring DSM activity in the CCZ.

Table 2: PACIFIC ISLAND COUNTRIES WITH INTERESTS IN DEEP SEA NODULE MINING.
Data from World Bank, 2017 (1) and Miller *et al.* (9)

2.2 Clarion Clipperton Zone

The Clarion Clipperton Zone (CCZ) is a deep sea plain in the north-eastern equatorial Pacific, roughly the size of Europe. It encompasses some six million square kilometres of seafloor at a depth of 3,000 metres or more (34). The CCZ is of particular interest for DSM exploration as it contains high concentrations of nodules scattered on the seafloor. The nodules contain commercially valuable metals such as manganese, nickel, cobalt, and copper (35).

The CCZ is also of great ecological interest. It contains a variety of deep sea environments with different sized nodules, productivity, depth gradients and topographic features such as seamounts, hills and channels (36). Research in the CCZ has begun to shed light on deep sea biodiversity (37). One study recorded 330 species in an area of 30 square kilometres, where more than two thirds of the species were previously unknown to science (37).

> **Almost all of the scientific data about the biology, ecology and biodiversity of deep seabed habitats comes from a handful of studies at small sites in the CCZ. Scientists have sampled only 0.01 per cent of the CCZ area (38). There is almost no published information about the biodiversity and ecology of nodule grounds elsewhere in the Pacific. It is clear that very little is known about deep seabed habitats with nodules.**

2.2.1 Deep sea life

Deep sea polymetallic nodules provide hard surface habitats for a wide range of species such as deep water corals, sponges, sea urchins, sea stars and jellyfish (Fig. 3). Isopods, nematodes, copepods, and polychaetes also occur in these waters (10, 34, 39-43). Megafauna include omnivorous fishes, cephalopods such as squid and octopus, deep sea shrimp, sea cucumbers, and sea stars (10).

The nodules and surrounding sediments also provide habitats for distinct microbial communities that could play a variety of roles in ecosystem processes (44, 45). The presence of both hard substrates in the form of nodules and soft substrates as sediment creates a combination of habitats that results in greater species diversity (39).

While nodules are not found on seamounts, nodule mining adjacent to seamounts could affect them if sediment plumes created by mining or waste discharge are carried by currents or upwellings onto them. The seamounts in the CCZ region may be particularly important for pelagic species and deep sea and open ocean biodiversity. Fish and marine mammals congregate around seamounts for shelter and/or to forage for food (46). Even killer whales (*Orcinus orca*) have been found to spend time over seamounts with tracking data suggesting they use these areas for hunting (47). Apart from whales, seamounts are used by a range of species including sharks (48), tunas and billfishes (49), and deepwater snappers which in some areas are important fisheries (50). Seamounts may also be used by migratory species as important navigation markers and waypoints (51).

Many of the deep sea species of the CCZ are new to science and belong to entirely new species groups (39, 52, 53). Scientific knowledge of the CCZ's biodiversity and the classification of these new species is very limited (38-40, 52). The density of fauna can be high, depending on the site, and varies according to nodule coverage as nodules themselves provide habitats for many of these species (34, 54). It is evident that these deep seabed environments are diverse ecosystems, inhabited by a wide range of species of which many are new to science.

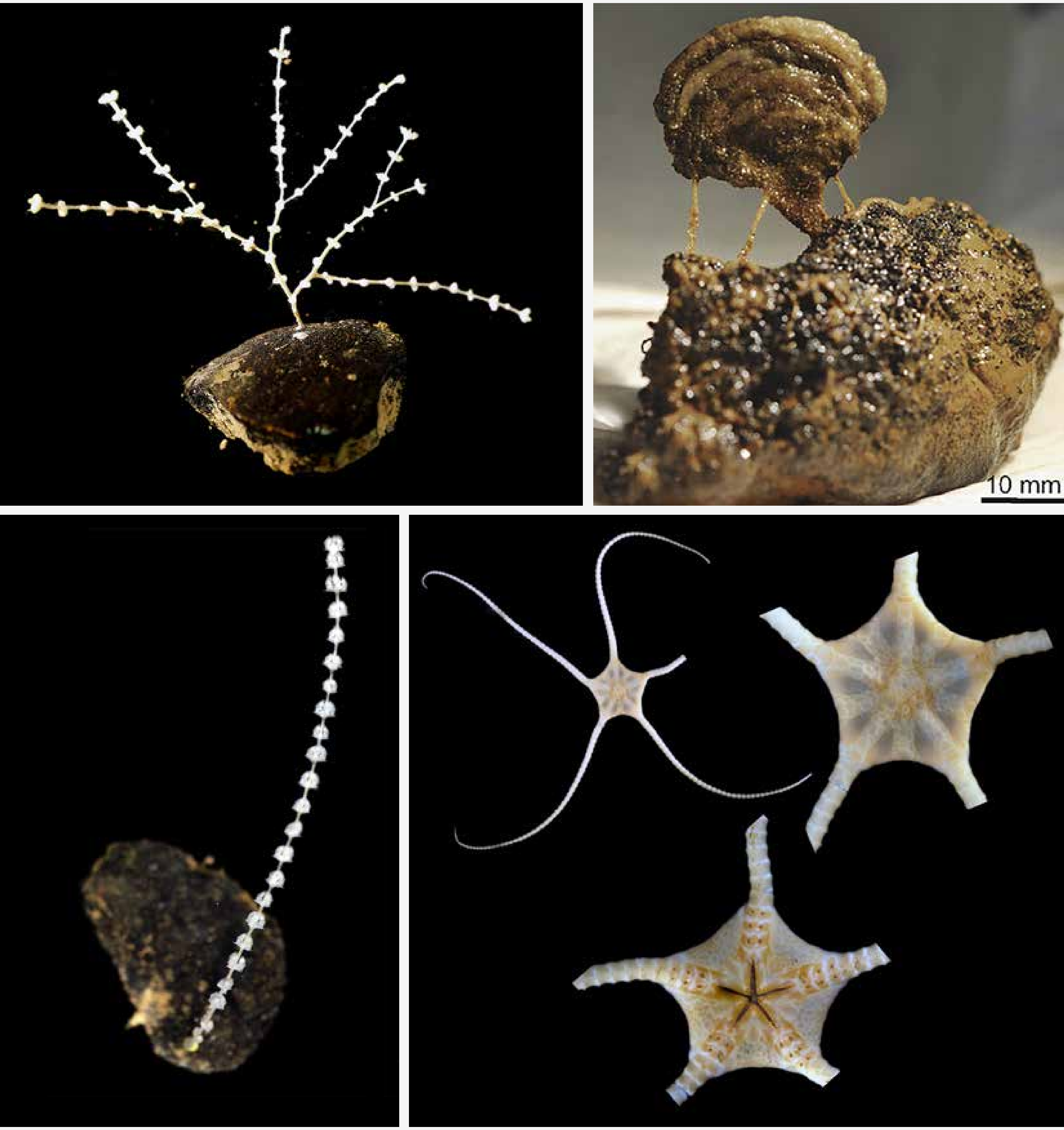
Figure 3: DOMINANT MEGAFAUNA OBSERVED IN THE EASTERN CCZ

[top] Purple sea cucumber (*Psychropotes* cf. *semperiana*); [above] deep sea cuccumber (*Amperima holothurian*); [below] unidentified fish from the family *Ophidiida*; [left] and the fish *Bathysaurus mollis* and a brittle star (*Relicanthus* sp.) seen in a manganese nodule bed in the Clarion Clipperton Zone. Images: DJ Amon & CR Smith, University of Hawai'i

Figure 3: DOMINANT MEGAFAUNA OBSERVED IN THE EASTERN CCZ

[top right] Xenophyophore plate-like morphotype 1: *Psammina* sp. *in situ* close up;
Images: DJ Amon & CR Smith, University of Hawai'i

[top left] *Abyssoprimnoa gemina*. [bottom left] *Calyptrophora persephone;* [botton right] *Ophiomusium* cf. *glabrum*.
Images: AG Glover, TD Dahlgren & H Wiklund, Natural History Museum, London



A brittle star (*Relicanthus* sp.) seen in a field of manganese nodules.
Image: DJ Amon & CR Smith, University of Hawai'i

2.2.2 Management

The ISA has held many meetings of experts to explore options for protecting the CCZ's deep sea species and habitats. These recommended protected areas in different ecological zones over an area of 1,440,000 square kilometres comprising 24 per cent of the CCZ (36). The ISA has created a Marine Protected Area (MPA) network of nine Areas of Particular Environmental Interest (APEI) which each cover about 160,000 square kilometres (55).

The design of deep sea MPA networks is still in its infancy. As stated by Wedding *et al.* (35): "The science of establishing MPA networks and minimizing human impacts is relatively new for deep sea mining." In theory, the APEI network should protect areas that support representatives of the range of deep sea species and habitats including endemic species that are found nowhere else and should be close enough to each other to allow larvae to flow between these refuges (enabling connectivity) (61). However, due to limited biological sampling and understanding(34, 39, 55), there is insufficient information to know whether the nine areas are representative or if they are well enough connected to ensure recolonisation and recovery of areas impacted by DSM (34, 39, 55).

Furthermore, the configuration of the nine areas is compromised as they were placed at the CCZ margins to accommodate existing exploration licences (see Figure 2). This has prompted calls for the ISA to suspend approval of further licences until networks are properly designed and implemented (35). This would also prevent "land grabs" via exploration licences that provide companies with exclusive rights to seabed areas (56).

Mining licences issued in the future are expected to contain Preservation Reference Zones (57). These no-impact zones are likely to be limited and there are no criteria for identifying and establishing them (58). Their effectiveness as a conservation measure is questionable.

It is uncertain whether Areas of Particular Environment Interest and Preservation Reference Zones will provide adequate protection for deep sea ecosystems and biodiversity. Neither have they been designed to protect mobile species that move across these areas or to address the impacts of plumes generated by DSM-related discharges higher in the water column or at the surface.

3 | MINING PROCESSES

The exploration and mining of polymetallic nodules is technically challenging due to depths (3 to 6 kilometres underwater), distances from shore of more than 1,000 kilometres, high pressure at sea floor (300-600 bars) and low temperatures of 0-10o C. (59, 60). Mining companies are trying to develop methods and machinery that will overcome these significant obstacles.

Mining is envisaged to involve remotely operated vehicles (ROVs) such as skimmers, crawlers or collectors (19). These would collect nodules from the seafloor and transfer them into a vertical riser pipe that pumps them to a support vessel on the surface (9, 61).

According to one engineering report on nodule mining, "This particular case, being a completely new concept, has no proven designs available as a benchmark and hence, requires intense brainstorming and investments to tackle the problem …" (61).

Many different designs have been conceptualised (see 61). With the exception of Global Sea Mineral Resources NV (GSR) of Belgium, there is almost no information about the technologies companies intend to use. No information could be found on how mining operations plan to discharge waste.

The limited information companies have disclosed is summarised below using three of the most active companies as examples.

3.1 DeepGreen Metals

DeepGreen Metals Inc is a private company based in Vancouver, Canada. In 2011, the ISA granted its wholly owned subsidiary Nauru Ocean Resources Inc (NORI) a 15-year licence to explore 74,830 square kilometres of the CCZ for nodules with nickel, manganese, cobalt and a copper content grade of 7 per cent (Table 1) (13, 62, 63). DeepGreen has partnered with Danish marine services company Maersk Supply Service A/S which provides two vessels, management of the project and engineering services (64).

DeepGreen says its approach to deep sea nodule mining is environmentally friendly and would not create any waste or tailings. "I think zero tailings is a phenomenal objective for a mining company to have," a senior executive said (13). The company, through NORI, says this is possible due to the nodules location on top of the seafloor (13, 62). The proposed mining methods and status of equipment and technology development are unclear.

3.2 Global Sea Mineral Resources

Global Sea Mineral Resources NV (GSR) is a subsidiary of Belgium's Dredging, Environment and Marine Engineering NV (DEME) (37, 65). In 2013, ISA granted GSR a 15-year licence to explore for nodules over 76,728 square kilometres of the eastern part of the CCZ (40, 66).

GSR has been testing a tracked ROV called Patania which undertook successful trials in 2017 (Fig. 4) (60, 66, 67). The company has also developed a 25-tonne pre-prototype Patania II (Fig. 4) (60, 68, 69). The Patania II incorporates the track design of Patania but also includes four vacuums to collect nodules (66).

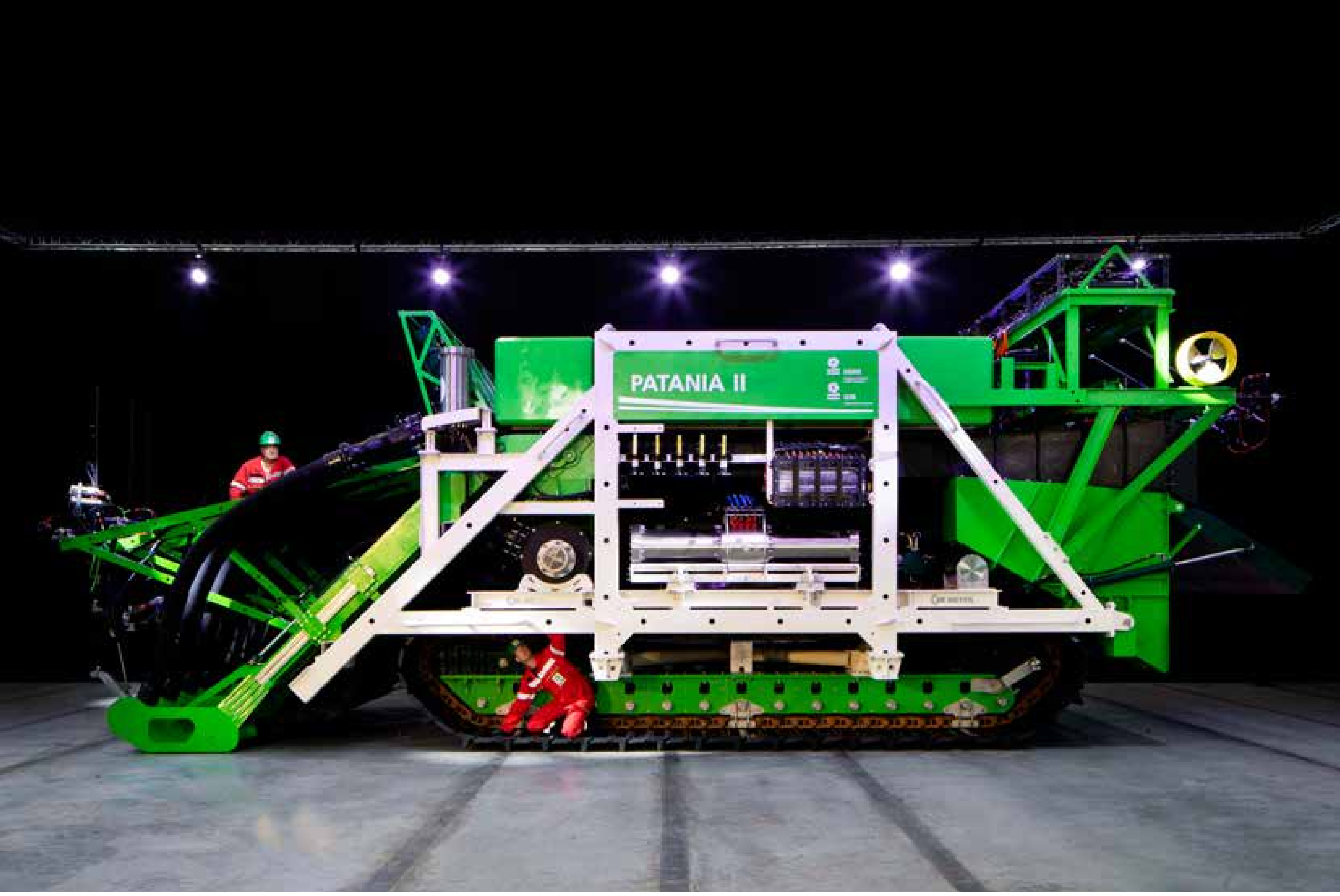


Figure 4 The Patania II which GSR is testing to collect nodules from the seabed in the CCZ
Image: DEME Group: https://www2.deme-group.com/

Patania II uses an active pick-up system that includes four major subsystems: a nodule-collection system comprising a collector head, jet water pumps and all sensors to monitor suction; a two-track propulsion system; a nodule-separation and discharge system; and vehicle systems (60). By the time it becomes operational, GSR will have invested an estimated USD 100 million in the project (67).

GSR has been testing the performance and impacts of Patania II (37, 66). In 2019, the vehicle attempted to collect nodules over an area 300 metres by 300 metres, 4 kilometres below the surface while remaining connected to the surface support vessel (37, 65). The 5-kilometre umbilical cable — which allows Patania II to be controlled and communicate with the surface vessel — broke during the test (67, 69). Further testing was postponed until 2020 (67, 69).

The company says its trials of Patania II will include research to record the vehicle's environmental impacts, specifically the range and coverage of resulting sediment plumes (37). As Patania II will not be connected to a riser pipe and there will be no discharge of mining waste, the data collected will only describe the impacts of one part of the mining process. Given the lack of knowledge about deep sea biodiversity and ecology, the data may be difficult to interpret (37).

GSR has been commended for making at least some limited information available about the proposed mining process, and for attempting to monitor the environmental impact of the trials with collaborating scientists (37). A GSR patent for another nodule-collecting vehicle is available (70) but it bears little resemblance to either of the Patania vehicles.

3.3 UK Seabed Resources

UK Seabed Resources Ltd is a wholly owned subsidiary of Lockheed Martin UK, the British arm of Lockheed Martin Corporation of the United States. Lockheed Martin UK has partnered with the UK Department for Business, Energy and Industrial Strategy. As the United States has not ratified UNCLOS, Lockheed Martin's involvement in the CCZ is through its partnership with the United Kingdom which is a signatory state.

The ISA has issued two 15-year licences to UK Seabed Resources to explore for nodules in two areas of the CCZ (Table 1) (2, 71-73). The first licence (UK I in 2013) encompasses 58,640 square kilometres while the second (UK II in 2016) covers 74,919 square kilometres (72).

The company has not tested ROVs or investigated potential environmental impacts within the two exploration areas. It proposes to test a collector prototype in 2022 (72). No images or further details of the company's deep sea mining equipment could be found.

POLYMETALLIC NODULE WITH SHARK TOOTH FROM 5000M DEPTH OF PACIFIC. PHOTO: VELIZAR GORDEEV

4 | IMPACTS

4.1 Overview

If it proceeds, deep sea nodule mining in the Pacific would disrupt species habitats and environments previously exposed to very little physical disturbance. A wide range of direct and indirect impacts may arise including the destruction of habitats and the animals living in them and the smothering of surrounding habitats and species by sediment plumes as well as and noise and light pollution (9).

Scientists have expressed concerns about DSM. Central to these is the lack of knowledge about the biology, ecology and diversity of species of the deep underwater (abyssal) plains where nodules occur and how mining might affect them (9, 39, 74). The ecosystems targeted for deep sea mining are highly susceptible to long-term damage as they are structured ecosystems dominated by diverse, rare and unique species, which will likely take a very long time to recover from disturbance (9, 74, 75).

Studies such as DISCOL and MIDAS[2] suggest that physical modification and effects of deep seabed mining on the seafloor will persist at least for decades (2, 9). Furthermore, the geographic scale of the impact of nodule mining is likely to be vast. Projections suggest that each individual mining operation may disturb between 300 and 800 square kilometres per year, with impacts spreading over an area two to five times larger due to deposition of suspended sediments (19).

4.2 Ecosystems and biodiversity

The impacts of nodule mining on seabed species and habitats are likely to derive from physical disturbance of the seabed including the removal of nodules which in themselves are habitats; the effects of sediment plumes created by seabed vehicles and waste discharges; and other sources of pollution including noise, light and the release of toxic materials from leakages and breakages of riser pipes, and from the seabed vehicles.

4.2.1 Physical disturbances

The mining of nodules would remove critical substrate for species such as deepwater corals and sponges attached to them. As nodules take millions of years to form (6), the removal of these habitats would effectively be permanent (58). It is unknown whether species associated with nodules would recover once nodules are removed (9). Given that many species associated with nodules, such as deepwater corals, are "virtually absent" from nodule-free areas, severe and long-term depletions of these species are likely (58).

Vanreusel *et al.* (58) note that the removal of nodules "will definitely lead to significant biodiversity loss, some of which may never recover considering that nodules only grow a few millimetre per million years, and that some taxa such as alcyonacean and antipatharian corals in this area occur exclusively on hard surfaces."

Impacts are unlikely to be limited to species permanently attached to nodules

2. DISCOL (disturbance and recolonization experiment) and MIDAS (managing impacts of deep sea resource exploitation) are two major scientific efforts to better understand how seabed mining might affect deep sea species and habitats.

such as sponges and corals. These species provide habitats for mobile organisms which, in turn, are food sources for other species. Deep sea octopuses attach themselves to dead sponges where they brood their eggs, and appear to forage around the nodules (76). The long brooding period, low fecundity, and naturally low mortality rate of octopus suggest they are adapted to stable environmental conditions and will be highly susceptible to disturbance (76). The removal and disturbance of nodules is also likely to reduce microbial diversity and to affect the ecosystem functions performed by microbes in deep sea environments (45).

The physical disturbance caused by seabed mining machinery is expected to be long lasting. Estimates are limited by the time frame and monitoring program of experiments. Tracks made during a mining experiment in the CCZ by the Ocean Minerals Company (OMCO) consortium in 1978 were clearly visible 26 years later, and there was reduced diversity and biomass of nematode worms in disturbed areas (77). Recovery is likely to be reduced by the slow growth and long lifespan of some deep sea species. For example, some Canadian sponge reefs are more than 9,000 years old, with individual sponges growing to more than 100 years (78). In the East China Sea, an individual deep sea sponge has been found with a lifespan of 11,000 years (79).

These findings are corroborated by the DISCOL experiments which showed that deep sea ecosystems remained severely depleted when monitored 36 years after initial disturbance. Anchored species and those that feed by filtering out particles from seawater were particularly affected and the densities of mobile species were reduced by half (see case study: DISCOL). Physical disturbance also had long-term effects on biological processes, with carbon-cycling and respiration rates remaining significantly reduced after 26 years (80). Similar experiments in the Indian Ocean documented significant changes in macro-fauna biomass and composition after disturbance (81). While some species recovered after 44 months, other taxa such as polychaetes and crustaceans did not (82). Overall, experiments show that species composition remains altered after decades, and the loss of hard substrate such as nodules and changes to sediment structure may mean that changes will last over hundreds of thousands to millions of years (58, 83, 84).

ROVs are expected to compact and deform seabed sediments to depths of 0.5 metres (85) with a "lethal effect on most species" (86) and to cause changes to geochemistry, for example, by introducing oxygen into subsurface low-oxygen sediment layers (85, 87).

Van Dover *et al.* (18) conclude that it is not possible that deep sea mining will not result in a net loss of biodiversity.

4.2.2 Sediment plumes

Sediment plumes are clouds of sediment particles spread in water by prevailing currents. Deep sea nodule mining is expected to generate sediment plumes via ROV movement and mining activity, leakage from riser pipes, accidental spillage and disposal of waste water (9, 83, 86). As a result of the plumes, impacts of nodule mining would be felt far beyond the actual mine site and could affect "down current" benthic and pelagic ecosystems (34).

The sediments of deep ocean abyssal plains contain very fine particles which resettle slowly (92). The distance a sediment plume will travel depends on sediment

DSM SITE REMEDIATION AND BIODIVERSITY OFFSETS

Remediation of the physical impacts of nodule mining and subsequent biodiversity loss is generally viewed as unrealistic (18). Remediation costs are projected to be prohibitively expensive — 100 to 1,000 times higher than the costs of remediating mine sites on land (88). Furthermore, as the science of remediation in the deep sea is in its infancy, its technical feasibility and likelihood of success are unknown. (18). A cost-benefit study of deep sea mining noted that it was "not technically feasible" to replace the services provided by the deep sea ecosystems (25). According to Van Dover *et al.*, (18) "mining with no net loss of biodiversity … in the deep sea is an unobtainable goal."

"Offsets" are a tool sometimes used to compensate for habitat destruction by developments on land, whereby alternative areas are protected or restored. The goal is to achieve no net loss of biodiversity. For DSM however, this is viewed as an "impossible aim" due to the vulnerability and uniqueness of deep sea ecosystems, limited technological capacity to minimise damage, and significant lack of information about the ecology and resilience of deep sea species and habitats (75).

FIGURE 5: a 26-year-old test-mining track illustrates how slowly abyssal ecosystems of the deep seabed recover from physical disturbance. Image: sampling the DISCOL plow tracks. Image: Geomar, ROV Kiel 6000

CASE STUDY: Scientific tests of deep sea nodule mining impacts (DISCOL)

The biggest ecological impact trial on the effects of deep sea mining ran from 1988 to 1997. Called DISCOL (for DISturbance and recCOLonization), it took place within an 11 square kilometre plot in the Peru Basin of the Pacific Ocean. An eight metre wide plough-harrow raked the sediment without removing anything from the seabed (68). The resulting sediment plume damaged seafloor biota by smothering. The extraction of nodules would have evidently damaged the area further (68).

Surveys three and seven years after the disturbance showed that the abundance of mobile macro-fauna returned to levels comparable to adjacent areas. However, this may have occurred from migration of adults and juveniles from adjacent areas, which would not be possible if these were also disturbed as expected with commercial-scale mining (89, 90).

The DISCOL study site has been revisited by scientists four times, most recently in 2015. This survey found that species abundances and distributions for some species were still changed 26 years after the initial impact (91), and the area that was ploughed 30 years earlier showed little recovery (Fig. 5) (2, 37, 68).

Scientists have noted that this was an experimental track. Impacts from commercial-scale mining would be so much greater as to be "incalculable" (89-91). It has been noted that "the vast spatial scales planned for nodule mining dwarf other potential impacts" (19).

> **"Still, the heavy machinery, crisscrossing its areas in grids directed from robotic submersibles, would compact the seafloor and likely kill much that is under its treads. German researchers dragged a sled over the seabed 3 miles down nearly 30 years ago, and when rechecked in 2015, the tracks looked perfectly fresh"** (2)

grain size, shape, density and concentration; the biological and chemical reactions that clump sediment particles together; and oceanographic factors such as water density stratification, temperature, and currents (93-95).

The impacts of a plume will depend on its composition — particularly the metals it carries — as well as how long they last, the deposition rate, what species occur in the deposition zone, and the biochemical or toxicological properties of the particles.

These factors would vary between nodule fields and would need to be defined for each mine site to predict how far a sediment plume might spread and what its impacts would be. While the movement of plumes created by small-scale experimental disturbances have been studied, there are no data available on plumes expected to be generated by operational remotely operated vehicles in deep sea mining.

Estimates of sediment plume size and dispersion are based on a small number of disturbance experiments and computer models, but predictions vary widely. Due to their different underlying assumptions, it is difficult to compare the modelling studies. Nor is it possible to determine the implications of their findings for deep sea species and habitats. Perhaps the only prediction that can be made with certainty is that the suspension and deposition of sediments by nodule mining would significantly impact seabed fauna. DSM would be occurring in habitats that are normally very stable and where species are not adapted to high levels of sedimentation (40).

Remotely operated vehicles

The characteristics and impacts of plumes created by deep sea ROVs will depend on the design and operation of the machines. It is not clear exactly what machinery would be used but computer models suggest that 16 to 20 per cent of the sediment disturbed by the vehicles might become suspended with the rest displaced or remoulded into "patchy" lumps on the seabed (86, 93). Coarser sediments might clump together and fall relatively close to mining vehicles (92). Another study suggested that an eight metre vehicle moving on the seabed could create a 56 metre plume (86). One paper suggested that fine-grain sediments could disperse up to tens of thousands of kilometres before resettling (38).

Mine waste

The ISA has stated that a 20-year mining operation would impact an area of 8,500 square kilometres (96) but there is no publicly available research indicating how much sediment would be suspended during mining or how mine waste would be treated and released. One study estimated that a mining operation could discharge up to 50,000 tonnes[2] of sediment laden-water per day (17).

It is not clear how much sediment would be disturbed and eventually transported, processed and discarded during mining. This review was unable to locate any studies on the range and effects of plumes generated by the dispersal of DSM waste.

Examples of waste discharged from land-based mines into marine environments may be instructive. Research has shown that tailings from the Kisault molybdenum mine in Canada travelled more than 5 kilometres in the marine environment from the pipe discharge (74). Tailing plumes from deep sea discharge pipes from the Lihir gold mine in Papua New Guinea (PNG) have been found to travel more than 20 kilometres from the outfall while tailings from the Misima gold mine in PNG covered an area of up to 20 square kilometres (74).

Deep sea tailings disposal from land-based mines has been shown to change seabed ecology. Waste from the Lihir mine "substantially reduced" seabed life across the sampled depth range from 800 metres to 2,020 metres (97).

The composition of sediment from nodule mining would be likely to differ from that from land-based mines. Depth of discharge, rate and oceanographic characteristics are additional factors that would require site-specific studies for each mine. This is a critical knowledge gap that must be addressed to determine the level of impact — and whether management tools such as Areas of Particular Environmental Interest are effective (98).

It is known that natural disturbance and sedimentation rates in deep sea abyssal plains are very low. Sediment accumulation in the CCZ is estimated to be between 0.20 centimetre and 1.15 centimetre every 1,000 years (99). An ROV mining within 12 square kilometres for one year would cause sediment accumulation of up to 1 centimetre within 1 to 2 kilometres and more than 0.1 centimetre up to 10 kilometres away (94). This equates to sedimentation of up to 500 times the natural rate in areas 10 kilometres from the mining site. The impacts of a "relatively small scale disturbance" on the seabed were still detectable 40 years after the initial disturbance (94). Given the scale at which commercial nodule mining would occur, it is likely that these effects would be magnified many times.

4.2.3 Smothering, metal toxicity and nutrient loads

Smothering and clogging

Plumes generated by nodule mining would be expected to smother and bury seabed fauna and "clog up" filter feeders. In particular, micro-organisms can be expected to be significantly affected by sedimentation as they are very small and easily buried (45). For deep sea species that depend on bioluminescence, increased turbidity may interfere with functions such as catching prey, defence against predators and communication with others of the same species. Experimental evidence from the MIDAS study shows that sediment disturbance reduces food availability for some deep sea animals, and may cause declines in microbial abundance and affect biological processes such as nitrogen cycling (94).

Studies from ocean outfalls of land-based mines indicate that species survival is extremely variable. Some species, especially mobile species, may be able to tolerate up to 10 centimetres of sedimentation while others are unable to cope with as little as 3-5 mm of deposition (74). Fukushima *et al.* (100) found that the abundance of sediment feeders, such as sea cucumbers, was significantly reduced by sediment-deposition experiments at a depth of 5,300 metres, while numbers of sponges and brittle stars were unaffected.

Research is yet to be conducted on the survival and recovery rates of deep sea species with regard to levels of sedimentation expected from nodule mining.

Metal toxicity

Nodule mining may expose deep sea and other marine species to metal toxicity (74). DSM could break open nodules and release toxic concentrations of metals into the surrounding water (101). These metals could have lethal and sub-lethal effects including bioaccumulation. While the toxicity of metals on some marine species has been studied at surface conditions, the high pressures and low temperatures of deep sea environments could increase the toxicity of certain metals such as copper but not others such as cadmium (101, 102). This complexity means that the ecotoxicology of nodule mining is unknown.

Furthermore, very little is known about the physiology of deep sea species. Some researchers conclude that it is not possible to predict toxicity levels and thresholds resulting from deep sea mining, and that these impacts need to be considered on a case-by-case basis (94, 101).

Metal toxicity could also affect surface-dwelling or mid-water species if mine waste were released at these depths, or transported to shallow waters through upwelling. Metals can be toxic to phytoplankton and zooplankton and can be accumulated through the food chain (101, 103). There are no studies on the bioaccumulation of metals and eco-toxicity from deep sea mining for surface marine food webs. However, given that plankton bioaccumulate metals and that plankton are the base of pelagic food webs, it is highly plausible that metal contaminants entering shallow waters would be rapidly taken up and passed along marine food chains. If contaminated food chains include commercially fished species, human consumers would be at risk of metal toxicity.

Nutrient loads

Sediment plumes could rapidly release nutrients into nutrient-poor waters. The upper water layers of the open ocean are typically clear, with very low concentrations of nutrients and trace metals such as iron, zinc and cadmium. This limits phytoplankton growth. Sediment brought from the seabed and released at surface could alter this balance.

It could also impact plankton in the water column by increasing turbidity and reducing light and thus photosynthesis. Nutrient increases could also cause blooms of phytoplankton and cyanobacteria (104). The lack of information about how DSM would affect pelagic food webs is a critical knowledge gap that requires urgent attention. The effects of nutrient loading on deep sea species and habitats are likewise unknown.

4.3 Non-seabed marine species

Companies have not disclosed how nodule mining waste would be managed. If it were to be discharged or accidentally spilled in surface or mid waters, plumes would increase turbidity, reduce photosynthesis and affect marine food webs. Waste discharges may also introduce inorganic nutrients that could trigger blooms of plankton or blue-green algae, and introduce toxic metals into pelagic food chains (see Section 4.2.3). These factors may affect a wide range of species associated with various depths of the water column.

Deep sea nodule mining may also impact ocean ecosystems and species in shallower pelagic waters through the activities of surface support ships and infrastructure.

Many marine species make long-distance migrations across the Pacific including through the CCZ. Migrations are crucial to complete biological processes that sustain these species and their populations such as foraging and reproduction (105). Disrupting these migrations could impact populations and create, for some species, significant conservation concerns.

Apart from fisheries (see Section 4.4), this review was unable to identify information assessing the risks posed by nodule mining to open-ocean species. Thus, we present below examples of open ocean species, some of which also dive to depth, and the ways in which deep sea nodule mining may affect them. In the absence of research

A WHALE SHARK (*RINCHODON TYPUS*) FEEDING — LISTED AS "ENDANGERED" ON THE IUCN RED LIST, INDICATING A VERY HIGH RISK OF EXTINCTION IN THE WILD IN THE NEAR FUTURE, WHALE SHARKS COULD BE IMPACTED BY DEEP SEA MINING.

data, these projected impacts should not be discounted and may be extrapolated to indicate potential impacts on other open water species.

4.3.1 Whale sharks

Whale sharks (*Rinchodon typus*) are a globally threatened iconic fish species with considerable value for ecotourism (106). Whale sharks migrate through the CCZ. In 2011, a tagged individual showed a migration that started in Panama and primarily moved west through the CCZ (107). Another whale shark tagged and tracked in 1995 followed a similar route (Figure 6).

The whale shark is listed as "endangered" on the IUCN Red List, indicating a very high risk of extinction in the wild in the near future. The species could be affected by discharge of waste from nodule mining at shallow to mid depths. Such discharges could alter planktonic communities which whale sharks feed upon, affecting them in unpredictable ways. For example, small-scale feeding of whale sharks for tourists in the Philippines resulted in changes in the movement and migration patterns of some individuals which became residents at feeding sites (106).

Any toxic metals in mine waste that can bioaccumulate in long-lived species such as whale sharks would have a range of sub-lethal effects such as impaired reproduction, health and fitness. Blue sharks (*Prionace glauca*) in the open ocean have been shown to accumulate pollutants to levels that render them unsafe to eat, with evidence of damage to shark DNA and enzyme function (108). Given that whale sharks live longer than blue sharks and have been shown to remain at sites where food is plentiful, there is potential for mining discharge to lead to bioaccumulation and sub-lethal impacts on this species.

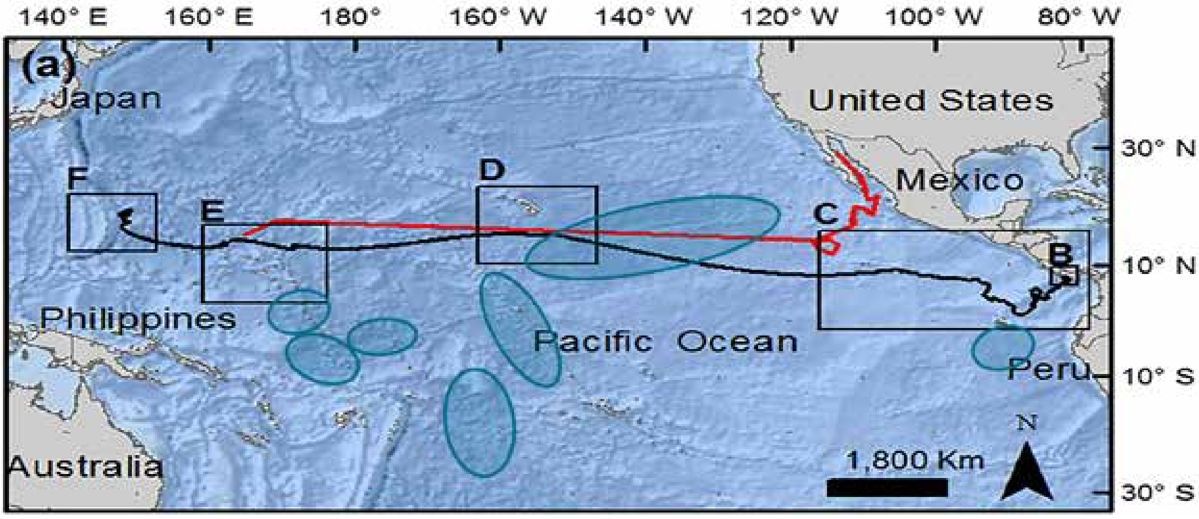


Figure 6: MIGRATIONS OF WHALE SHARKS ACROSS THE PACIFIC.
Lines show migrations in 2011 and tracked from Panama to the Mariana Islands (black route) and another whale shark tagged in 1995 which migrated from Mexico to the Marshall Islands (red route) Guzman *et al.* 2018 (3). Blue ovals indicate location of nodule fields.

4.3.2 Leatherback turtles

Tracking studies have shown that leatherback turtles (*Dermochelys coriacea*) transit through the CCZ on long-distance migrations with seasonal foraging (December to February) within the zone (109, Fig. 7). Like whale sharks, they could also be affected by nutrient enrichment and metal toxicity caused by waste discharge in shallow waters.

Increased nutrient enrichment and turbidity can cause jellyfish blooms (110). Given that leatherback turtles are specialist jellyfish predators (111), it is conceivable that turtle migration behaviour could be affected by creating artificial concentrations of food.

The turtles dive to depths of more than 1,000 metres and could encounter plumes at these depths. As long-lived species, the turtles could also bioaccumulate metals released by seabed mining and potentially be subject to bio-toxicity. The turtle is listed as "vulnerable" on the IUCN Red List, indicating a high risk of extinction in the wild in the medium-term future. The potential for mining to affect migration and fitness should be seriously considered.

4.3.3 Deep diving whales

Whales such as the sperm whale (*Physeter macrocephalus*) and Cuvier's beaked whale (*Ziphius cavirostris*) can dive to extreme depths. The sperm whale, listed as "vulnerable" on the IUCN Red List, occurs throughout the Pacific and has been repeatedly recorded as diving to depths of 1,860 metres to forage (112, 113). Cuvier's beaked whale, listed by IUCN as a species for which data is deficient, has been recorded at 2,992 metres and can remain at depth for extended periods (114). It is possible that the beaked whale may dive even deeper but this has not been recorded due to technical limitations of satellite tags (115). There is some evidence that this species could dive to depths of more than 4,000 metres. Scientists have suggested that scour marks found on the deep seabed in the CCZ may have been caused by beaked whales some 22,000 years ago (116). The species appears to have anatomical adaptations to withstand dives of up to 5,000 metres (117) which suggests that it could reach areas directly impacted by deep sea mining.

SPERM WHALE POD UNDERWATER — LISTED AS "VULNERABLE" ON THE IUCN RED LIST, SPERM WHALES OCCUR THROUGHOUT THE PACIFIC AND HAVE BEEN REPEATEDLY RECORDED AS DIVING TO DEPTHS OF 1,860 METRES. IMAGE: DMITRY KOKH

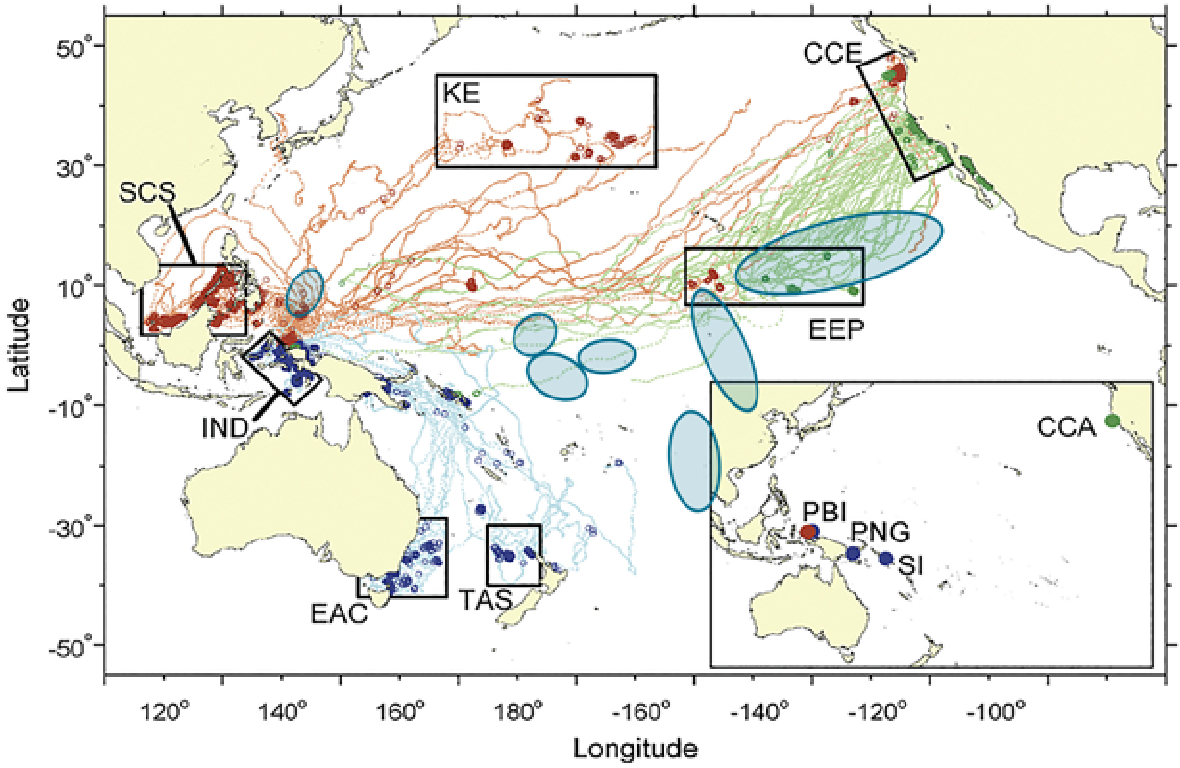


Figure 7: THE MIGRATION MOVEMENT OF LEATHERBACK TURTLES (*Dermochelys coriacea*) including traverses across the CCZ from Benson *et al.* (5). Colour of track indicates deployment season: red = summer nesters, blue = winter nesters, green = deployments at Central California foraging grounds. Inset shows deployment locations: PBI = West Papua, Indonesia, PNG = Papua New Guinea, SI = Solomon Islands, CCA = Central California, SCS = South China Sea. Black boxes represent eco-regions for which habitat associations were quantitatively examined: Sulu and Sulawesi Seas, IND = Indonesian Seas, EAC = East Australia Current Extension, TAS = Tasman Front, KE = Kuroshio Extension, EEP = Equatorial Eastern Pacific and CCE = California Current Ecosystem. Blue ovals indicate general areas of nodule mining interest.

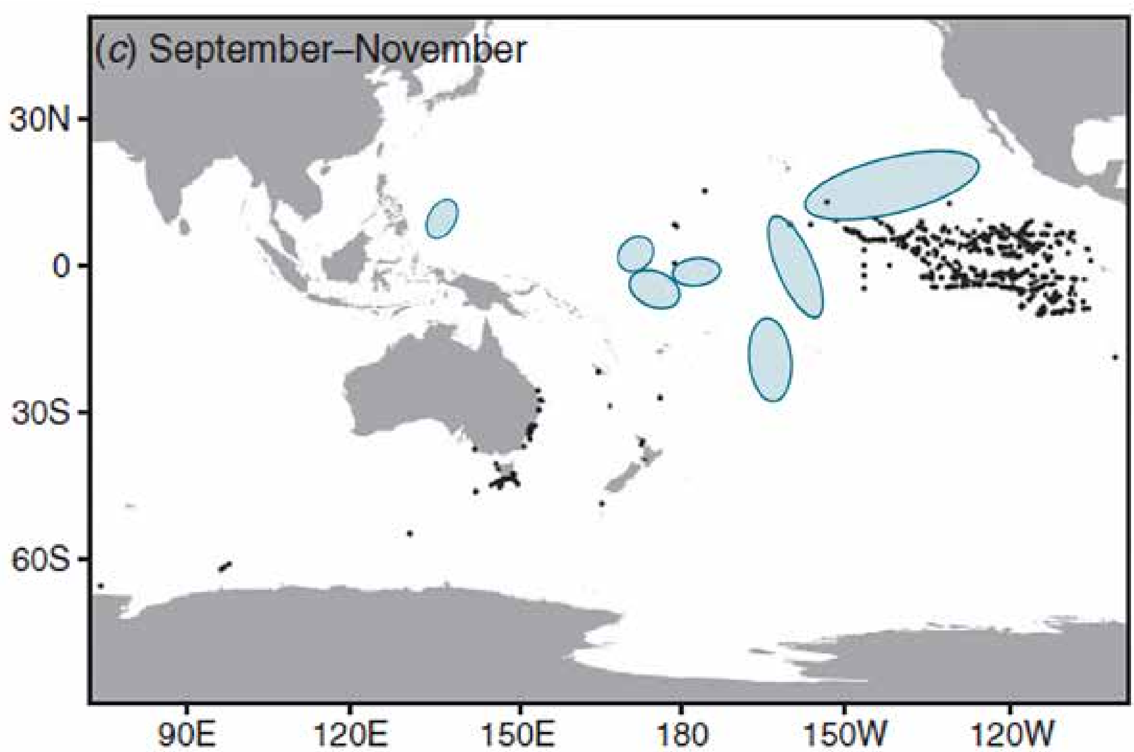


Figure 8: A MAP OF TRACKING DATA FROM GOULD'S PETREL (*Pterodroma leucoptera*) between September and November, Priddel *et al.* (7). Blue ovals indicate location of nodule fields.

GOULD'S PETREL. IMAGE: LUKE SEITZ

If nodule mining proceeds, deep-diving whales could encounter sediment plumes generated in deep or shallower waters. As described in Section 4.2, nodule mining would alter the composition of deep sea ecological communities and may impact the abundance of food sources, affecting deep-diving whales in ways that cannot be predicted. The whales could also bioaccumulate toxic concentrations of metals. In the absence of research data, such impacts cannot be discounted and should be explicitly considered in risk assessments.

4.3.4 Seabirds

Seabird stranding and mortality could result from disruptions to migration patterns due to changes in the movement and populations of fish prey (118). These changes could arise from the enrichment of surface waters driving plankton blooms — if surface waste discharge methods are used or if accidental spills occur. In addition, lighting associated with DSM infrastructure and the underwater infrastructure itself could cause fish aggregations that alter migration patterns. Like whale sharks and turtles, seabirds could also bioaccumulate toxic metals.

Many different species of seabirds migrate through the Pacific Ocean such as Gould's petrel (*Pterodroma leucoptera*), which has been tracked using the waters of the CCZ (119, Fig. 8). The petrel is listed as "vulnerable" by the IUCN Red List. The sooty shearwater (*Ardenna grisea*) migrates annually through the CCZ between New Zealand and the coasts of California and Alaska (105). This species is assessed as "near threatened" on the IUCN Red List. With many populations declining worldwide, the impacts of deep sea mining on seabirds must be considered in risk assessments and environmental impact assessments.

4.4 Fisheries

The Pacific supports large-scale commercial fisheries and smaller scale artisanal, subsistence and recreational fisheries. These fisheries are extremely important to local economies. The region supplies more than half the world's tuna (120) and plays a significant role in global seafood trade. For Pacific economies, the fees and revenue generated by foreign and domestic pelagic fisheries provide a vital source of wealth and investment (121). Tuna also contributes to the economies of Southeast Asian countries such as Thailand where canning Pacific tuna is a major economic activity (122). In addition, tuna fisheries contribute significantly to more developed economies in the Asia-Pacific region such as Chinese Taipei, Japan and Republic of Korea (123).

Pacific tuna is mainly caught by large industrial fishing nets known as purse seines — which mostly target skipjack tuna (*Katsuwonis pelamis*) — and long-line vessels that target yellowfin tuna (*Thunnus albacares*), albacore tuna (*Thunnus alalunga*) and bigeye tuna (*Thunnus obesus*). In 2018, the value of these fisheries exceeded more than USD 6 billion (124). Tuna fisheries also generate fees and employment for Pacific economies. In 2017, USD 500 million in licence and access fees were generated, providing more than 20,000 jobs (121).

In addition small-scale subsistence and artisanal fisheries are widespread in coastal waters and vital to the food security of Pacific islanders (120). These fisheries also provide important income for coastal and island communities to support basic household needs, health care and school fees. It is accepted wisdom in the Pacific region that tuna fisheries represent wealth, while coastal and reef fisheries represent food (e.g. 125).

Pacific fisheries also include deepwater fisheries targeting snappers and groupers around seamounts at depths to 250 metres and deepwater trawl fisheries (50). Seamounts appear to be important fish habitats with data showing a clear "seamount effect" with more species being caught closer to seamounts (49, 126).

The potential impacts of nodule mining on fisheries can be divided into surface impacts, mid-water impacts and seafloor impacts (24, 126):

Surface: disturbance and impacts from physical presence of semi-permanent ships and support platforms. Impacts may arise from surface discharges, and noise and light pollution. Structures may also affect fish migrations and distribution by acting as fish-aggregating devices.

Mid-water: disturbance caused by riser pipes, discharges, processing of water and waste, and vertical movement of ROVs and other equipment.

Seafloor: physical disturbance and habitat disruption by ROVs and mining equipment that generates sediment plumes, disturbance from noise and light pollution in dark environments, the generation and spread of sediment plumes, and deposition of sediments from production and tailing disposal.

DSM generated sediment plumes may have a myriad of effects. Tuna have been shown to avoid turbid water so persistent plumes could alter movement patterns (74). Fish abundances have declined near deep sea tailings outfalls from the Lihir gold mine in Papua New Guinea (127). If mine waste is discharged at the surface, plumes might reduce primary productivity by blocking light, and could also affect the behaviour of surface and diving mammals and birds (126).

As sediments or tailings sink through the water column, they may be consumed by organisms that accumulate toxic metals and chemicals from metal processing (104, 127). These pollutants might also be taken up by the pelagic organisims in the "scattering layer" — a dense layer of large numbers of fishes, crustaceans and squids that make vertical migrations between deep waters more than 1,000 metres deep to the surface every day and night (128, 129).

At the scattering layer mine waste could cause blooms of cyanobacteria (104) or chemical reactions leading to oxygen depletion, and create visible plumes through the mid water layers.

Bigeye and yellowfin tuna can dive to depths of more than 1,000 metres (130, 131) and thus could also be directly affected (130, 132). These tuna also forage within the scattering layer (131) and could consume and accumulate toxins.

Tuna fishing takes place in parts of the CCZ, and the spatial overlap of fishing and nodule fields is particularly high for some countries. For example, yellowfin and bigeye tuna are caught in large numbers in the EEZs of Kiribati and Tuvalu which also have interests in nodule mining (Fig. 10).

To fully understand the potential affect of nodule mining on fish stocks, it is important to consider the exposure of different life stages. The modelled distribution of tuna larvae in the Pacific differs between species (132). Skipjack and yellowfin tuna larvae show the greatest spatial overlap with nodule fields, particularly in the EEZs of Kiribati and Tuvalu, and the northern edge of the Cook Islands EEZ (Fig. 11).

DSM could affect future tuna fisheries. As climate change progresses, tuna are expected to shift away from the Western Pacific and into waters of the Central and Eastern Pacific (133). One modelling study predicts that over the next 80 years, a greater proportion of the Pacific's skipjack tuna will be located within the EEZs of Kiribati and Tuvalu in which nodule deposits also occur (Fig. 12). It is also predicted that the yellowfin tuna biomass will increase in the CCZ, peaking around 2050 (Fig. 12).

> **Despite the significance of fisheries, only one risk assessment of the potential impacts of deep sea mining on Pacific fisheries has been undertaken. Due to a dearth of data, it contains many assumptions, especially about how mining would occur. The study concludes that risks posed by deep sea mining to tuna fisheries are limited because the depths where mining would take place are beyond the depths of tuna (55). This should be viewed with caution as the authors recommend more detailed risk assessments including "extensive site-specific studies … tailored to the specific resource, location, and mining technology" (50). Such caution is underscored by the knowledge that bigeye and yellowfin tuna dive to depths greater than 1,000 metres (130, 131)**

An earlier assessment suggests that if surface processing and support operations are extensive, and if plumes occur in surface waters with subsequent effects on pelagic ecosystems, the risk to tuna fisheries will significantly increase (126).

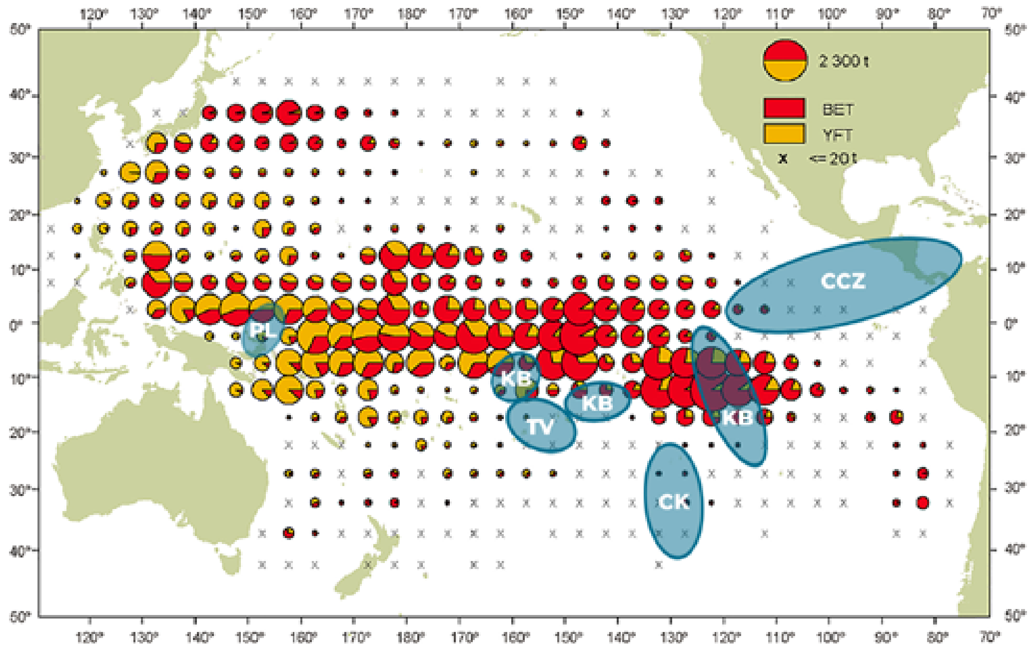


Figure 9: **AVERAGE ANNUAL CATCHES OF BIGEYE AND YELLOW TUNA** by longline vessels from China, Chinese Taipei, Japan and Republic of Korea between 2013 and 2017. Circle size denotes amount of tuna caught. Blue ovals represent the Clarion Clipperton Zone (CCZ) and the Peru Basin (PB), and the general area of the EEZs with nodule presence: the Cook Islands (CK), Kiribati (KB), Palau (PL), and Tuvalu (TV) (1). Tuna catch data from IATTC 2019 (8).

Transboundary and cumulative impacts from DSM are yet to be considered in relation to fisheries. Tuna are highly migratory and will encounter multiple human induced environmental changes across their range and during different parts of their life cycle. If mining affects tuna in one area of the Pacific, catches in another area would most likely be affected. In addition, the consequences of cumulative exposures to DSM induced impacts are unknown — as are the cumulative exposures to DSM and other environmental stressors.

The transboundary and cumulative impacts of nodule mining may affect the regional health of open ocean fisheries. Regional and national costs and benefits should therefore be considered in DSM decisions.

If sediment plumes, light or noise from nodule mining were to affect seamounts, fisheries associated with these may be significantly impacted. Snapper and other seamount fish may be unable to move to alternate habitats (24,50,126). Similarly, should deep sea nodule mining occur within 100 kilometres of Pacific islands, coastal fisheries and mariculture would be exposed to moderate to high risks (50).

Given the economic importance of fisheries to the Pacific region at local, national and regional levels, a precautionary approach to nodule mining is warranted. More information is needed to identify the spatial overlaps between proposed mine sites as well as their associated plumes, and infrastructure with migratory routes and fish habitats critical for different life cycles. Research is also required to understand the ecotoxicology and potential bioaccumulation of metals released at different depths in mine waste, and to determine how nutrient enrichment will affect plankton, and thus pelagic fishes and squids which form the foundations of pelagic food webs.

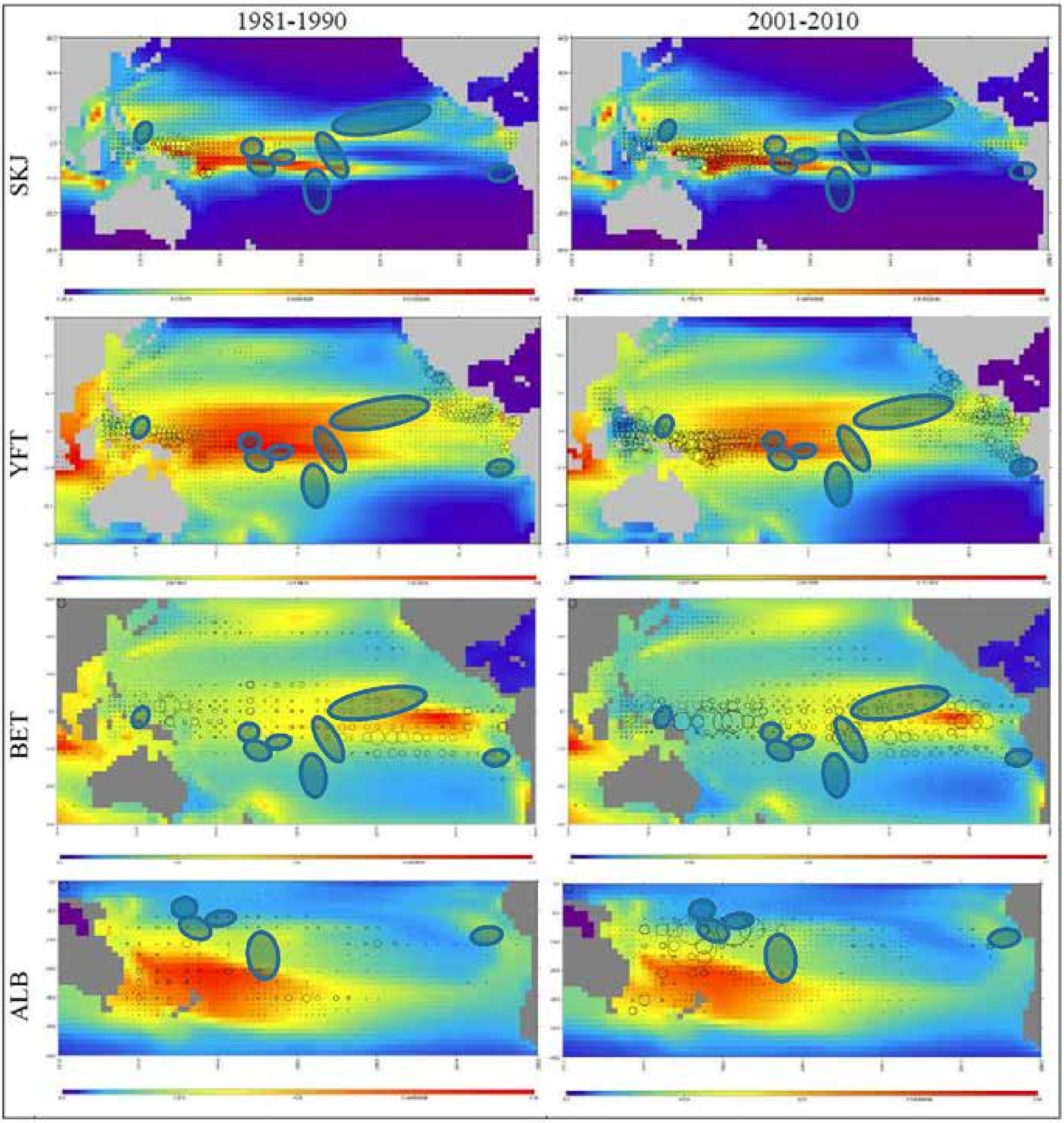


Figure 10: PREDICTED TUNA DISTRIBUTIONS BASED ON HISTORICAL CATCH DATA. Total observed catches are shown as circles, and the colours show the modeled density of tuna with red showing where tuna are most concentrated. Blue ovals show areas of interest for nodule mining as indicated by nodule presence. SKJ = skipjack tuna, YFT = yellowfin tuna, BET = bigeye tuna, ALB = albacore tuna. Figure from Senina *et al.* (6).

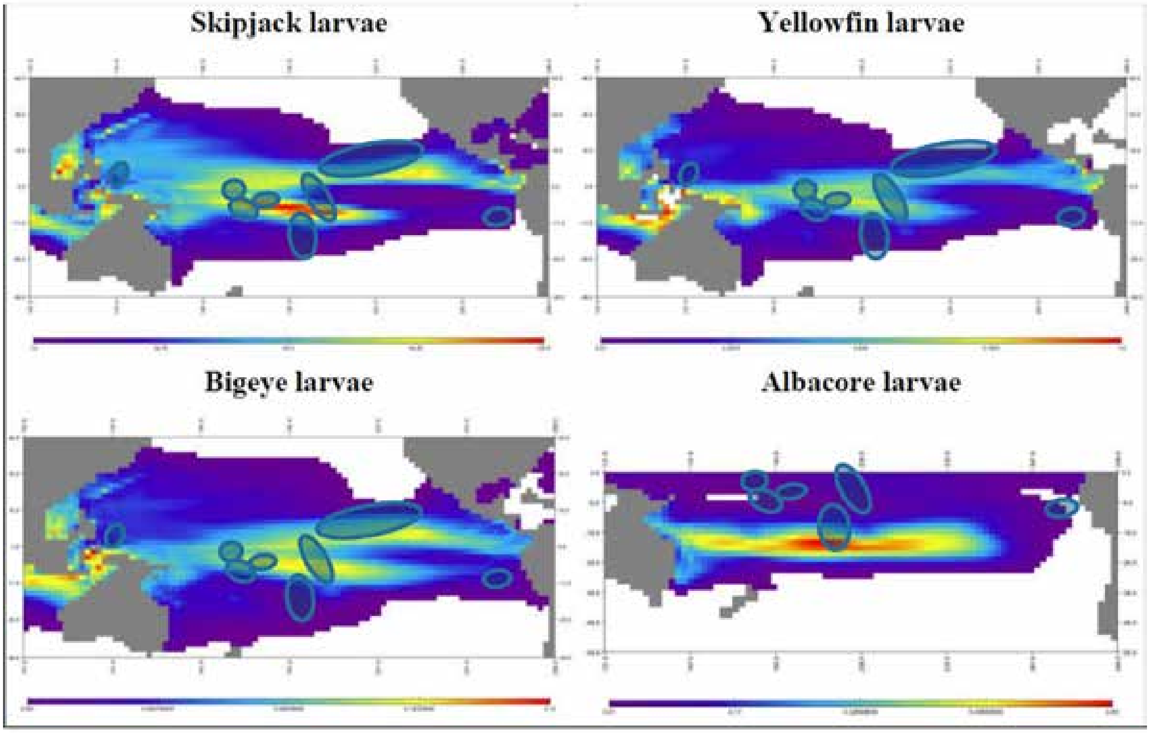


Figure 11: Mean predicted distributions of tuna larvae densities (numbers/sq km) for 2001-2010. Blue ovals show areas of interest for nodule mining as indicated by nodule presence. Figure from Senina *et al.* (6).

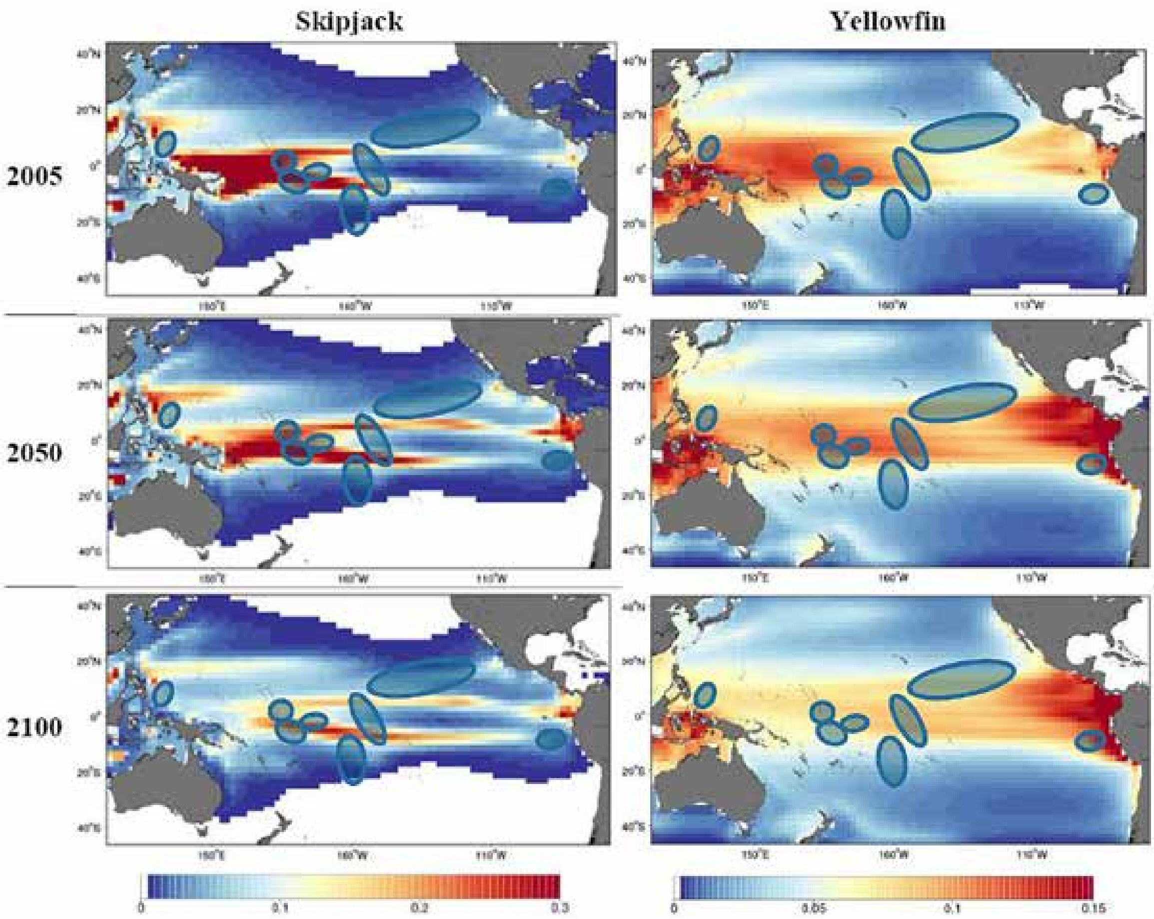


Figure 12: PROJECTED MEAN DISTRIBUTIONS OF SKIPJACK AND YELLOWFIN TUNA BIOMASS across the tropical Pacific Ocean under a high-emissions scenario (IPCC AR8.5) for 2005 and from the simulation ensembles in the decades centred on 2045 and 2095 including projected average percentage changes for the outlined area east and west of 150°W. Blue ovals show indicative areas of interest for nodule mining as indicated by nodule occurrence. Figure from Senina *et al.* (6).

4.5 Light pollution

Light pollution is a growing concern in marine environments (134). The surface waters of the open ocean are bright during sunlight hours, especially the nutrient poor, clear waters of the open Pacific. But deeper abyssal waters below 4,000 metres are completely dark except for bioluminescence (135). Species in these environments have adapted to these dark conditions and could be significantly impacted by lights from nodule mining operations. The lights of crewed submersibles exploring the mid-Atlantic ridge were found to have permanently damaged the retinas of deep sea shrimps (136). However, there is almost no information on the potential effects of light pollution on deep sea species, and these impacts need to be quantified.

In addition, DSM operations would entail support vessels floodlighting surface water which could aggregate fishes. Lights are already used in the Pacific to attract fish for easy harvesting (137). Lights associated with DSM infrastructure could also disrupt the vertical migration of pelagic species in the scattering layer and disrupt the foraging behaviour of tuna species.

4.6 Noise pollution

Noise pollution is the increase of noise levels due to human activities above natural ambient levels (138). Underwater noise pollution is a growing concern with noise from ships, military sonar, underwater seismic blasts and other activities already affecting marine life. The impacts range from changes in behaviour to actual physical damage (139, 140). Boat noise has been shown to change the swimming and schooling behaviour of tuna which could affect spawning and feeding (141). High-power sonar has been implicated in the stranding of whales and dolphins (139). Chronic noise pollution is known to reduce the survival of coral reef fishes (139) and potentially contributes to population decline in northern elephant seals (*Mirounga angustirostris*) (138).

Governments have developed mandatory controls and market-driven incentives to achieve noise abatement including spatial-temporal restrictions on noise-generating activities such as restricting activity during whale migrations or fish spawning. They have also developed preventative measures that use less intense noise sources to temporarily displace animals before a potentially harmful noise is emitted — from a seismic survey, for example. Industry-specific technologies are also being explored. These include ship-silencing technologies such as new propellors and hull designs as well as operational measures such as reducing speed in sensitive areas or revising shipping routes (140).

The acoustic impacts that would result from DSM appear to be unknown (142). While noise does affect aquatic species, this review was unable to identify any literature specifically investigating these impacts on deep sea species. The noise generated by DSM technology such as ROVs, riser pipes and pumps as well as associated support vessels and infrastructure could affect tuna — as seen with the impacts of boat noise in the Mediterranean (141). DSM-related noise could also affect the movement of pelagic larvae by confounding normal acoustic cues (138). Such risks are yet to be properly assessed.

4.7 Carbon cycling and climate change

The oceans play a vital role in regulating the Earth's climate and cycling crucial elements such as carbon (143, 144). It is estimated that the world's oceans stored up to 155 billion tonnes of carbon created by human sources in 2010 (145). Historically, the deep sea has been dismissed as a sparse, food poor and inactive zone, with little role in regulating and affecting ocean conditions and environments, but these assumptions are now being challenged (146). As more research is conducted, it is becoming apparent that the deep sea, mid-water and surface ocean ecosystems are interconnected by energy and nutrients cycling between them, and that deep sea biological productivity is more extensive than previously thought (147).

On land and in sunlit zones of the ocean, plants (photoautotrophs) use sunlight to create energy through photosynthesis. In the deep sea, there is no sunlight so the primary producing deep sea species are chemoautotrophs, species that feed on inorganic chemicals such as methane, sulfides and inorganic elements to create energy and the building blocks of life (146). The sea floor can be seen as an immense "bioreactor" for cycling nutrients.

Carbon, nitrogen, silica and iron in the organic matter that falls from surface and mid-water layers are processed by microbes in deep sea ecosystems. Inorganic nutrients are recycled (146) and some of the carbon may be stored for thousands of years (148). These processes suggest that deep sea habitats play a role in the global carbon cycle and particularly in carbon storage.

Deep sea microbes also play a role in sequestering methane, a potent greenhouse gas (144). The extent to which deep sea ecosystems mitigate climate change is unknown (146). Also unknown is the extent to which DSM, through disrupting deep sea ecosystems and their carbon cycling, might exacerbate climate change or result in the release of carbon stored in the deep seabed, thereby contributing to global greenhouse gas emissions.

A study investigating the potential carbon footprint of DSM operations in the CCZ (149) found that DSM operations would make a small but notable contribution to global marine sourced greenhouse gas emissions.

4.8 Connectivity, cumulative pressures and transboundary considerations

The world's oceans are under stress. Climate change is already causing deoxygenation, marine heatwaves and acidification, and the economic impacts are being felt (150). The deep sea is predicted to mirror these impacts affecting a wide range of environmental conditions, fishes and invertebrates (151).

It is increasingly apparent that the deep seabeds and water columns are linked by water movements, species movements and biogeochemical processes. This means that what happens on the deep seabed could affect surface waters (152) and changes in surface layers could affect the deep sea (147). This connectivity also includes horizontal movements. There is increasing evidence that impacts occurring in the open ocean areas beyond national jurisdiction could have effects on pelagic ecosystems which, in turn, may affect coastal waters and the communities using them (153).

Recent research conducted in the south-east Atlantic Ocean suggests that deep sea fishes play an important role in enabling connectivity between the deep ocean and pelagic realms through widespread seasonal migrations that are hypothesised to transfer and redistribute energy (154). While similar studies are yet to be conducted for the deep Pacific Ocean, such dynamism could be anticipated there. If nodule mining disrupted the movement of deep sea fishes and ocean connectivity, the consequences for deep sea and pelagic ecosystems could be significant.

The potential cumulative impacts of nodule mining require careful consideration. Cumulative impacts occur when the effects of several separate activities build on each other and create a larger impact than any of them would alone. It is possible that various sources of impact associated with DSM could be cumulative. For example, light and noise associated with nodule mining operations combined with the discharge of mine waste in mid or surface waters could provoke a tipping point for tuna migrations that neither would on their own.

Furthermore, it is also likely the impacts of nodule mining would interact with other environmental stresses. For example, ocean acidification is a significant issue for some deep sea species (155) and could magnify the impacts of sedimentation on deep sea animals by reducing their ability to recover from smothering.

LIGHT AND NOISE ASSOCIATED WITH NODULE MINING OPERATIONS COMBINED WITH THE DISCHARGE OF MINE WASTE IN MID OR SURFACE WATERS COULD PROVOKE A TIPPING POINT FOR TUNA MIGRATIONS THAT NEITHER WOULD ON THEIR OWN. IMAGE: A. PAVEL

BOY IN CANOE, PAPUA NEW GUINEA: PACIFIC PEOPLES RECOGNISE THE CONNECTIVITY BETWEEN DIFFERENT OCEAN ENVIRONMENTS, AND VIEW THE DEEP SEA AS CONNECTED TO THE SHALLOW SEAS AND REEFS THAT ARE PART OF THEIR TENURE. IMAGE: ALEKSEY

5 | SOCIAL AND ECONOMIC DIMENSIONS

5.1 Common human heritage

Much of the proposed nodule mining would occur in the high seas in areas beyond national jurisdiction. Under the United Nations Convention on the Law of the Sea (UNCLOS), activities in such areas of common human heritage must be carried out for the benefit of humanity as a whole (5).

Arguments that DSM would be of net benefit to the world were initially made in the 1970s. There have since been significant changes in global attitudes, policies and scientific understanding about marine conservation. These question whether commercial exploitation of the deep sea is "really in the interest of humanity" (156).

Nodule mining may also take place within the national boundaries of some Pacific economies such as the Cook Islands and Kiribati, raising questions about how the social and economic costs and benefits would be assessed. It has been argued that such assessments should be conducted by independent experts and should consider fair and equitable distribution of wealth as well as the long-term environmental value of deep sea ecosystems (157).

Pacific economies and their communities would be on the frontline of impacts should nodule mining proceed. Pacific peoples strongly depend on the health of their ocean to provide food and income from fisheries and tourism, sectors already highly vulnerable to climate change (120). Any additional pressure from new industries such as DSM would need to be carefully considered.

5.2 The Pacific way

As most proposed nodule mining would be developed in deep waters far from coastlines and EEZ boundaries, it is easy for decision-makers to assume there will be minimal impacts to communities, their economic activities or values. In many Pacific cultures, however, present generations are viewed as custodians — not owners — of marine resources, with responsibility to maintain and enhance the resources for future generations (33).

Pacific peoples recognise the connectivity between different ocean environments, and view the deep sea as connected to the shallow seas and reefs that are part of their tenure (33).

Many of the tensions experienced with terrestrial mining in the Pacific are also emerging with DSM — tensions over economic gain and development versus social and environmental harm (157). In Papua New Guinea, a petition and many other civil society representations have been made to PNG national and provincial governments calling for a halt to DSM. In New Zealand, a broad cross-section of community organisations has rallied to stop seabed mining in the country's waters, including winning a case in the Court of Appeal to prevent seabed mining in the Taranaki Bight (158). In the Cook Islands, community organisations have commissioned independent studies, held meetings and produced materials presenting alternative views and encouraging Pacific Islands to be cautious

(33). In 2013, the Tenth General Assembly of the Pacific Conference of Churches passed a resolution to stop DSM in the Pacific (26).

In response to the concerns expressed by Pacific civil society, the President of Fiji Frank Bainimarama supported by Prime Minister of Vanuatu Charlot Salwai and Prime Minister Marape of PNG called for a ten-year moratorium on seabed mining in Pacific national waters (159). In early 2020, a powerful group of Fijian Chiefs warned they would not allow seabed mining in their province (160).

5.3 Valuing the deep

It is suggested that nodule mining could generate wealth for governments through licence fees and royalties, and could progress their development goals (25, 157). An analysis of three Pacific economies suggests that DSM (including nodule mining in the Cook Islands) could provide net economic benefits for the Cook Islands and PNG but not for the Republic of Marshall Islands (25, 161).

However, the financial feasibility of these operations is yet to be demonstrated, and the uncertainties involved means that their profitability is far from assured (162, 163). In the past, deep sea resource ventures have resulted in substantial economic losses for mining companies (20, 21). It is notable that the only DSM project to be granted an operating licence to date resulted in community opposition and, when it failed, significant financial loss for the PNG government (see Case Study: Solwara 1).

The example of terrestrial mining is often used to argue the case for DSM, but the experience on the ground is mixed. Revenue from land-based mines can provide much needed funds for education and healthcare, improve livelihoods and support business development with positive "downstream" effects (164). Large-scale land-based mines, however, often fail to deliver benefits to communities and national economies and cause significant environmental and social harm. The Pacific region has played host to some of the world's most socially and environmentally disastrous mining projects, most notably Ok Tedi and Panguna in Papua New Guinea and the "phosphate islands" of Nauru and Banaba in Kiribati (23, 165-168). Benefits from terrestrial mining are also often not equitably distributed and the local communities most negatively affected are frequently not fairly compensated (157).

In addition, DSM would differ from terrestrial mines in ways that could reduce the leverage national governments have to negotiate profit-sharing and compliance with regulations. DSM operations at any one location are envisaged to be relatively short lived and the infrastructure would be mobile, allowing companies to readily relocate mining operations.

The duration of possible economic benefits from nodule mining operations is unclear. The relatively small work force required for DSM would generate few local jobs (163). In addition, the costs of any environmental accidents would most likely be heavily borne by those most reliant on the health of the ocean for their livelihoods.

Pacific economies that choose to take part in nodule mining would need to establish clear objectives, and robust and transparent mechanisms to manage and share earnings from DSM operations (169). Mechanisms by which DSM benefits would be fairly and equitably distributed are yet to be established (156).

5.4 A catalyst for conflict

DSM is already changing political relationships and creating local, national and regional conflicts between proponents and opponents of projects (163). The governments of Cook Islands, Nauru and Tonga wish to pursue DSM, while others propose a moratorium (157, 170).

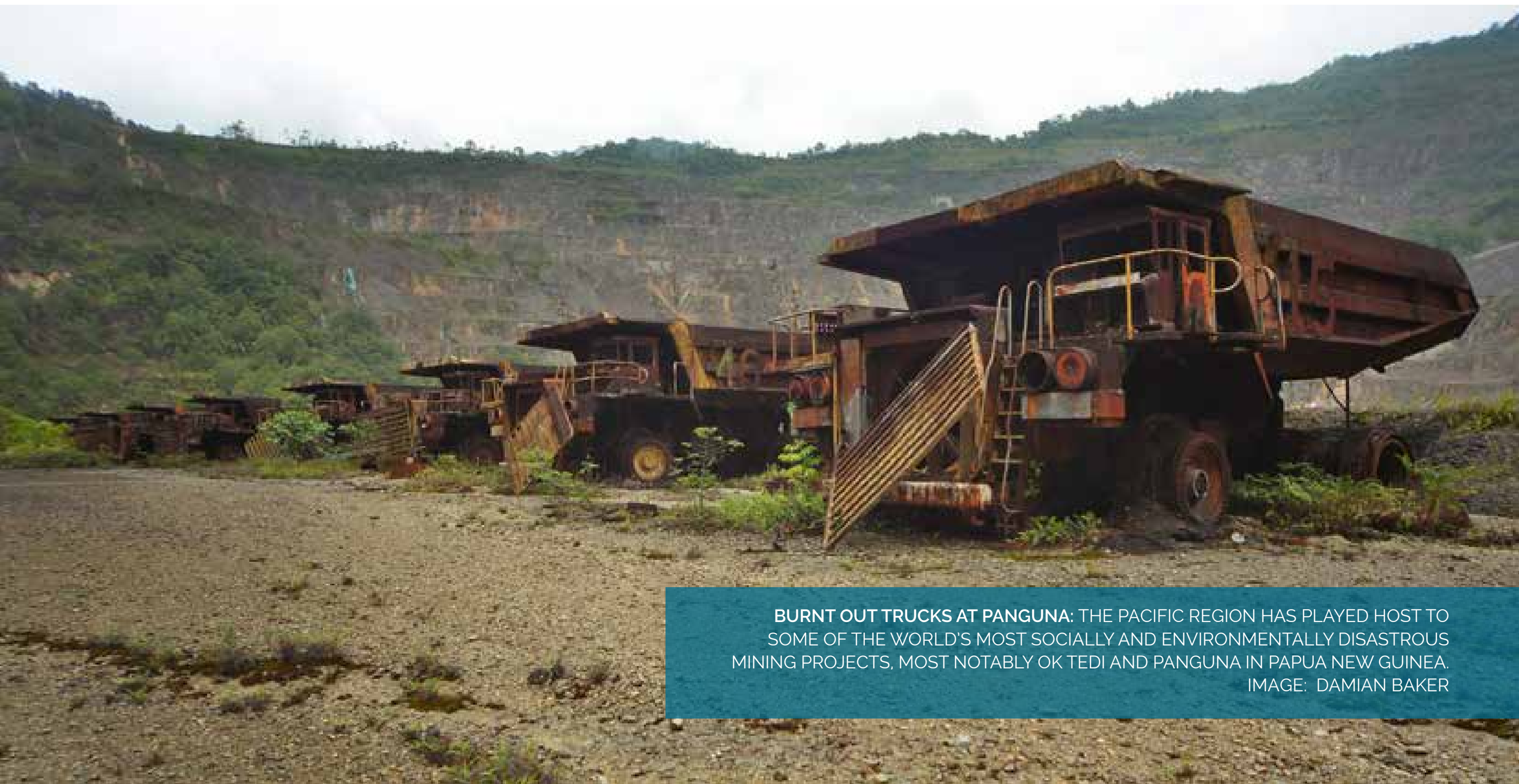
Within national waters, conflicts could also arise between resource managers, communities, traditional custodians, governments and mining companies over perceived inequities in ownership, access and benefits, and the legitimacy of DSM operations (33, 157, 171). For example, while the Cook Islands government supports DSM, local community organisations oppose it (33, 157) and it has been reported that a senior government official lost her job for supporting a moratorium on deep sea mining (170).

Some of these conflicts stem from insufficient scientific information about DSM impacts, and from concerns over risks to natural resources, the environment, community health, and livelihoods (157, 171). If mining resulted in the release of toxic metals and bioaccumulation in food webs, artisanal and subsistence fishers could be exposed to dietary contamination (172).

In Tonga, concerns have been expressed that processes for DSM decision-making are compromised by poor national capacity and power imbalances between government officials, international entities, local officials and community leaders. There are perceptions that agendas and methods do not reflect islander culture or aspirations (173, 174).

Mining-related conflicts over benefits, compensation and environmental degradation are widely known in the Pacific. Extreme cases of conflict have led to armed uprisings as seen in Bougainville (175) and more recently in Hela province in the highlands of PNG where landowners protested against the lack of benefits from the ExxonMobil Liquified Natural Gas project (177).

Independent studies are required to examine the costs and benefits of nodule mining, and must factor in the social, cultural and political elements relating to each location. They should also be informed by the reasons that most land-based mines in the Pacific have failed to deliver the benefits expected.



BURNT OUT TRUCKS AT PANGUNA: THE PACIFIC REGION HAS PLAYED HOST TO SOME OF THE WORLD'S MOST SOCIALLY AND ENVIRONMENTALLY DISASTROUS MINING PROJECTS, MOST NOTABLY OK TEDI AND PANGUNA IN PAPUA NEW GUINEA. IMAGE: DAMIAN BAKER

CASE STUDY:
Solwara 1, Papua New Guinea

PNG's experience of the Solwara 1 project to mine massive seafloor sulphides *is presented here as a case study of the socio-economic risks associated with DSM.*

The Solwara 1 DSM project driven by Canadian company Nautilus Minerals Inc, was the world's first licenced DSM venture. The project aimed to mine massive seafloor sulphides produced by hydrothermal vents in the Bismarck Sea. Nautilus received its mining licence for the Solwara 1 deposits in 2011, marked out a benefit zone for landowners, and began to conduct community consultations. These have been criticised as a tool by which the company attempted to manage opposition to Solwara 1 (157).

Opposition to the project grew with civil society activists, church leaders, communities, and politicians vigorously raising arguments relating to lack of scientific information about the impacts of the operation, lack of "free, prior and informed consent" and religious objections based on both traditional cultural and Christian values (26, 157, 171).

IMAGE: JONATHAN MESULAM, ALLIANCE OF SOLWARA WARRIORS AND WEST COAST DEVELOPMENT FOUNDATION (NEW IRELAND, PNG) WITH HIS SON WILLIAM HOLDING AN OPEN LETTER FROM PNG CIVIL SOCIETY PUBLISHED IN THE POST COURIER ASKING THE PNG GOVERNMENT TO CANCEL NAUTILUS MINERALS DEEP SEA MINING LICENCES. JUNE 2019.

View here: http://www.deepseaminingoutofourdepth.org/joint-letter-calling-for-the-papua-new-guinea-government-to-cancel-all-nautilus-minerals-deep-sea-mining-licences-and-to-ban-seabed-mining-in-png

Nautilus was accused of misrepresenting community reactions expressed during public consultations (171). The company's environmental impact assessment and approvals process were criticised as flawed (172, 177), calling into question the project's legitimacy and transparency.

> ***"They come with their stories about technology and lack of life at the sea floor. How do we know if we can trust them? There is no proper awareness from the company and no two way discussion with government. Landowners are reduced to being spectators and are blocked from decision-making. There are many unanswered questions — how will the revenue be spent, who will benefit, why is the ore being shipped off. Those of us next to the benefit zone fear impacts from Solwara1 but we will gain no benefits."*** **(176)**
>
> Compilation of comments about Nautilus' community consultation, from a group of landowners living close to the proposed Solwara 1 site in New Ireland Province .

In 2017, coastal communities launched legal proceedings against the PNG Government in a bid to obtain key documents related to the licencing of Solwara 1 and the environmental, health and economic impacts of the project.

In 2019, the project ceased operating due to its inability to raise finances and has since been declared bankrupt. The project left the PNG government with a legacy debt of AUD 157 million, roughly equivalent to one third of the country's health budget in 2018 (3, 22). The Prime Minister has described the project as a "total failure"(159).

CONCLUSION

What Science Says About Mining Deep Sea Nodules in the Pacific

Common human heritage

This review of 250 scientific and other sources finds that the mining of deep sea polymetallic nodules would result in severe and irreversible damage to deep sea ecosystems which include unique and largely unstudied species. It also finds that there are a great many under-researched and unknown variables that constitute a high degree of risk to marine ecosystems more broadly and to the people who rely on them.

These risks and uncertainties present a dilemma to decision-makers in the Pacific seeking to generate national income. The reality that confronts them is that it would be impossible to fully assess the social, cultural, economic and environmental impacts until after commercial mining has begun. By that stage, mitigating impacts could be difficult or ineffective. Many members of civil society in the Pacific therefore reject DSM as an experimental industry that treats islanders as its guinea pigs (178, 179).

Social and economic gains for Pacific island economies are unclear as the commercial viability of DSM ventures is unproven. A cost-benefit analysis of nodule mining in the Cook Islands indicates there is "a great deal of uncertainty around potential yields" as the technology is still experimental. (25).

Investors, governments and communities would not know if benefits could be realised until significant economic, political, social and environmental capital has been expended. This risk has already had severe consequences for Papua New Guinea. Its experience with the failed Solwara 1 venture has added significantly to national debt, with government officials publicly stating regret for investing in the project (Section 5 Case Study). The project's failure has led to calls for PNG to ban seabed mining in its waters and has reinforced calls for a regional Pacific moratorium on mining.

One of the biggest challenges in understanding the environmental impacts of nodule mining is that most assessments are theoretical and rely on modelling rather than empirical data. This is due to a dearth of research and the unprecedented nature of deep sea mining.

The trials of small-scale experimental disturbances are valuable and underscore the extremely slow recovery time in deep sea environments, as signs of recovery have yet to be seen several decades later. However, these trials are unable to replicate the range and scale of impacts that would result from commercial nodule mining.

Scientific knowledge is lacking in numerous areas and is insufficient to adequately understand the full range of impacts and risks associated with deep sea nodule mining and whether or not any of these can be managed.

AREAS LACKING KEY INFORMATION INCLUDE:

- Technologies and methods that would be used in nodule mining including the riser pipes and the depth of waste discharge (apart from minimal information from Belgian company Global Sea Mineral Resources — see Section 3);
- Volume of suspended sediment and mine waste that would be generated by the undefined technologies and methods, and their dispersal through ocean waters and across the seabed;
- Chemical reactions and ecotoxicological characteristics associated with sediment plumes and mine waste;
- Effects of nutrient loading on marine species in shallow, mid- and deep waters;
- Noise and light pollution produced by these undefined technologies and methods and their effects on species from the surface to the deep sea;
- Physical and ecological impacts on habitats, species and ecological processes of the deep sea as well as the water column extending to the surface - and hence the ecosystem services that may be lost;
- Impacts on pelagic species of the scattering layer (a dense body of pelagic species that make nightly migrations from deep to surface waters) which are important prey for many other species, including those commercially fished such as tuna;
- Population dynamics of deep sea species associated with nodules, especially with regard to their capacity to recolonise damaged areas;
- Migrations of deep sea fishes in the Pacific Ocean and the effect of nodule mining on such movements;
- Linkages between surface, mid and deep water ecosystems (including via migrations of deep sea fishes) and the communication of impacts between them;
- Risks for fisheries of high global, regional, national and local economic value in the Pacific;
- Cumulative and trans-jurisdictional impacts on species, habitats and ecosystems;
- Adequacy of proposed conservation measures such as Areas of Particular Environmental Interest established by the International Seabed Authority in the Clarion Clipperton Zone or biological reference zones proposed within each mining lease (see Section 2.3.1). This is critical given that remediation of the physical impacts of nodule mining is viewed as unrealistic;
- Effects of nodule mining on carbon cycling and storage; and
- Social and economic costs and benefits to Pacific island economies.

THIS REVIEW HAS IDENTIFIED SEVERAL KEY FINDINGS SUPPORTED BY MULTIPLE LINES OF EVIDENCE FROM SEPARATE PUBLICATIONS. THE KEY FINDINGS ARE THAT:

- Deep sea habitats and ecosystems are much more biodiverse than originally believed;
- Mining nodules would remove for millions of years the hard substrate that supports sessile organisms and provides important foraging grounds for mobile species;
- Different deep sea species would respond differently to sedimentation and physical disturbance;
- Community composition of mined areas is expected to be substantially altered over very long time frames regardless of varying tolerances;
- Recovery of benthos would be slow if at all, and all species reliant on nodules would be permanently lost from mined areas;
- Deep sea habitats are valued as part of global human heritage. In the Pacific, they are also valued as part of traditional maritime tenure, connected to shallower seas and reefs - a knowledge system that western science is only now starting to catch up with;
- Proposed deep sea mining is already causing social and political conflicts in the region; and
- Civil society opposition to deep sea mining is strong and social licence appears to be low.

The accumulated evidence from 250 peer reviewed scientific articles and other literature indicates that the impacts of nodule mining in the Pacific Ocean would be extensive, severe and last for generations, causing essentially irreversible damage. The evidence does not support assertions that nodule mining would have minimal environmental impacts.

Expectations that nodule mining would generate social and economic gains for Pacific island economies are based on conjecture and are unsubstantiated. The impacts of nodule mining on communities and people's health and food security are understudied and require rigorous independent investigation.

We conclude that a precautionary approach to nodule mining is warranted.

AFTERWORD

Adopting a Precautionary Approach – Calling for a Moratorium

DEEP SEA MINING CAMPAIGN | MININGWATCH CANADA

The Deep Sea Mining Campaign and Mining Watch Canada commissioned this report to enable more informed debate about deep sea mining. The seabed of the world's oceans represents the common heritage of humankind. Yet there is little public debate about this emerging industry and its potential to destroy fragile ecosystems.

In the Pacific, companies plan to send machines to the sea floor within the next decade. DeepGreen Metals Inc of Canada has set a target of 2023 and Global Sea Mineral Resources NV of Belgium is aiming for 2027. At the time of writing, the International Seabed Authority (ISA), a multilateral agency set up under the United Nations Convention on the Law of the Sea, plans to finalise regulations for the exploitation of seabed mineral resources in 2020.

This review finds that the costs of deep sea nodule mining in the Pacific Ocean are likely to outweigh the asserted but unsubstantiated benefits. Many impacts and risks cannot be quantified at this stage, partly because the necessary studies have not been conducted and partly because there are many unknown variables associated with this unprecedented extractive industry.

The stakes are high — irreversible damage to marine ecosystems that support the *many* (via national economies, food security, livelihoods, spiritual and cultural connections and potential biomedical) versus the *few* (commercial interests of primarily a handful of investors).

In 2018, the European Parliament adopted a resolution on international oceans governance that calls on European states to stop sponsoring deep sea exploration in international waters and to support a moratorium on deep sea mining. This call has been echoed by the Environmental Audit Committee of the British House of Commons and the UN Envoy on Oceans at the World Economic Forum in Davos in January 2019 called for a 10 year moratorium on DSM. Last year the Government of Fiji announced it would impose a moratorium on seabed mining in its national waters and urged other governments in the region to do likewise during the Pacific Islands Forum Leaders Meeting in Tuvalu in August 2019. The Governments of Papua New Guinea and Vanuatu have indicated their support.

The Deep Sea Mining campaign is a member of the Deep Sea Conservation Coalition, a group of more than 80 non-governmental organisations. We call for a moratorium on deep sea mining, on the adoption by the ISA of regulations for exploitation and on the issuing of exploitation and new exploration licences unless and until:

1. The environmental, social and economic risks are comprehensively understood;
2. It can be clearly demonstrated that deep seabed mining can be managed in such a way that ensures the effective protection of the marine environment and prevents loss of biodiversity;
3. Where relevant, there is a framework in place to respect the free, prior, informed consent of Indigenous peoples and to ensure consent from potentially affected communities;
4. Alternative sources for the responsible production and use of the metals also found in the deep sea have been fully explored and applied, such as reduction of demand for primary metals, a transformation to a resource efficient, closed-loop materials circular economy, and responsible terrestrial mining practices;
5. Public consultation mechanisms have been established and there is broad and informed public support for deep seabed mining, and that any deep seabed mining permitted by the International Seabed Authority fulfils the obligation in recognising that international waters are the Common Heritage for all of humanity;
6. Member States reform the structure and functioning of the International Seabed Authority to ensure a transparent, accountable, inclusive and environmentally responsible decision-making and regulatory process to achieve the above.

In face of the predicted impacts and significant risks highlighted in this report, a moratorium on deep sea mining in the Pacific is the only responsible way forward.

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