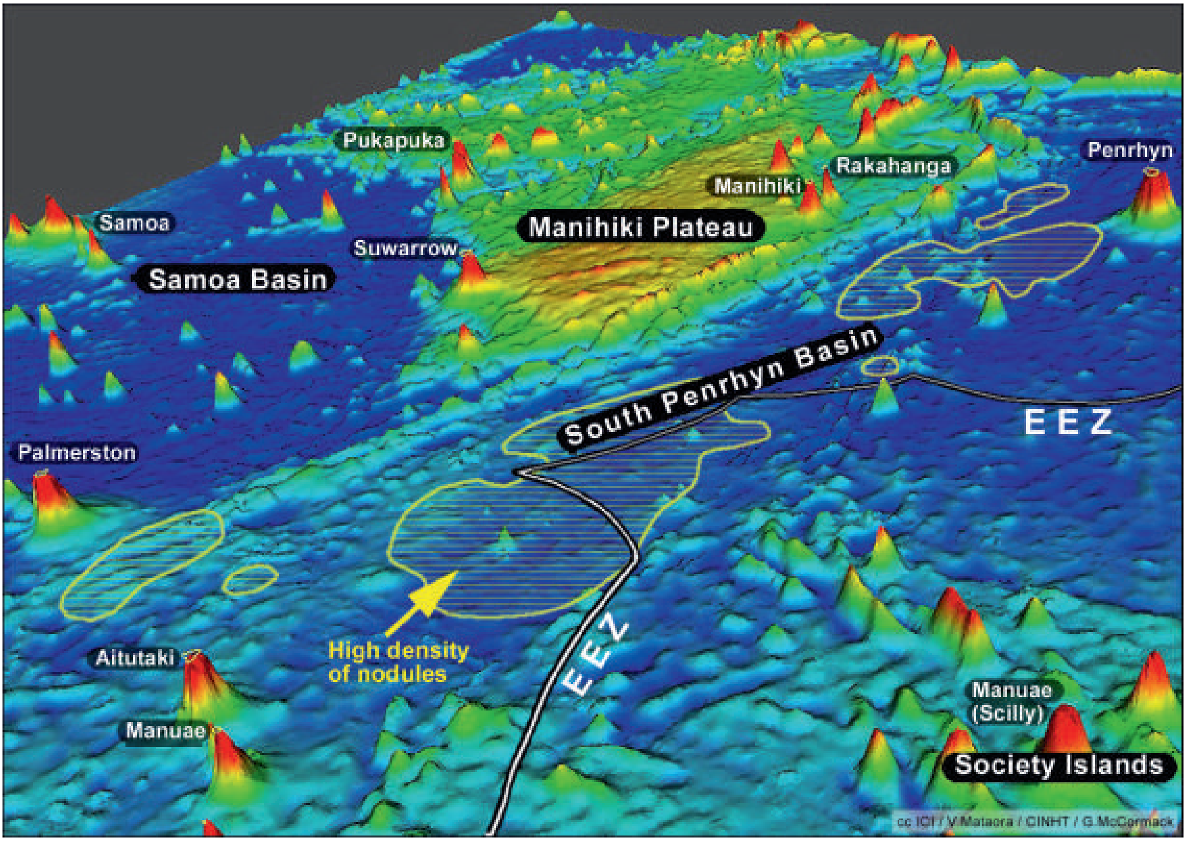
Cook Islands Seabed Minerals

a precautionary approach to mining



Gerald McCormack

second edition, with corrections

Cook Islands Natural Heritage Trust
Rarotonga 2016

Abbreviations and acronyms

1° = primary
2° = secondary
dt = dry tonnes
M = million
Ma = million years (from *megaannus*) for dates and duration
mbsl = metres below sea level
Mdt/y = million dry tonnes per year
M/y = million per year
ppm = parts per million
t = tonne = 1,000kg (a.k.a. metric ton with symbol mt)
wt = wet tonnes

AABW = Antarctic Bottom Water
BPA = Biodiversity Preservation Area
CBD = Convention on Biological Diversity
CISWF = Cook Islands Sovereign Wealth Fund
CCD = Carbonate Compensation Depth
CCZ = Clarion-Clipperton Zone
DSC = Deep Sound Channel
EEZ = Exclusive Economic Zone
EIA - Environmental Impact Assessment
GDP = Gross Domestic Product
REY = Rare Earth Elements + Yttrium
SBMA = Cook Islands Seabed Minerals Authority
SMS = Seabed Massive Sulphides
SPB = South Penrhyn Basin
ISA = International Seabed Authority, a UN agency
WCPFC = Western and Central Pacific Fisheries Commission

Front cover
An oblique view of the Cook Islands seafloor with the South Penrhyn Basin and its nodule fields in the foreground and the Manihiki Plateau in the background.

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Disclaimer

The views in this booklet are those of the author based on a review of more than 300 scientific papers and expedition reports concerning the marine environment and the polymetallic nodules of the Cook Islands.

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Contents

Figures and Tables

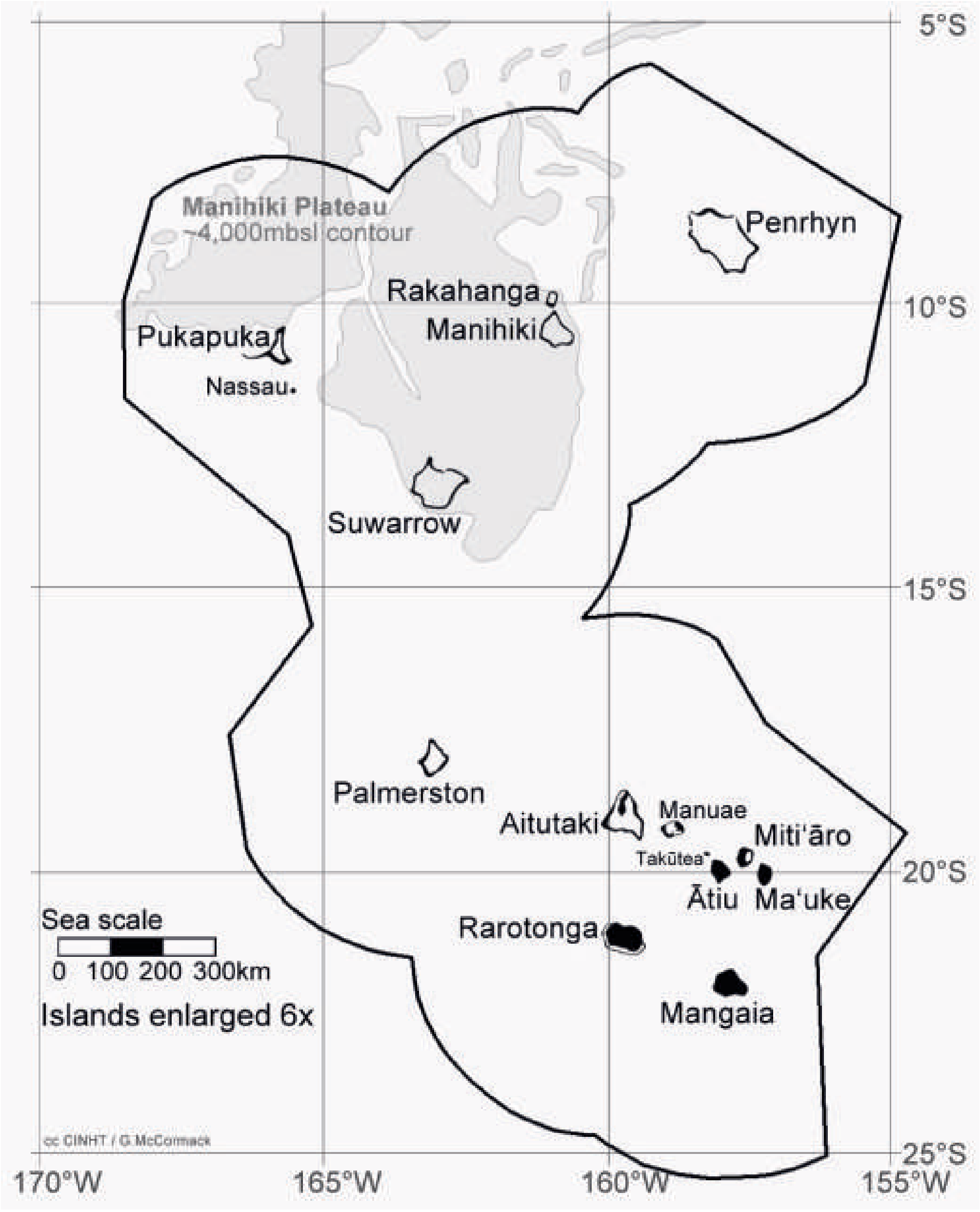


Figure 1. Map of the Cook Islands with islands enlarged.

1. Cook Islands – background

The Cook Islands is a small country in the central South Pacific with French Polynesia to the east and Samoa to the west. Since 1965 it has been self-governing in free association with New Zealand whereby its nationals have New Zealand passports and citizenship. As a sovereign nation within the Realm of New Zealand, the Cook Islands is an independent party to various international conventions, including the Convention on Biological Diversity, which commits it to use the Precautionary Principle and Ecosystem Approach to conserve its biodiversity.

The country consists of fifteen small islands with a total land area of 240km² scattered over an Exclusive Economic Zone (EEZ) of about two million square kilometres (**Figure 1**). The islands divide geographically into two groups with the six Northern Group islands around 10°S, and the nine Southern Group islands around 20°S. The southern islands are mainly high islands, including one young volcanic island (Rarotonga), one almost-atoll (Aitutaki) and four uplifted limestone-volcanic islands (Mangaia, Ātiu, Maʻuke and Mitiʻāro). The northern islands are low coral-reef islands, mainly atolls, with Penrhyn the largest and most northerly. ***The facing map has the islands enlarged 6x over the background to show their physical form.***

In 2015 the Cook Islands had a resident population of about 13,000 of whom 10,000 or 75% lived on Rarotonga, which is the administrative and commercial centre of the country. The resident population has been in decline since the 1990s through migration to New Zealand where more than 60,000 Cook Islanders live, and Australia where there are about 8,000.

As a colony of New Zealand (1901-1965) the Cook Islands thrived on exporting tropical fruits and vegetables to New Zealand, while the opening of

Rarotonga International Airport in 1973 led to a significant increase in tourism. Agricultural exports started to decline in the 1980s and ceased twenty years later.

In the meantime tourism grew; today there are about 120,000 visitors annually accounting for about 60% of the Gross Domestic Product (GDP) (or US$158M). Around 80% of visitors are from New Zealand and they mainly visit from June through October. While visitor numbers continue to increase slowly, the 2013/2014 Budget Statement noted "July and August are becoming increasingly unable to take additional arrivals".

The locally managed pelagic fishery started in the 1990s. It is based on harvesting Skipjack and Albacore Tuna in the Northern Group (8-16°S) for overseas processing. In 2014/15 the whole fishery was about 6% of GDP (or US$15M).

The fishery is managed by the Ministry of Marine Resources in accord with the Western and Central Pacific Fisheries Commission (WCPFC), which was established in 2004 under an international treaty to manage the conservation and sustainable use of the highly migratory fish stocks, namely the tunas, broadbill and marlin.

While the fishery is presently sustainable, it is unclear how much it can be increased. Plans to significantly increase purse-seining Skipjack in 2016 have provoked considerable debate about sustainability.

As tourism and the pelagic fishery both approach maximum sustainable limits, seabed mining is seen as a potential new revenue stream. Globally there are four polymetallic nodule fields recognised as potentially commercially viable with three in the Pacific and one in the Indian Ocean. Three of the fields are in international waters under the control of the International Seabed Authority (ISA), of which the

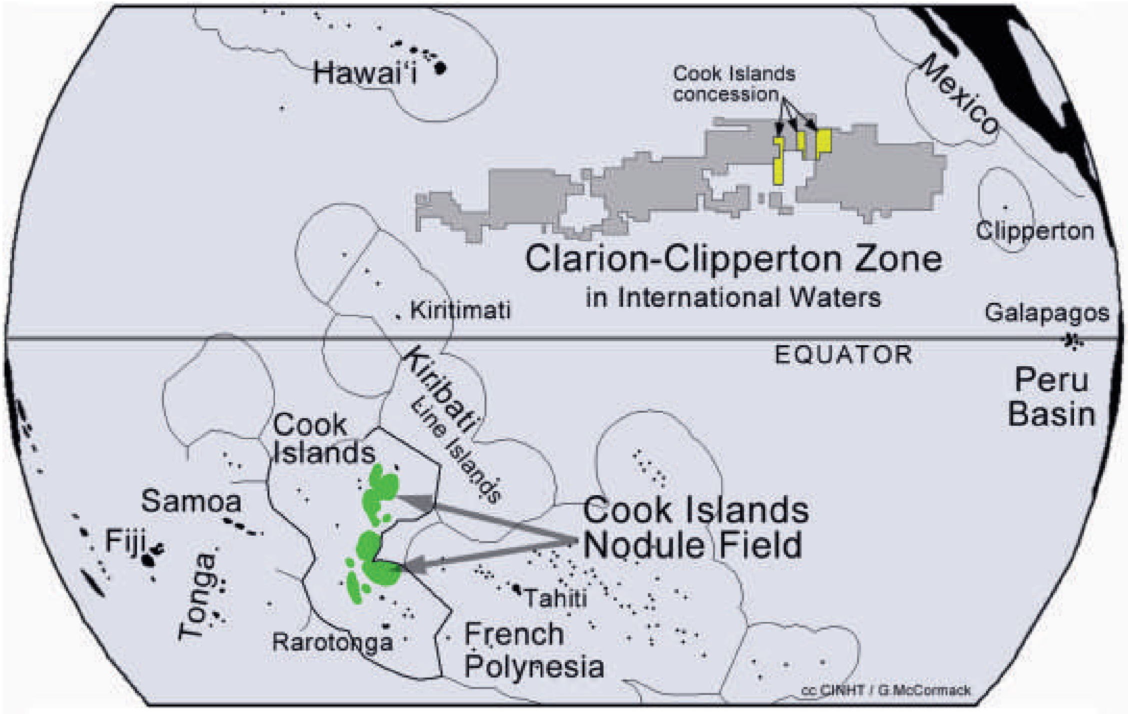


Figure 2. Cook Islands and Clarion-Clipperton Zone (CCZ) nodule fields. The Cook Islands nodule field (*green*) shows the main areas with high densities of nodules. The CCZ nodule field (*grey*) is outlined as the outer borders of the contiguous Exploratory Concessions. The Cook Islands has an Exploratory Concession (*yellow*) in the CCZ in partnership with the Belgian company G-TEC Sea Mineral Resources (GSR).

Clarion-Clipperton Zone field is the largest and most researched. The fourth significant field is under national jurisdiction in the Cook Islands. (**Figure 2**)

The high concentration of polymetallic nodules in the Cook Islands seabed is due to the particular environmental features of the South Penrhyn Basin, located between Aitutaki in the south and Penrhyn in the north.

The Cook Islands nodule field has been surveyed since the early 1970s. Its commercial value was established in the 1990s through the 1993 assessment by the East-West Center in Honolulu, and the 1996 feasibility study by Bechtel Corporation, the largest engineering company in the United States. Although the study was favourable, the subsequent declining value of Cobalt led to a loss of interest.

When metal prices improve and it is commercially viable to mine seabed nodules they could provide a very significant revenue stream for the Cook Islands (***see pages 12-13***). In 2009, the Seabed Minerals Act established the Seabed Minerals Authority to manage the resource, and the government is establishing a Cook Islands Sovereign Wealth Fund (CISWF) to handle the revenue for the benefit of all Cook Islanders now and in the future. There are several CISWF operating scenarios but they are beyond the scope of this study.

While there is little doubt the seabed nodules will one day be worth mining, the question is: Can they be mined in an environmentally acceptable way? If mining occurs, the bigger question is: How will the country ensure the mining is continuously environmentally acceptable?

2. The Precautionary Principle

The Precautionary Principle gained international recognition as Principle 15 of the Rio Declaration on Environment and Development at the Earth Summit in 1992. At the Summit, the Principle was also included in the Convention on Biological Diversity (CBD) of which the Cook Islands was a foundation member.

The Precautionary Principle is commonly included in environmental policy and regulations, including the Cook Islands Seabed Minerals Policy 2014 and the Exploratory Regulations 2015. The 2014 Policy stated that "The precautionary approach means that the Government cannot use the absence of data to avoid taking protective measures to require the prevention, mitigation, or remedy of any such impacts where cost-effective measures are available to do so." The 2015 Regulations stated that any Exploratory Licence holder "must apply the Precautionary Approach and employ best environmental practice, including best available technology...".

Applying the Precautionary Principle means that before a development activity is approved, the responsibility is on the developer to reasonably prove that their technology, processes and mitigation measures will minimise environmental impacts to acceptable levels. The distinction between acceptable and unacceptable environmental impacts should be a community decision based on the best available scientific information. The conclusions of different community groups will be an important part of the Environmental Impact Assessment (EIA) which will determine if, and under what conditions, nodule mining can occur.

This booklet presents an overview of the physical and biological environment around and above the nodule fields. This information is used to identify specific ways the environment could be negatively impacted by mining and it proposes procedures that could effectively minimise those impacts.

The review concludes that criteria of maximum-acceptable environmental impacts could be established in advance, based on the nodule mining proposal of engineers at Southampton University (Agarwal et al. 2012). These criteria could evolve as more information becomes available.

Furthermore, if Exploratory Licence applicants knew in advance the criteria of maximum-acceptable environmental impacts for mining, only consortia confident of achieving those standards would apply. In this way, an exploratory contractor could be confident of progressing through the EIA to a Mining Licence to recover the immense investment in exploration and technology development; and more importantly, it would mean that the Cook Islands could be confident that seabed mining would be an environmentally acceptable activity. Independent monitoring of activities would ensure that impacts continued to be minimal and acceptable.

3. Nodule Distribution and Value

In the Cook Islands the polymetallic nodules are mainly in the South Penrhyn Basin (SPB) at about 5,200mbsl (metres below sea level). The nodules are blackish spheres with a smooth surface, typically 2-8cm diameter. They lie on the surface of the red sediment where they grow by the continuous addition of minerals from seawater, having formed around an inert nucleus, such as a shark tooth or rock fragment.

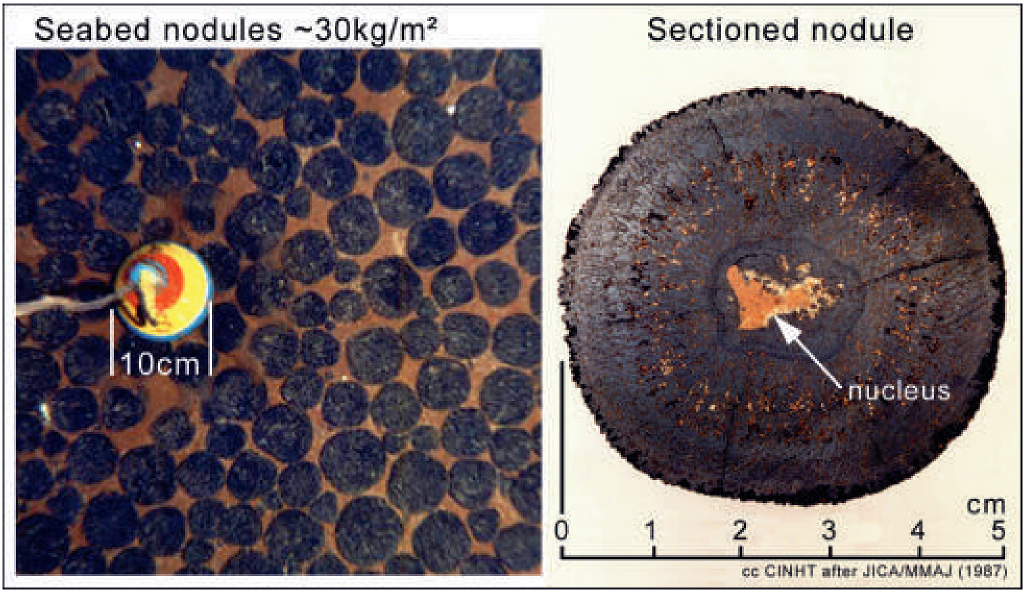


Figure 3. Nodules on the SPB seabed and one sectioned. The left image shows nodules on the South Penrhyn Basin seabed at a density of more than 30kg/m². They are typically spheroidal, 2-8cm diameter and all are on top of the sediment. The sectioned nodule shows the inert nucleus around which the deposition of minerals commenced.

A typical 5cm diameter nodule weighs about 150g (wet weight) and has taken about 13 million years (13Ma) to grow (Hein et al. 2015). In the South Penrhyn Basin there are large areas with nodule densities of 30kg/m² or more. (**Figure 3**)

The main minerals are Manganese (Mn), Cobalt (Co), Nickel (Ni) and Copper (Cu) which provide the core value of nodules. In addition, Cook Islands nodules contain significant amounts of Titanium (Ti) and the "Rare Earth Elements plus Yttrium" (REY). Although not included in baseline evaluations, the Titanium is likely to be extracted and will provide added value. The REY are increasing in demand for modern technology, such as TV screens, hybrid vehicles and energy-efficient light bulbs. However, despite their increasing value the very high cost of separating the REY metals makes this unlikely in the near future.

The Clarion-Clipperton Zone (CCZ) nodule field (**Figure 2**), between Hawai'i and Mexico, has been well studied since the 1970s when several industrialised countries staked claims. The Zone, being in International Waters, came under the control of the International Seabed Authority (ISA) in 1994 and since 2001 it has been packed sardine-tight with 15-year Exploratory Concessions, each of 75,000km^2 or equivalent to 66% of New Zealand's North Island (114,000km^2).

The ISA allocation system provided 150,000km^2 to developed states. After exploration the states relinquished a commercially equal half for use by ISA itself or for reallocation to a developing state. Under this system, the Cook Islands as a developing state has an Exploratory Concession, which it is developing in partnership with the Belgian company, G-Tec Sea Mineral Resources (GSR). ***See Appendix 1 for more details on the Clarion-Clipperton Zone licence allocations.***

Compared to most South Penrhyn Basin nodules, Clarion-Clipperton Zone nodules have grown by a different process, have a different mineral composition, and are more valuable weight-for-weight based on the main 4-metals comparison: US$1,100 to US$600 per dry tonne based on 3-year average prices for Mn+Co+Ni+Cu (Hein et al. 2015). (**Table 1**)

Nodule composition (dry[1])

Component	SPB general	CCZ
Iron Fe	16%	6.16%
Manganese Mn	17%	**28.4%**
Cobalt Co	**0.38%**	0.21%
Nickel Ni	0.38%	**1.30%**
Copper Cu	0.23%	**1.07%**
4-metal US$[2]	*$600/dt*	*$1,100/dt*
Titanium Ti	**1.28%**	0.32%
∑REY[3]	**0.17%** 1,678ppm	0.08% 813ppm

[1] % per dry weight excludes pore water 27% for SPB and ~30% for CCZ

[2] Mn+Co+Ni+Cu value 2015 (after Hein et al.)

[3] ∑REY = the 14 natural Rare Earth Elements + Yttrium

Composition: Hein et al. 2013 (for CCZ) & Hein et al. 2015 (for SPB)

Table 1. The composition of nodules and their value. The table shows that South Penrhyn Basin nodules differ from Clarion Clipperton Zone nodules in composition and value.

However, this value difference is offset in the extensive South Penrhyn Basin areas with more than 30kg/m², which is double the density of the typical best areas of the Clarion-Clipperton Zone. In such areas, the South Penrhyn Basin nodules are about equal to those of the CCZ in value per-square-metre. Hein et al. (2015) concluded "the [Cook Islands] EEZ is potentially a world-class metal resource".

The first six Exploratory Licences in the Clarion-Clipperton Zone expire in 2016 (March-June). However, as of January the six "Pioneer Investors" (China, France, Japan, Korea, Russia and the Eastern Europe Group) have all applied for 5-year extensions, hoping for metal prices to increase to make mining commercially viable. Although metal prices fluctuate wildly, the five years 2010 through 2015 showed an over-riding decline on InfoMine.com: Mn and Co down 40%, Cu down 25% and Ni down 50%. Profitable seabed nodule mining is not likely any time soon.

In the Cook Islands system the contractor-retained portion of each Exploratory Concession will be about 5,500km², a mere 7% of the contractor-retained areas in the Clarion-Clipperton Zone. The assumption is that a commercially viable mine would harvest 2.5Mdt/y (million dry tonnes per year) for 20 years. Although the 5,500km² concessions in the SPB with high densities of nodules could support two such 20-year mines, areas with fewer nodules might not support a 2.5Mdt/y 20-year mine. The initial tendering system is based on relatively small areas and it is likely that adjustments will need to be made in the future based on the results of the exploratory research to ensure each mine will be viable and profitable.

At 2015 values, the main 4-metals from a 2.5Mdt/y mine would have a gross value of about US$1,500M/y. Although the way government revenue will be calculated is unclear, we can obtain an indicative value by applying a simple 3% resource royalty to the gross metal value. Such a royalty would generate an annual revenue of US$45M, which is about 3x the revenue from fisheries or 30% of the revenue from tourism.

In the Central Area of the South Penrhyn Basin with its high density of nodules, such a mine would need to harvest an area about 2.5x the area of Rarotonga each year. The Central Area alone could support one mine of 2.5Mdt/y for 120 years; or two mines for 60 years. The resource is immense and it will have immense value sometime in the future.

However, more is not always better. It has been estimated that two 2.5Mdt/y mines in the South Penrhyn Basin would supply 24% of the global demand for Cobalt and 26% for Titanium. Hein et al. (2015) concluded that this level of production could negatively impact world prices and mine profitability.

4. The Environment and Best Practice

The Cook Islands seabed consists of the high Manihiki Plateau in the northwest, north of Suwarrow; and the very deep South Penrhyn Basin (SPB) from Penrhyn southward to Aitutaki. The polymetallic nodules are on the SPB seabed at about 5,200mbsl, under the influence of Antarctic Bottom Water (AABW) flowing northward from Antarctica. (**Figure 4**)

The SPB has several large areas with more than 20kg/m² of polymetallic nodules (***hatched and outlined in yellow***). The largest high density area is known as the Central Area; this review is mainly focused on the environmental parameters and nodules of this area.

The easiest way for the Cook Islands to develop ideas of best practice for deep seabed mining is to look at the experience of other countries. Pacific countries developing deep sea mineral resources include: Papua New Guinea with many Exploratory Licences and one Mining Concession for Seabed Massive Sulphides

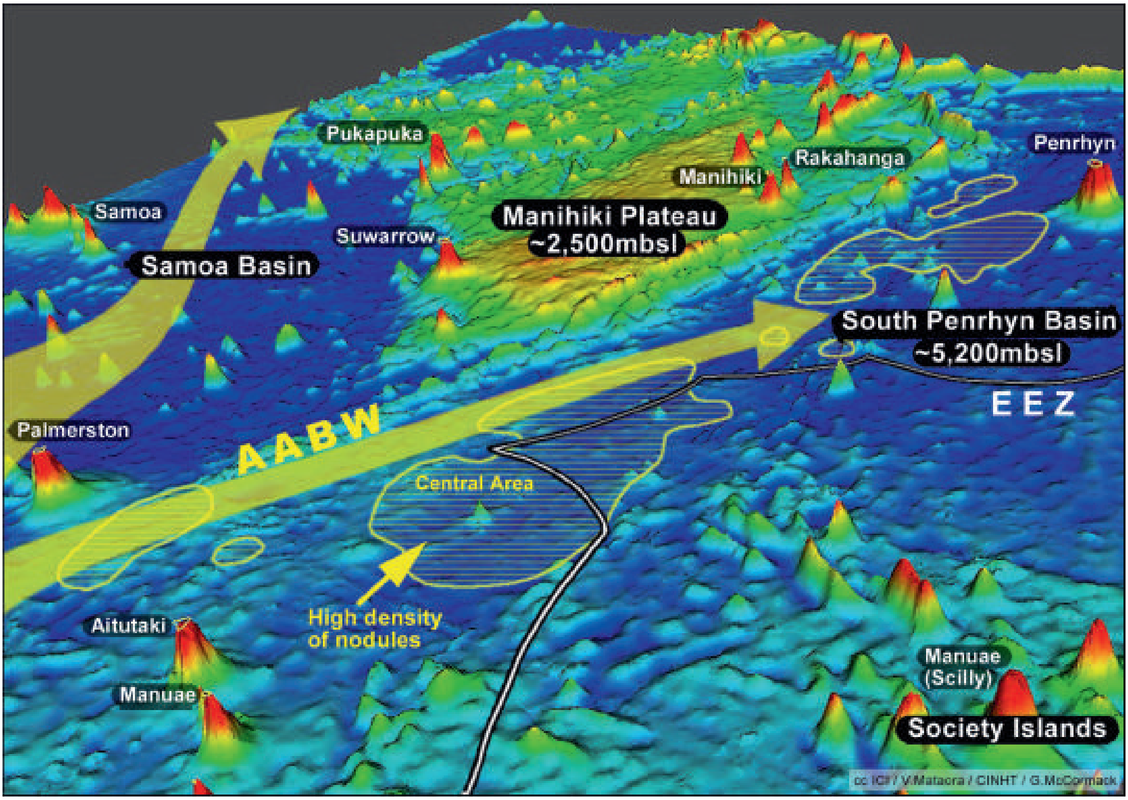


Figure 4. The seafloor of the Cook Islands. In the northwest the immense Manihiki Plateau has a large area about 2,500mbsl (metres below sea level). In the east the South Penrhyn Basin is a rather uniform plain 5,200mbsl with large areas of polymetallic nodules (*outlined and hatched yellow*). The Antarctic Bottom Water (AABW) is oxygen rich and near freezing. It is about a kilometre high and flows northward through the South Penrhyn Basin.

(SMS); and Tonga with many Exploratory Licences for Seabed Massive Sulphides in the Lau Basin. New Zealand had Exploratory Licences for iron sands off Taranaki and phosphates between Christchurch and the Chatham Islands, although both applicants were declined Mining Licences in 2015. Unfortunately there is little the Cook Islands can learn from these countries because the environments, mineral deposits and proposed mining systems are radically different from the Cook Islands situation.

The Cook Islands can learn most from the Clarion-Clipperton Zone nodule field, even though that nodule field has significant differences in having a much higher surface productivity, an extensive silicate sediment, a weaker AABW current, and a large percentage of buried nodules that obtain minerals from water within the sediment rather than directly from the AABW seawater.

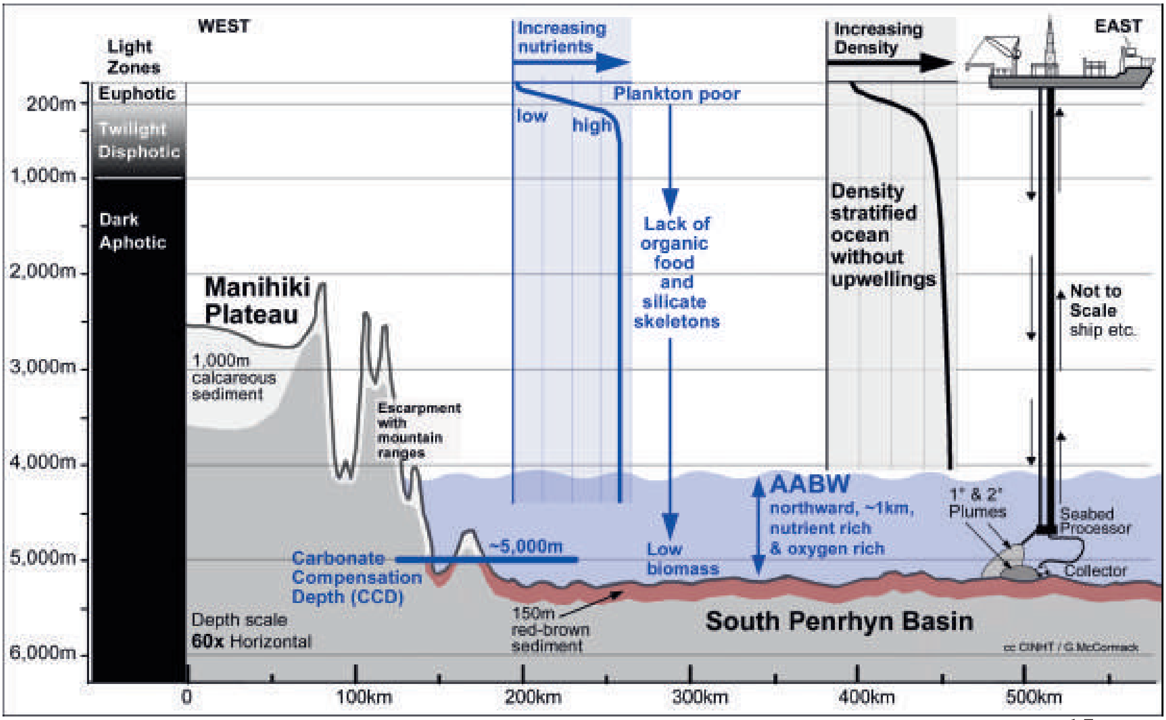
Despite these differences, the primary environmental concerns of mining abyssal seabed nodules are similar: (1) sediment plumes on the seabed; (2) discharge of nutrient rich water in the water column, with or without sediment; (3) intense noise; (4) intense light; and (5) destruction of seabed biodiversity.

5. South Penrhyn Basin Environment

Figure 5 presents some of the key aspects of the environment related to nodule mining in the South Penrhyn Basin (SPB). On the left is the depth in metres and a light scale showing ample sunlight to 200m and a twilight zone to 1,000m. Below 1,000m it is totally dark or pitch black; and most animals in this zone use bioluminescence to communicate, hunt prey and avoid predators.

The seafloor profile shows the Manihiki Plateau in the west (*left*), which is around 2,500mbsl (metres below sea level) including a 1,000m thick layer of pale

Figure 5. The key environmental features of the South Penrhyn Basin. The nodules are concentrated on the relatively flat seabed at around 5,200mbsl dominated by the very cold oxygen-rich AABW. See the main text for a discussion of the important features.



calcareous sediment composed of the skeletons of dead plankton sunk from the ocean surface. To the east (*right*), the plateau has a rugged 100km wide escarpment descending down to the extensive SPB abyssal plain at about 5,200mbsl, which has a thin red-brown sediment composed of the fine dust blown from distant continents.

The Carbonate Compensation Depth (CCD) is the depth by which all carbonates are dissolved. In the South Penrhyn Basin the CCD is about 5,000mbsl which means the abyssal plain below this depth lacks calcareous sediments and also lacks animals requiring a calcareous skeleton.

Figure 5 includes a generalised nutrients profile for the Central Area of the South Penrhyn Basin (SPB). This profile shows very low nutrient levels in the surface waters down to about 100mbsl, a rapid increase of nutrients to about 500mbsl, and then continuing high levels all the way to the seabed.

Plant plankton need sunlight and nutrients to make food by photosynthesis. The SPB has an abundance of sunlight, but the near absence of surface nutrients leads to very low levels of plant plankton and very little productivity. Such areas have very clear blue water and are known as Oligotrophic Regions or "biological deserts". ***See Appendix 2 for more information on pattern of plankton productivity in the Pacific.***

The very low level of plant plankton and pelagic animals means there are very low quantities of corpses and faeces to sink down to provide food for seafloor animals. As a result the central SPB seabed is expected to have a very low biomass of seabed life. ***See Appendix 3 for information on the quantitative relationship between "sinking food" and seabed biomass.***

In the SPB there has been limited sampling of Megafauna and Macrofauna. Megafauna are animals larger than 40mm which means that those living near or on the seabed can be recorded photographically.

They are mainly sea-cucumbers, prawns and jellyfish, along with a few fish. In the SPB, Megafauna was less common and less diverse than in the Clarion-Clipperton Zone.

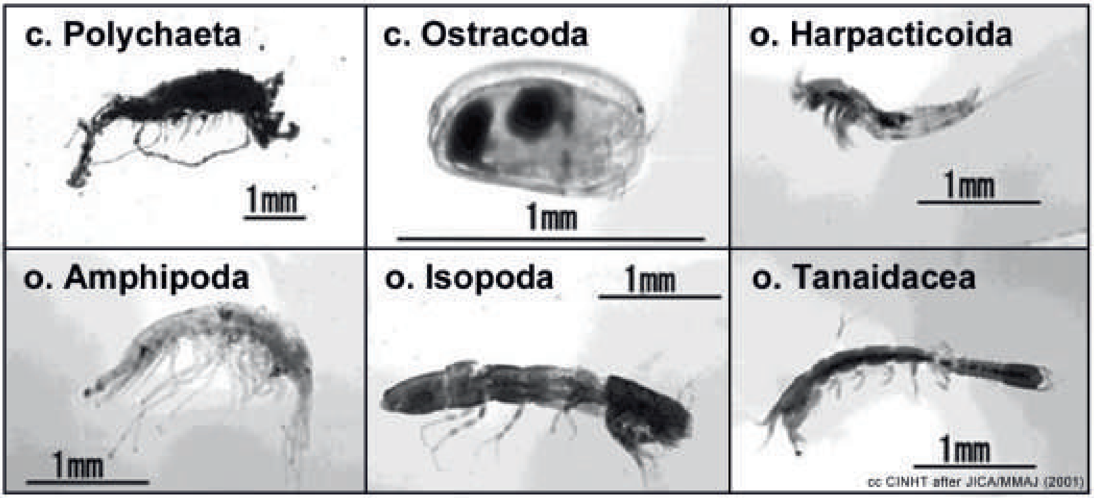


Figure 6. Macrofauna of the South Penrhyn Basin. Five samples found nine distinct species in the following taxonomic groups: nematoda, bivalvia, polychaeta, annelid, ostracoda, harpacticoda, tanaidacea, isopoda, and amphipoda.

The SPB typically had 20-40 individuals/m², in contrast to 400-800 in the CCZ, and in terms of species richness the SPB had less than 12 species/m² compared to 80-100 species/m² in the CCZ.

Within the sediment the largest animals are Macrofauna which are up to 40mm and as small as 0.3mm, with most less than 5mm longest dimension. In the SPB they are mainly crustacea and worms, and they all live in the top 2cm of the sediment. (**Figure 6**)

Compared to Macrofauna in the Clarion-Clipperton Zone the SPB has a very low biomass and low species richness. Although the sampling has been inadequate, initial indications are that most species are wide-ranging rather than restricted. ***See Appendix 4 for more on the ranges of the nine known species.***

Smaller than Macrofauna at less than 0.3mm are the Meiofauna. These have not been surveyed but surveys in other abyssal areas indicate that SPB Meiofauna is probably mainly nematode worms.

The smallest organisms are the Microfauna consisting mainly of bacteria. The Microfauna is the dominant biomass on the nodules and in the sediment, probably more than double the biomass of

Macrofauna. They are mainly aerobic bacteria using the oxygen from the oxygen-rich AABW, which diffuses deep into the sediment.

Despite the low level of species diversity and probable low level of limited-range species, it is important to accept that removing the nodules will severely damage animals and their habitat in the mined area. Although large areas will not be mined for various reasons, such as steepness, it is important to take proactive measures to ensure no species is driven to extinction. This can be achieved by the establishment of seabed Biodiversity Preservation Areas (BPAs) ecologically equivalent to the mine area. ***See page 24-25.***

Another result of the very low level of surface nutrients is the near absence of silicate-based plankton to sink to the seabed. Consequently, the SPB abyssal plain lacks siliceous sediment (less than 1%) and seabed animals that require a silicate skeleton. This is in marked contrast to the Clarion-Clipperton Zone where silicate sediments and animals with silicate skeletons are relatively abundant.

The primary mining concern arising from the nutrient profile is that the release of any nutrient rich bottom-water near the surface would cause a dramatic increase in nutrient levels followed by a major increase in plankton and animal life. While this might initially sound like a benefit, it could also make the surface ecosystem unstable. In the face of the unknown environmental consequences, the Precautionary Approach indicates that best practice is to pump all uplifted water and sediment back to the seabed.

Close inspection of the nutrient profile shows that nutrient levels are rather similar from 1,000m downward and therefore consideration could be given to returning bottom water to 1,000mbsl rather than to the seabed. However, sediment should not be released anywhere in the water column because it can clog feeding mechanisms and reduce visibility for bioluminescent animals.

Figure 5 also includes a profile of water density against depth. The profile shows that density increases rapidly down to about 1,000mbsl and then increases very slowly to the seabed. This density increase is mainly caused by decreasing temperature.

The coldest water in the Pacific Ocean is in the Antarctic Bottom Water (AABW) that flows north from Antarctica, forming a current about a kilometre high on the seabed. This current is so cold (about 1°C) and dense it splits to flow west and east around the Manihiki Plateau because it cannot rise up to flow over the top.

The environmental benefit of the increasing density with depth, combined with the absence of upwelling currents in the South Penrhyn Basin, is that any sediment plumes caused by activity on or near the seabed will not rise into the surface waters to damage ecosystems or disrupt fisheries. Nevertheless, sediment plumes should be minimised to reduce the amount of resettling sediment which could smother nearby animals living in the sediment.

The initial maximum-acceptable sediment plume could be based on the Southampton system which was less than two tonnes of sediment per tonne of nodules (2:1). This is very modest compared to some active collectors at 12:1, and passive collectors are typically around 20:1.

6. Whales and Seabed Mining

Each year a few Humpback Whales visit the Southern Group islands between early July and late October. Research has shown that these whales are mainly en route to Tonga and that they rarely use the detour a second time. (**Figure** 7)

In the tropical South Pacific, humpbacks do not hunt food; they live on their stored fat or blubber. Without the need to dive for food they spend almost all their time within 50m of the surface. Around islands they relax, court, give birth and raise calves, and males sing loud and long. At sea they migrate at 3-6km/hr mainly along relatively straight paths.

North of Aitutaki humpbacks are rare and it is unlikely that any would encounter a surface ship or platform associated with seabed mining in the Central Area (***C in Fig. 7***). However, humpbacks are common around Palmerston; any mining in the South Area (***S in Fig. 7***) would need to give them special consideration.

Although rarely seen, we do have deep-diving Sperm Whales and beaked-whales. These toothed whales usually hunt within 1,000m of the surface with some dives to about 2,000mbsl. The deepest recorded whale dive was to 3,000mbsl by a Cuvier's Beaked Whale. In the SPB such a dive would terminate 2,000m above any seabed equipment.

While whale encounters with technology are very unlikely, loud noise could disturb their behaviour. The toothed whales, such as the Sperm Whale, Cuvier's Beaked Whale, and dolphins use high frequency sound (1,000-100,000Hz) to communicate and echolocate their prey. While most noise associated with mining machinery will be low frequency, the uplift system might emit high frequency noise which could interfere with toothed whale communication and sonar hunting.

The baleen whales such as the Blue Whale, Fin Whale and Sei Whale communicate with low frequency calls in the range 5-200Hz. The exception is the male Humpback Whale which sings long songs with a frequency range from 20Hz to 3,000Hz.

Blue and Fin Whales are known to communicate over thousands of kilometres with very low frequency calls (5-30Hz) in the Deep Sound Channel (DSC), which is between about 700 and 1,500mbsl. It is important to reduce low frequency noise from the uplift system in the DSC.

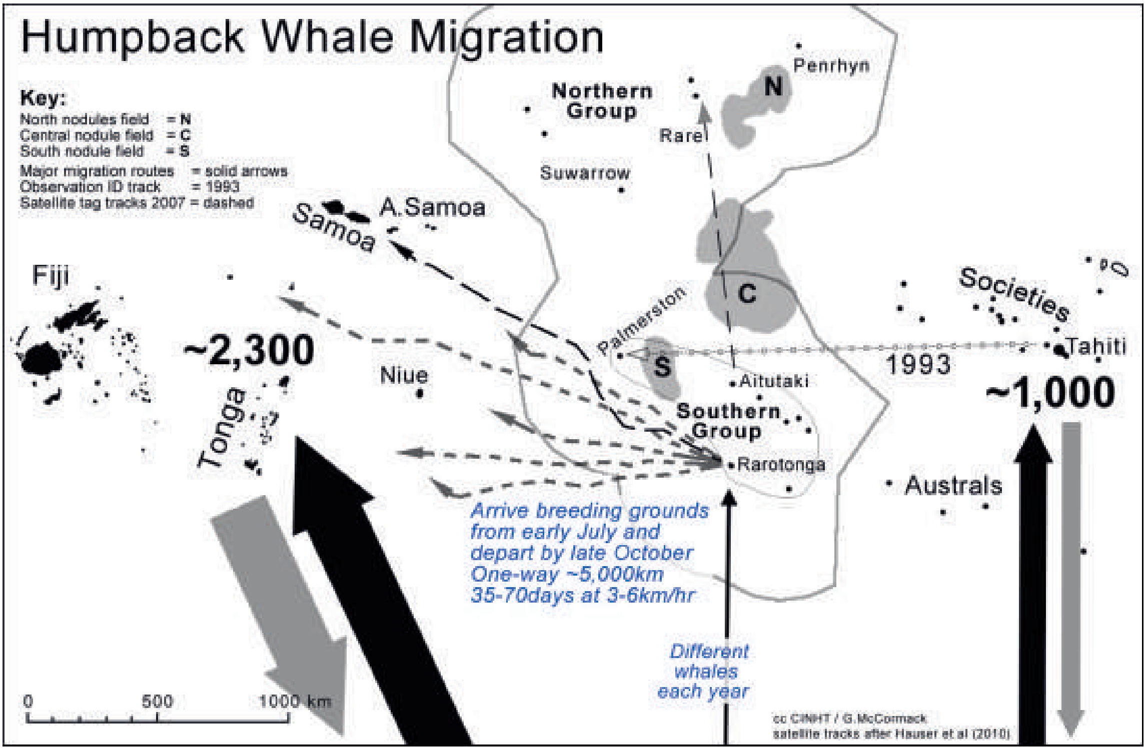


Figure 7. Humpback Whale migration. Each year about 2,300 whales migrate to Tonga and about 1,000 to the Societies and Australs in French Polynesia. The few whales visiting the Southern Cook Islands are mainly en route to Tonga as shown by genetic studies and the tracks of six whales tagged in 2007 (*arrows of circles*).

Humpbacks do not communicate in the Deep Sound Channel. Nevertheless a male humpback song at 170dB (in water) is probably audible for about 500km, from Rarotonga to Palmerston. Low frequency mining noise should be monitored and assessed in relation to the proximity of Humpback Whales. ***See Appendix 5 for more information on the intensity and frequency of underwater sounds in relation to whale hearing.***

In general, seabed mining is unlikely to produce any noises that would startle or disorientate toothed or baleen whales. Nevertheless, as a precaution it is important that equipment developers minimise noise. They should also provide intensity and frequency data for assessment by experts in relation to whales and dolphins so mitigation can be implemented if necessary.

7. Precautionary Approach Focal Points

The above outline of the environment surrounding the nodule fields enables us to identify features of the environment that could be negatively impacted by seabed mining. The Precautionary Principle applies to each of these environmental features, whereby the developer must establish in the Environmental Impact Assessment (EIA) that their activities will have minimal and acceptable impacts. One way to focus discussion on levels of impact is to establish criteria of maximum-acceptable impact on each important aspect of the environment.

Figure 8 illustrates the mining system proposed by Southampton University engineers; it identifies each aspect of the environment impacted and suggests some acceptable levels of impact. The illustration also shows a seabed Biodiversity Preservation Area which could ensure zero extinction of seabed animals.

The aspects of mining that require criteria of maximum-acceptable impact include:

A. primary (1°) seabed sediment plume from the collectors should be less than 2:1 (plume to nodules) to minimise the smothering of nearby seabed animals, and the secondary (2°) sediment plume with the returning water should also be minimised (***Fig. 8 #1 and 4***);

B. uplifted slurry of nodules, water and sediment should be completely isolated from the water column to prevent any contamination or other effects on marine biodiversity (***Fig. 8 #2***);

C. all nutrient rich water, with or without sediment, taken up to the surface Production Support Vessel should be kept isolated and returned to the seabed to ensure surface waters are not enriched causing plankton blooms and to prevent sediment clogging filter-feeding mechanisms of animals in the water-column (***Fig. 8 #3***);

D. low frequency noise should be less than that likely to interfere with Humpback Whale song

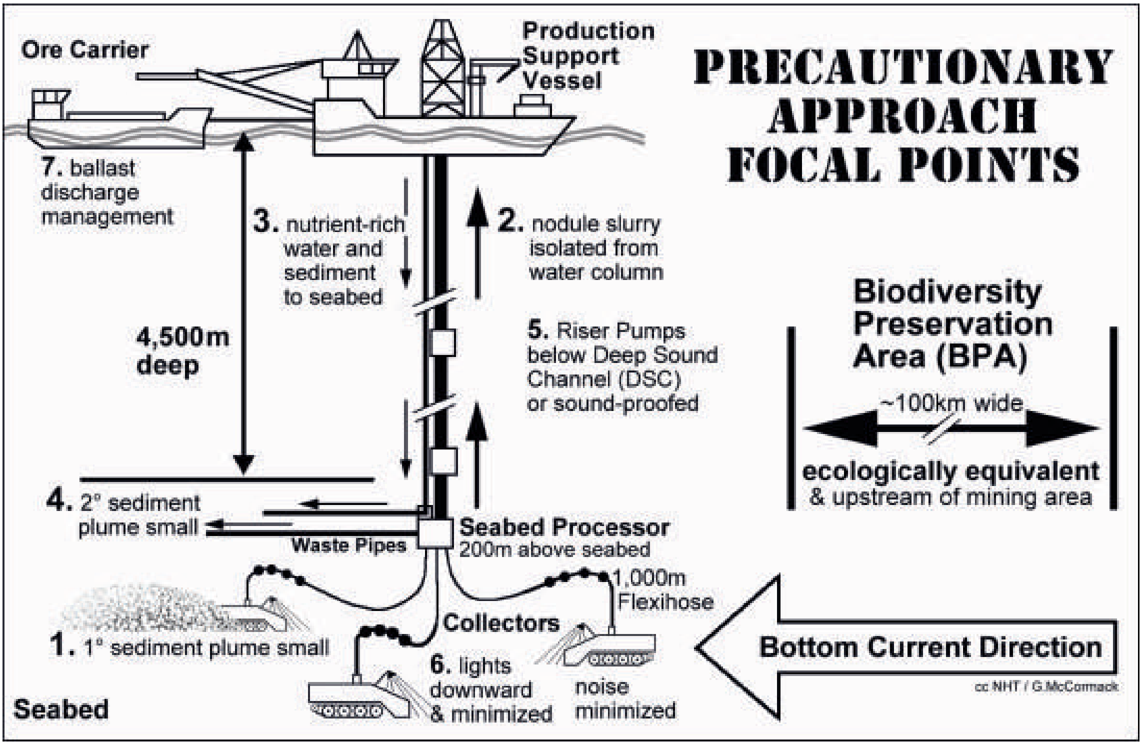


Figure 8. Precautionary Approach focal points. The Precautionary Principle requires the developer to establish that their system will have minimal and acceptable impacts at each focal point. Regardless of best technology and processes, animals on the seabed will be destroyed by the direct impact of collectors. The Ecosystem Approach should be used to establish a suitable Biodiversity Preservation Area to ensure zero extinction.

communication, and minimised within the Deep Sound Channel (~700-1,500mbsl) which is used by Blue and Fin Whales to communicate over long distances (*Fig. 8 #5*);

E. white lights on seabed collectors should be downward pointing and minimized to reduce impacts on bioluminescent animals; these impacts could be further reduced by the use of yellow, orange or red light, which is invisible to deepsea bioluminescent animals (*Fig. 8 #6*); and

F. mid- and high-frequency noise emitted by collectors, uplift pumps and nodules in uplift pipes should be below levels likely to interfere with toothed-whale echolocation and communication.

Note: This booklet does not discuss the environmental issues associated with smelting. This will occur overseas in countries with abundant electricity and water, and land to dispose of the immense quantity of slag.

8. Biodiversity Preservation Areas

The seabed collectors will remove nodules, the only hard substrate for microbes and animals. They will also mechanically damage the small benthic animals in the sediment. The only way to ensure no species becomes extinct is to fully protect parts of their populations.

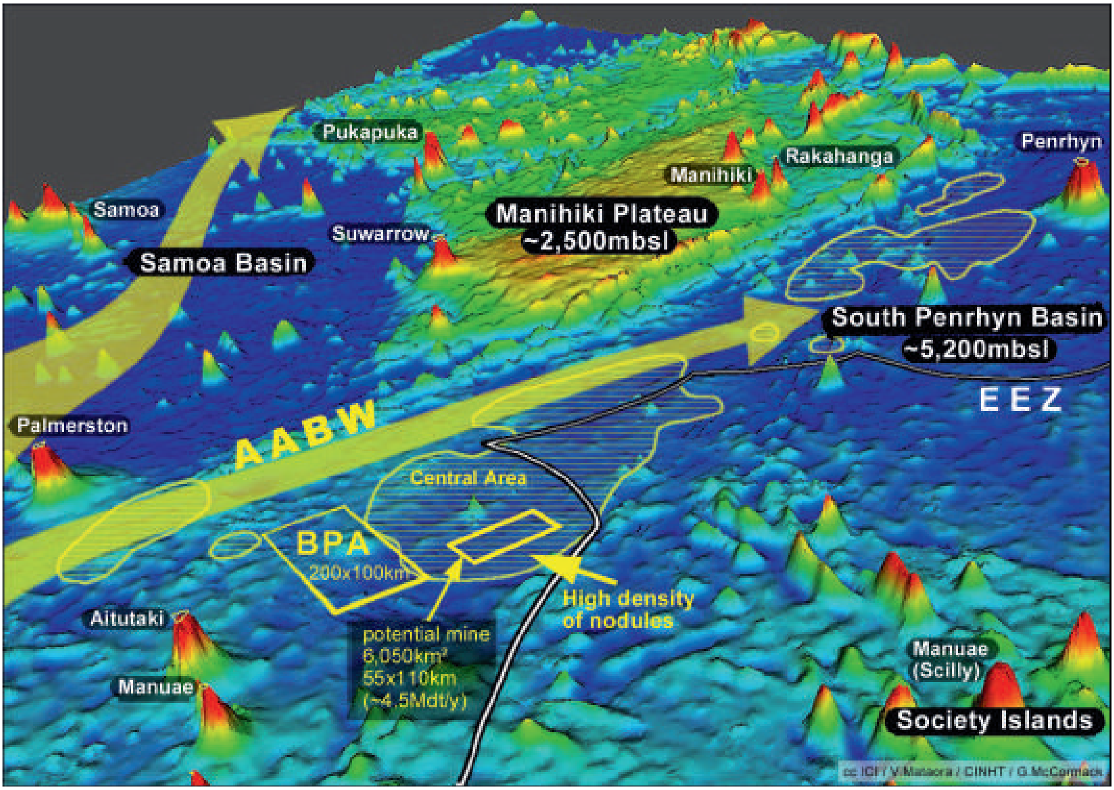


Figure 9. Overview of a mine site and its Biodiversity Protection Area (BPA). In the South Penrhyn Basin the Antarctic Bottom Water (AABW) flows north on the seabed and the BPA should be up-current or south of the mine site. In this way mobilised sediment from the mine site will not resettle on the BPA and eventually larvae from the BPA will recolonise the mine site.

This will happen automatically to some extent, because the collectors will be unable to access steep areas. However, as a precautionary measure to achieve zero extinction, suitable seabed Biodiversity Preservation Areas (BPAs) should be established.

BPAs should be established using the Ecosystem Approach to identify an area ecologically equivalent to the mine site and located distantly or up-current (southward), to protect it from sediment resettlement (**Figure 9**). Ecological equivalence can be established by morphological and genetic recognition to ensure species in the mine area are also in the BPA. However, the international shortage of taxonomists means most species will not be identified with Latin names.

The Clarion-Clipperton Zone has nine preservation areas known as Areas of Particular Environmental Interest (APEIs) which have been established using the extensive biological knowledge obtained by the industrialised countries with Exploratory Concessions. In an equivalent system the Cook Islands should require Exploratory Licence holders to undertake sufficient biological sampling within and near their concessions to enable ecologically equivalent areas to be found for the establishment of effective BPAs.
See Appendix 6 for a comparison of mine areas and preservation areas in the Cook Islands and in the Clarion-Clipperton Zone.

9. Concluding remarks

It is remarkable that the Cook Islands is the only country in the world with a widely recognised commercially viable polymetallic nodule field within its Exclusive Economic Zone. This situation is due to the particular physical environment in the South Penrhyn Basin. Furthermore, these particular physical features and various resultant biological features could enable mining with minimal environmental impacts, when using the best proposed technology and processes. In addition to best technology and processes, benthic biodiversity needs to be further protected by the establishment of Biodiversity Preservation Areas that are ecologically equivalent and protected from sediment resettlement.

While the development of the best technology and processes will be expensive, it is not likely to be overly challenging to engineers. Thirty years ago there were experimental machines collecting nodules at 5,000mbsl, and currently there are prototype collectors at various stages of development.

The engineering challenge is not the development of deep seabed mining technology per se, it is the development of seabed mining technology and processes that will minimize each negative impact to an acceptable level. This booklet has identified the various aspects of the environment that will be impacted in addition to suggested acceptable levels of impact. The suggestions included: zero release of bottom water within 1,000m of the surface; zero release of seabed sediment in the water column at any depth; and restricting the primary seabed sediment plume to less than 2:1 (plume to nodules).

Before any mining is approved there will be an Environmental Impact Assessment. In applying the Precautionary Principle, the responsibility is on the developer to prove beyond reasonable doubt that their technology and processes will have minimal and acceptable impacts on each aspect of the environment. The EIA should also establish the required level of monitoring of environmental impacts, and require that such data be available to the public and independent assessors.

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Figure 3
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Table 1
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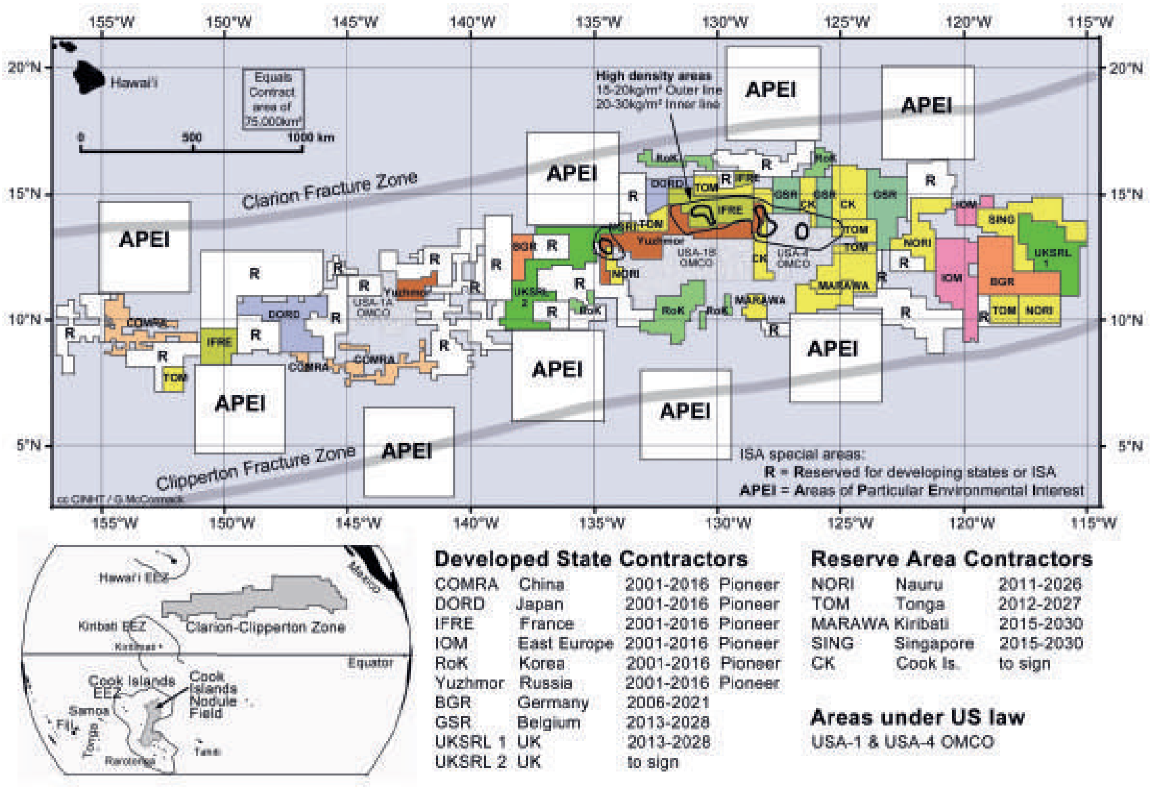
(2) Hein et al. (2015) Critical metals in manganese nodules from the Cook Islands EEZ, abundances and distributions. Ore Geology Review. 68:97-116.
Figure 6 & Appendix 4
JICA/MMAJ (2001) Report on the Cooperative Study Project on the Deepsea Mineral Resources in Selected offshore Areas of the SOPAC Region, Sea Area of the Cook Islands, Vol. 1.
Figure 7
satellite tracks from Hauser et al. (2010) Movements of satellite-monitored humpback whales, *Megaptera novaeangliae*, from the Cook Islands. Marine Mammal Science 26(3):679-685
Appendix 1
based on various maps by the International Seabed Authority (ISA)
Appendix 2
modified after http://www.science.oregonstate.edu/ocean.productivity/index.php
Appendix 3
modified after (1) Smith et al. (2008) Abyssal food limitation, ecosystem structure and climate change. Trends in Ecology and Evolution 23:518-528; and
(2) Hannides & Smith (2003) The Northeastern Pacific Abyssal Plain (chapter 7, p.208-237). *In* Black & Shimmield (eds) Biogeochemistry of Marine Systems. Blackwell Publishing, Oxford.

Further references

To make the text easier to read, the author has excluded references, except for the two key documents listed in the bibliography. If you have a particular interest in some aspect of the information, please contact the author for references.

Appendix 1: The Clarion-Clipperton Zone Nodule Field

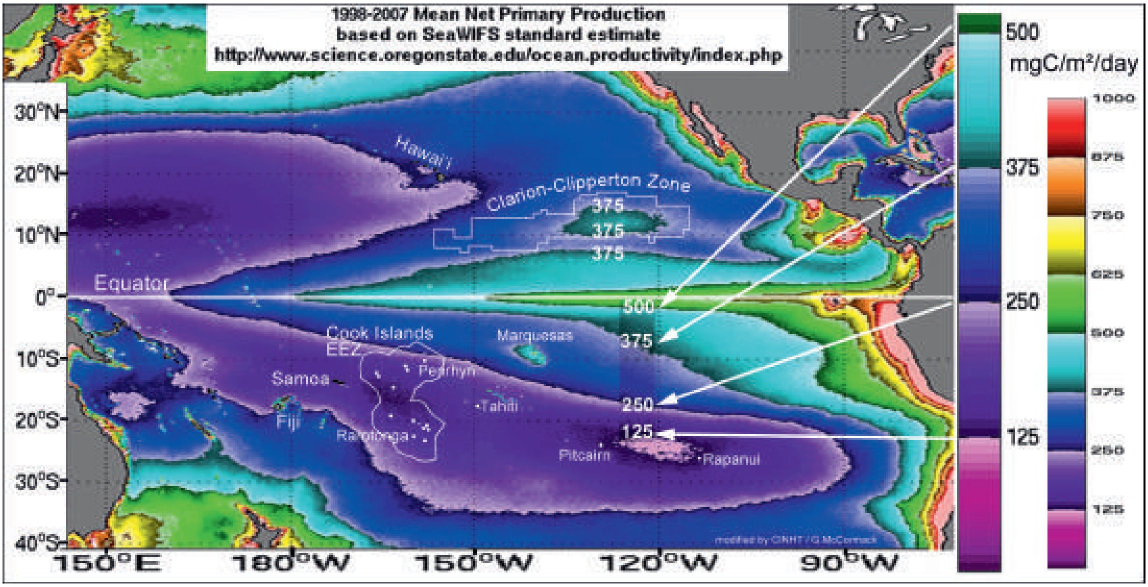


The Clarion-Clipperton Zone (CCZ) nodule field, between Hawaiʻi and Mexico, is an east-west band about 4,000km long and 600km wide. It has an area of about 1.7M km², equivalent to the area of Queensland (1.7M km²), 2.5x Texas (700,000km²) or a little smaller than the entire Cook Islands EEZ of 2M km².

The band is packed sardine-tight with 20 International Seabed Authority (ISA) Exploratory Concessions each of 75,000km²: ten with consortia sponsored by developed countries (including two by the UK); ten relinquished areas as Reserve Areas under ISA for use by itself or for reallocation to developing countries; and two non-ISA areas held under US law (totalling about 200,000km²). ISA has reallocated five of its Reserve Areas to developing countries (***yellow areas***), including one to the Cook Islands (***marked CK***).

Nine Areas of Particular Environmental Interest (APEI) have been established around the contiguous band of exploratory areas to preserve biodiversity in the area. The APEIs are equivalent to the Biodiversity Preservation Areas (BPAs) proposed for the Cook Islands situation.

Appendix 2. Pacific Ocean Productivity



The productivity of the ocean is a measure of the amount of chlorophyll available in plant plankton to convert sunlight and minerals into food. When there is plenty of sunlight, the limiter of productivity is the amount of nutrients or minerals in the surface waters.

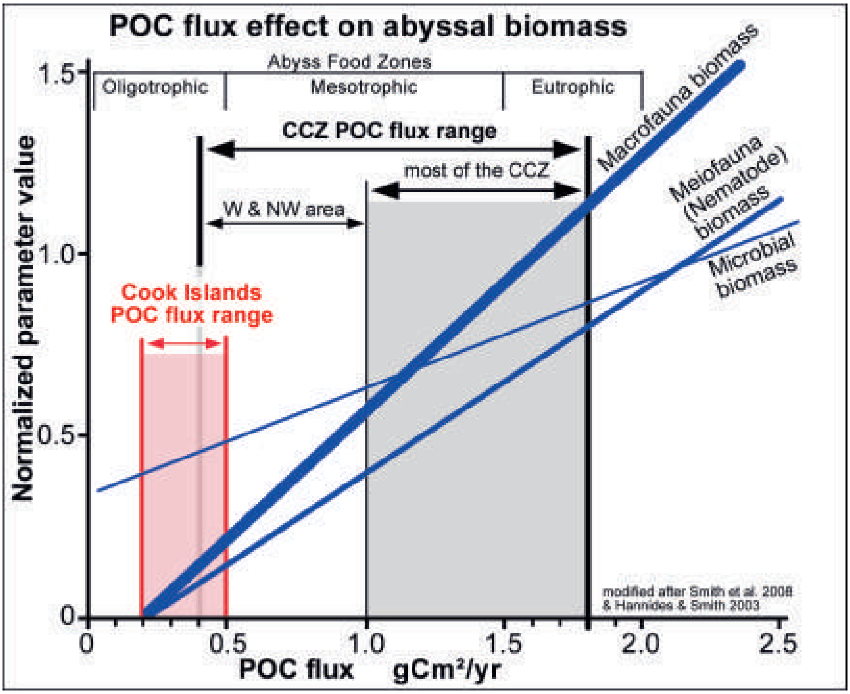
The illustration shows the productivity of the Pacific Ocean. In the South Pacific it shows a band of high productivity near South America and extending westward along the Equator (*green*), and this high productivity is based on the high nutrient content of the water.

The ***purple area***, inside the 250mgC/m^3/day line, extends from north of Fiji through the Cook Islands and French Polynesia to beyond Rapanui. This area has very low productivity because of low levels of nutrients in the surface waters caused by a lack of upwellings.

Within the Cook Islands the area of lowest productivity is from Aitutaki and Palmerston north to Manihiki; further north productivity increases, reaching a Central Pacific maximum at the Equator. The level of surface productivity controls the amount of pelagic marine life; in turn, this controls the amount of seabed life.

In the North Pacific the Clarion-Clipperton Zone (CCZ) has about twice the productivity of the South Penrhyn Basin, which is why the CCZ has a much greater biomass of seabed animals, a siliceous sediment and benthic animals with silicate skeletons. Furthermore, its nodules grow partially or completely within the sediment which gives them a different composition than those of the South Penrhyn Basin.

Appendix 3. "Sinking food" versus Seabed Biomass



The productivity of the ocean surface (*Appendix 2*) determines the amount of plankton and animals to form corpses and faeces to sink to the seabed as food for the benthic animals. Scientifically, the "sinking food" is referred to as the Particulate Organic Carbon flux or POC flux.

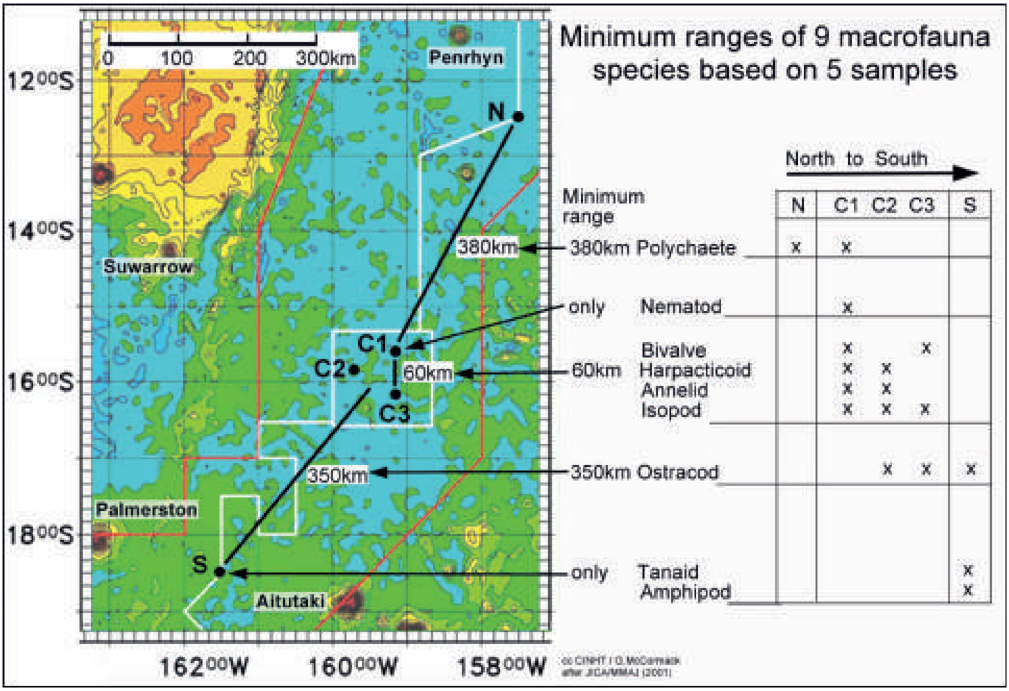
The graph shows increasing biomass upward and increasing POC flux to the right. Most of the Clarion-Clipperton Zone has a high POC flux of 1.0-1.8gCm^2/yr. The South Penrhyn Basin has a very low POC flux of 0.2-0.5gCm^2/yr (***in red***); mainly lower than the poorest areas in the CCZ.

Extensive research in the CCZ has shown that the biomass of Macrofauna and Meiofauna decline dramatically with decreasing POC flux (***right to left***). In simple terms, decreasing amounts of "sinking food" means decreasing amounts of animal life on the seabed.

The very low level of POC flux in the South Penrhyn Basin (***in red***) leads to the prediction that the biomass of seabed animals will be very low. The very few biological samples from the South Penrhyn Basin are consistent with this prediction.

The Microfauna or Microbial Biomass, mainly bacteria, is not as dramatically reduced by decreasing levels of POC flux (***right to left***). We would predict bacteria will be relatively common in the South Penrhyn Basin, probably weighing more than the total weight of Macrofauna and Meiofauna.

Appendix 4. The Ranges of Seabed Macrofaunal Species



The macrofauna of the South Penrhyn Basin has been sampled only five times! The five samples provided nine distinct species and a few unidentifiable fragments. The illustration shows the location of the samples and the species in each.

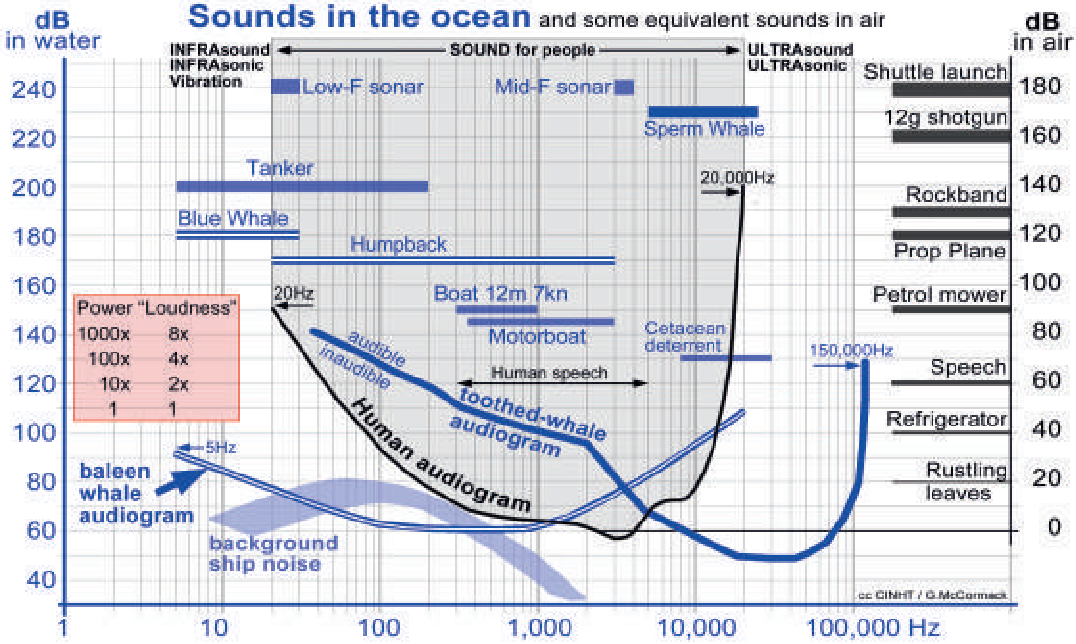
In terms of the range of each species, this woefully inadequate data shows four species had a range of at least 60km and two had a range of at least 350km. Three species occurred in only one sample which probably reflects the lack of sampling rather than limited ranges. In general, the data supports the expectation that species will have relatively wide ranges when the seafloor features are relatively uniform and the level of POC flux is uniform.

Although species-richness is relatively low on the abyssal plain there will be greater species-richness above the Carbonate Compensation Depth (CCD) on submarine mountains. Such areas should be made into biodiversity reserves.

In general, species-richness decreases eastward across the Pacific, being very high in Melanesia and low in the Cook Islands. The exception to this eastward decline is in volcanically active areas with Hydrothermal Vents or "black smokers" which are pockets of species-richness.

There are no volcanically active areas in the Cook Islands EEZ. The nearest Hydrothermal Vents to the South Penrhyn Basin are 1,000km east near Tahiti and 900km west near Samoa.

Appendix 5. Whale Hearing and Underwater Sound



This graph of hearing and sound shows frequency increasing to the right and intensity ("loudness") increasing upward. The intensity is measured in decibels (dB) with the dB-in-water scale adjusted to give dB-in-air equivalence. For example, a 12m boat at seven knots makes a noise of 150dB-in-water which is equivalent to a power mower of 90dB-in-air both measured at 1m.

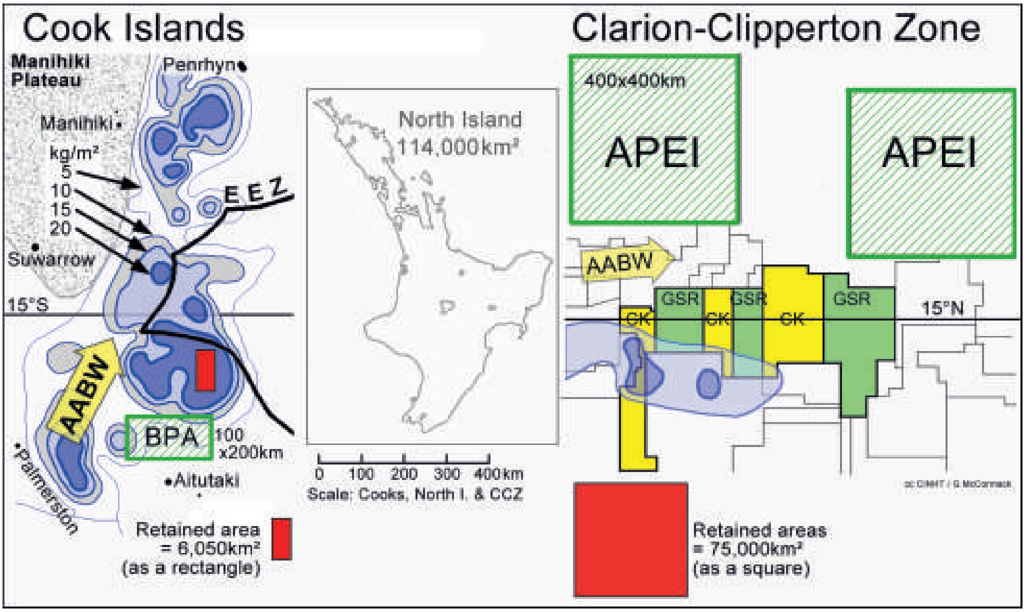
The U-shaped human audiogram (***black line***) shows that people hear as low as 20Hz and as high as 20,000Hz when sounds are loud. We are most sensitive in the range 200-5,000Hz, the frequency of human speech, which has an intensity of about 60dB-in-air.

The U-shaped audiogram for toothed whales (***blue line***), such as the Sperm Whale, show they are very sensitive to high frequency sounds (8,000 to 80,000Hz), while baleen whales (***blue-white line***) are most sensitive to low frequency sounds (10 to1,500Hz).

The call of the male Humpback Whale has an intensity of 170dB-in-water, which is about 4x as "loud" as a 12m boat at seven knots. The Sperm Whale has the loudest call of any marine mammal at 230dB-in-water; twice as loud as a 12g shotgun in air at 1m.

In seabed mining, the ships and seabed collectors are unlikely to generate very loud or startling noises. The most likely source of noise is from the uplift-pumps and the sound of nodules moving up the riser pipes. It is unclear what frequencies will be emitted, but all noise should be measured and assessed in relation to whales.

Appendix 6. Mines and Biodiversity Preservation Areas



In the Cook Islands the Exploratory Concessions are 1°x1° (~110x110km). The contractor retains 50% or an area of 6,050km², which is shown for convenience as a red rectangle of 110x55km. An effective Biodiversity Preservation Area (BPA) should be ecologically equivalent to the mine site and located up-current (south) to isolate it from sediment resettlement and to enable larvae to float down-stream to recolonise the mine site.

In the Clarion-Clipperton Zone (CCZ) each developed state contractor had an area of 150,000km²; after exploration they relinquished 50% to the International Seabed Authority (ISA). The Belgian company G-Tec Sea Mineral Resources (GSR) retained the green area labelled GSR, and ISA reallocated the relinquished 75,000km² to the Cook Islands shown in yellow and labelled CK. This Cook Islands concession, which is 66% of the area of North Island (NZ) or 12x the retained areas in the Cook Islands nodules field, is being developed in partnership with GSR.

In the CCZ, the preservation areas, Areas of Particular Environmental Interest (APEIs), are 400x400km. They have a core area of 200x200km to retain resettling larvae, and a 100km buffer zone to reduce the chance of mining plumes settling on the core area. The APEIs were not located up-current (west) because the pre-existing contiguous concessions formed an east-west band. The nine APEI were arranged to preserve parts of the nine ecological sub-regions caused primarily by different levels of surface productivity.

Summary

This booklet is an introduction to the Cook Islands seabed polymetallic nodules as a potential economic resource. It discusses the environment surrounding the nodules to identify aspects that could be negatively impacted by mining. These aspects are focal points for a Precautionary Approach and maximum-acceptable impacts are suggested related to a mining system proposed by engineers at Southampton University. Zero extinction of benthic animals and bacteria could be assured by the establishment of Biodiversity Preservation Areas that are ecologically equivalent to the mining areas and protected from plume sediment resettlement.

Author

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Previously, the author was the Science Advisor to the Ministry of Education (1980-1986); foundation Director of the Conservation Service (1988-1989); and Director of the Natural Heritage Project (1990-1999). He has a First Class Masters in Zoology from Auckland University (1972).

The author has published numerous newspaper articles, several posters and a few books on Cook Islands biodiversity. His keystone project since 1980 has been the development of a national biodiversity and ethnobiology database which has baseline information on 4,500 marine and terrestrial species of which about 2,500 have photographs to aid recognition. The database has been online since 2003 through the Bishop Museum in Honolulu.

He has participated in numerous conservation projects, including major roles in: initiating the Rarotonga Flycatcher Recovery Programme in 1987; writing the first Cook Islands National Biodiversity Strategy and Action Plan (NBSAP) in 2002; reintroducting of the Rimatara Lorikeet from French Polynesia to Ātiu in 2007; and the eradication of Common Myna on Ātiu 2009-2016.

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