NIWA
Taihoro Nukurangi

Environmental risk assessment of discharges of sediment during prospecting and exploration for seabed minerals

Prepared for Ministry for the Environment

January 2014

Authors/Contributors:
Alison MacDiarmid, Rachel Boschen, David Bowden, Malcolm Clark, Mark Hadfield, Geoffroy Lamarche, Scott Nodder, Matt Pinkerton and David Thompson

For any information regarding this report please contact:

Alison MacDiarmid
Principal Scientist
Marine Ecology
+64-4-386 0300
alison.macdiarmid@niwa.co.nz

National Institute of Water & Atmospheric Research Ltd
301 Evans Bay Parade, Greta Point
Wellington 6021
Private Bag 14901, Kilbirnie
Wellington 6241
New Zealand

Phone +64-4-386 0300
Fax +64-4-386 0574

NIWA Client Report No:	WLG2013-66
Report date:	January 2014
NIWA Project:	MFE14301

CR182

Published February, 2014.

Contents

Tables

Figures

Reviewed by Ashley Rowden

Approved for release by Julie Hall

Dr Ashley Rowden

Dr Julie Hall

Executive summary

The Ministry for the Environment (MfE) has identified that more detailed and comprehensive information is needed to fully inform policy decisions relating to the discharge of sediments during prospecting and exploration for seabed minerals. NIWA was engaged by MfE to undertake an assessment of the environmental risk of sediment discharges arising during exploration and prospecting for iron sands on the shelf along the west coast of North Island, phosphorite nodules on the Chatham Rise, and seafloor massive sulphide (SMS) deposits along the Kermadec volcanic arc.

The approach adopted for this assessment was a Level 1 Scale, Intensity, and Consequence Analysis (SICA) (Hobday et al. 2007). The effects or consequences of the activity were evaluated for each component of the ecosystem being considered and scored on a scale of 1 to 6, using a standardised set of prepared consequence descriptions, ranging from negligible to catastrophic. The effects taken into account were clogging of respiratory surfaces and feeding structures, shading of photosynthetic organisms, diminished capacity for vision by predators and prey, known toxic effects, noise, avoidance of the discharge area by mobile species, and smothering of organisms on the seafloor. The areas being assessed are those subject to mining prospecting or exploration activities authorised by a permit under the Continental Shelf Act 1964. The ecosystem components that NIWA evaluated were the benthic invertebrate community in the area, the demersal (bottom-associated) fish and mobile invertebrate (squid, octopus, large crabs) community, the air-breathing fauna, comprising marine mammals, seabirds and turtles, sensitive benthic environments, as defined in the Exclusive Economic Zone and Continental Shelf (Environmental Effects – Permitted Activities) Regulations 2013 (the Permitted Activities Regulations), and the pelagic community, including phytoplankton, zooplankton, fish and larger invertebrates.

The scale of discharges that could potentially arise from the prospecting and exploration phases of seabed mining range from 1 t or less to, in the case of iron sands, close to one million tonnes. To indicate where thresholds may occur whereby the risk of adverse effects to the environment would be minor or less during exploration for iron sands, we assessed discharges of sediment of 1 t, 10 t, 100 t, 1,000 t, 10,000 t, 100,000 t and 1,000,000 t. For phosphorite nodule deposits the largest scale of discharge, and for SMS deposits the three largest scales of discharge, were considered to be unrealistic during exploration phases given the likely restricted size of the resource in permit areas and were not assessed (see Table 3-1). Whether the discharge of sediment is into surface waters, mid-water or near the seabed (defined as in the bottom 5% of the water column) was also evaluated as this will determine the size of the consequent sediment discharge plume and the thickness and extent of the material deposited on the seafloor. At the lower range of discharges, multiple discharges arising from replicate sampling events over much of a permit area over the course of a permit period are expected. At the higher range of possible discharges, single discharges arising from test pit mining are the most likely scenario. For completeness, we assessed the consequences of the discharge being from a single point at one time, or from multiple points over the permit period that in total sum to the size of the discharge being considered (i.e. the same total amount but discharged over time and spatial scales relevant to the mineral in question).

Using this qualitative approach, we found that discharges of sediment during exploration and prospecting for seabed minerals could reach major or severe levels of consequence for the most sensitive marine benthic habitats occurring in each of the seabed mineral areas, depending on the size of the discharge, but that catastrophic consequences were likely never to be reached over the scales of discharge considered in the permit areas.

Severe consequences for sensitive marine environments were likely to be reached at a discharge scale of 1,000,000 t on the shelf along the west coast of North Island, and at a discharge scale of 100,000 t on the crest of the Chatham Rise Major consequences were reached at a discharge scale of 1,000 t along the Kermadec volcanic arc. These regional differences in sensitivity to discharge scales arise from the likely composition of sediment discharged, the nature of the receiving environments, and the scale and distribution of the most sensitive assemblages of organisms within each.

Moderate or greater consequences indicate an important transition in ecological significance. Moderate consequences for sensitive marine environments were reached at a discharge scale of 1,000 t in iron sands regions, at a discharge scale of 1,000 t on the crest of the Chatham Rise (phosphorite nodule region), and a discharge scale of 100 t along the Kermadec volcanic arc (SMS region).

Benthic communities, aside from those defined in sensitive habitats, showed varying levels of impact across the three assessed mineral regions. Most sensitive to the various scales of sediment discharge were the non-vent faunas along the Kermadec volcanic arc, including invertebrate assemblages on hard substrates. Least sensitive were the benthic communities along the relatively shallow, wave-swept west coast of the North Island. Over the range of discharges considered, the air-breathing marine fauna, as well as demersal fish and mobile invertebrates, were assessed as being the least vulnerable, principally because they can rapidly move away from the discharge point(s).

These risk assessments were carried out without taking into account avoidance or mitigation strategies by the mining companies. Best management practices for offshore mineral mining recommend discharging near the seabed to minimise the spread of sediments and avoiding discharges into areas containing sensitive or unique marine benthic habitats. While designed to mitigate the impact of mining itself, these best-practice principles could be applied to the discharge of sediment during exploration and prospecting phases of mining. The scale at which discharge over the point of extraction may provide a meaningful level of mitigation is 100 t and above where we assessed consequences to be minor or greater for exploration of all three mineral deposits. This scale of discharge is associated with bulk sampling or test pit mining of the mineral deposit. Our assessments indicate that discharging sediment close to the seabed may assist in minimising the extent of the area affected by the discharge. However, this may be impractical for all sampling undertaken during exploration other than test-pit mining when non-ore sediments could be discharged close to the seabed at, or near, the point of sampling.

Effective employment of mitigation strategies requires good knowledge of the spatial distribution of the different benthic habitats with respect to the distribution of the mineral resource within the permit area. This requires a degree of sampling effort to obtain the required basic information. The likely consequences of any associated sediment discharges on benthic and pelagic habitats will likely be negligible or minor.

1 Introduction

1.1 Background

In the course of preparing policy options for regulations in relation to discharges of sediment during prospecting, exploration and exploitation phases of seabed mining (Exclusive Economic Zone and Continental Shelf (Environmental Effects – Permitted Activities) Regulations 2013), the Ministry for the Environment (MfE) identified the need for further information following on from NIWA's previous advice (MacDiarmid et al. 2011). The previous report assessed the likely broad environmental effects from mineral mining activities. Subsequent discussions by MfE with government departments, stakeholders and iwi have highlighted that more detailed and comprehensive information is needed to fully inform policy decisions relating to the discharge of sediments during prospecting and exploration for seabed minerals, which are permitted activities under the Permitted Activities Regulations. Consequently, MfE contracted NIWA to undertake a further assessment of the environmental risk of sediment discharges arising during exploration and prospecting for iron sands, phosphorite nodules, and seafloor massive sulphide (SMS) deposits.

1.2 Objectives

MfE required NIWA to:

1. Make a risk-based assessment of the spectrum of environmental effects of discharging tailings and sediments from the exploration and prospecting stages of mineral mining operations into the marine environment, considering all aspects of risk to the marine environment.

This assessment must include assessing the risk of different likely scenarios for the discharge of tailings (for example, discharging tailings directly from the site of removal versus discharging them in a different location) for different environments in the Exclusive Economic Zone (EEZ) where the activity is likely to occur (i.e., the environments where iron sand, phosphorite nodule and SMS deposits occur).

2. Recommend thresholds (for example, volume, particle size, nutrient content, contaminant availability) whereby the risk of adverse effects to the environment would be minor or less.

3. Identify any other mitigation measures that could reduce the adverse effects to the environment, including sensitive habitats or species, to minor or less.

The deliverables will not include assessment of:

- discharges from the production stage of mineral mining
- discharges of water associated with sediments and tailings.

1.3 Approach

There are a number of approaches and methods that have been applied around the world to conduct ecological risk assessments. Several of these were reviewed by Rowden et al. (2008) and Baird and Gilbert (2010). Where the activity is deliberate and programmed to take place regularly and repeatedly in an area, such as in seabed exploration or prospecting, an exposure-effects approach (e.g. Smith et al. 2007; Sharp et al. 2009) is the most suitable. In this case risk is the sum of all the effects on the ecosystem, as the likelihood of the event occurring is unity (1). This contrasts with the approach taken to assess rare or unpredictable events, such as an oil spill. In these cases a likelihood-consequence approach summarises risk as the product of the expected likelihood of an event occurring and the ecological consequence of that event.

Risk assessment typically consists of three levels, increasing in detail from a qualitative assessment (level 1) to fully quantitative (level 3). Level 1 assessments are generally used in data poor situations where the scale of activity or its impacts on particular species, habitats or the ecosystem are uncertain or only partially described (Hobday et al. 2007). The approach adopted for this assessment was a Level 1 Scale, Intensity, and Consequence Analysis (SICA) (Hobday et al. 2007).

2 Methods

2.1 Risk assessment methodology

To conduct the SICA of the discharges of sediment arising from prospecting and exploring for seabed deposits of iron sands, phosphorite nodules, and SMS, the spatial and temporal scale of the activity was first determined from existing permits, other publically available information[1] or using information released to us for this assessment by Chatham Rock Phosphate Ltd (CRP). For SMS deposits, we made use of the Nautilus Solwara 1 Environmental Impact Statement (Coffey Systems, 2008). Although this proposed mining activity is in Papua New Guinea (PNG) waters, it is the most advanced SMS project globally and provides a model of how SMS exploration and mining might proceed in New Zealand. The intensity of the activity was then evaluated based on its scale, nature and extent (Hobday et al. 2007).

The effects or consequences of the activity were then evaluated by an expert panel of scientists (see Appendix A for details about participants relevant expertise) for each component of the ecosystem being considered and scored on a scale of 1 to 6, using a standardised set of prepared consequence descriptions, ranging from negligible to catastrophic (Table 2-1). The panellists met to evaluate the consequences of discharges in each mineral region, and then individually critiqued the scores until consensus was reached using an iterative process. The effects taken into account were clogging of respiratory surfaces and feeding structures of marine organisms, shading of photosynthetic organisms, diminished capacity for vision by predators and prey, known toxic effects, noise, avoidance of the discharge area by mobile species, and smothering of organisms on the seafloor. The ecosystem components evaluated were the benthic invertebrate community in the permitted area, the demersal (bottom-associated) fish and mobile invertebrate (squid, octopus, , large crabs) community, the air-breathing fauna, comprising marine mammals, seabirds and turtles, sensitive benthic environments, as defined in the Exclusive Economic Zone and Continental Shelf (Environmental Effects – Permitted Activities) Regulations 2013 (the Permitted Activities Regulations), and the pelagic community, including phytoplankton, zooplankton, fish and larger invertebrates. More detailed descriptions of the fauna and flora in the receiving environment are given in the results sections on iron sands (3.2.2), phosphorite nodules (3.3.2), and SMS deposits (3.4.2) below. The level of confidence in the information available to make each assessment was recorded based on the categories provided in Table 2-2.

For each region in which prospecting and exploration for iron sand, phosphorite nodules, and SMS deposits has, or is likely to take place, the available literature was reviewed to provide a brief overview of the mineral deposits and the environment that will be receiving the sediment discharges. This provides the context within which the risk assessment was undertaken.

[1] E.g., http://www.epa.govt.nz/EEZ/trans_tasman/application/application_docs/Pages/default.aspx

Table 2-1: Consequence levels for the intensity of the activity. Summary descriptions of the six sets of consequence levels for the proportion of the habitat affected, the impact on the population, community or habitat, and the likely recovery period. Modified from MacDiarmid et al. (2011) and Hobday et al. (2007).

Consequence level	Proportion of habitat affected	Population/ community/ habitat impact	Recovery Period
1 - Negligible	Affecting <1% of area of original habitat area	Interactions may be occurring but unlikely to be ecologically significant (<1% changes in abundance, biomass, or composition) or be detectable at the scale of the population, habitat or community	No recovery time required
2 - Minor	Measurable but localized; affects 1-5% of total habitat area	Possibly detectable with 1-5% change in population size or community composition and no detectable impact on dynamics of specific populations	Rapid recovery would occur if activity stopped – less than 8 weeks
3 - Moderate	Impacts more common; >5-20% of habitat area is affected	Measurable with >5-20% changes to the population, habitat or community components without there being a major change in function	Recovery in >2 months to 1-2 years if activity stopped
4 - Major	Impacts very widespread; >20-60% of habitat is affected/ removed	Populations, habitats or communities substantially altered (>20-50%) and some function or components are missing/ declining/ increasing well outside historical ranges. Some new species appear in the affected environment	Recovery occurs in 2-10 years if activity stopped
5 - Severe	Impact extensive; >60-90% affected	Likely to cause local extinctions of vulnerable species if impact continues, with a >50-90% change to habitat and community structure and function. Different population dynamics now occur with different species or groups now affected	Recovery period 1-2 decades if activity stopped
6 - Catastrophic	Entire habitat in region is in danger of being affected; >90% affected/ removed	Local extinctions of a variety of species are imminent/immediate. Total collapse of habitat, community or ecosystem processes. The abundance, biomass or diversity of most groups is drastically reduced (by 90% or greater) and most original ecological functional groups (primary producers, grazers etc.) have disappeared	Long term recovery to former levels will be greater than 1-2 decades or never, even if activity stopped

Table 2-2: Confidence rating, score and description.

Confidence rating	Score	Rationale for confidence score
	1a	No data exists and no consensus among experts
Low	1b	Data exists, but is considered poor or conflicting
	1c	Agreement among experts, but with low confidence
	2a	Consensus among experts, but with high confidence, even though data may be lacking
High	2b	Consensus among experts supported by unpublished data (not been peer-reviewed but is considered sound)
	2c	Consensus among experts supported by reliable peer-reviewed data or information (published journal articles or reports)

3 Results

3.1 Scale of discharges assessed

The scale of discharges that could potentially arise during prospecting and exploration for seabed minerals ranges from 1 t or less to, in the case of iron sands, close to one million tonnes. To indicate where thresholds may occur whereby the risk of adverse effects to the environment would be minor or less (the level of effect that determines that an activity is permitted), we assessed discharges of sediment of 1 t, 10 t, 100 t, 1,000 t, 10,000 t, 100,000 t and 1,000,000 t. Seabed sampling during mineral prospecting and exploration usually involves many small-scale, widely distributed sampling points, as occurs during surficial sampling, coring or drilling (e.g., Figure 3-1), with the incidental release or deliberate discharge of mainly fine sediments, as most of the coarse material is retained for later laboratory analysis for resource definition (e.g. Table 3-1). These samples are likely to be obtained over the course of a sampling programme that may span weeks to one or two years. Although it is highly unlikely that just a single discharge of 1 t of material will occur during this type of sampling, we evaluated this possibility.

Discharges totalling 10 t or 100 t are most likely to arise during bulk sampling operations, for instance, to retrieve samples large enough to provide sufficient material to trial processing methods on land (Figure 3-2). Although not specified in the permits issued to date, we assumed that the material discharged back into the marine environment during these activities will comprise mostly silts or muds that are incidentally lost or deliberately discharged during the sampling process (Table 3-1). The existing permits allow 1-3 years for the collection of these bulk samples and we have assumed that the discharges may occur as either a single event occurring on one day or multiple smaller events occurring over the course of the permit period throughout the permit area that sum to the total discharge tonnage considered (Table 3-1).

Large-scale release of sediments prior to mining is most likely to occur during test pit mining when extraction, processing, and discharge methods are trialled to refine the final mining techniques (Figure 3-3). To date, these test pits are allowed to be carried out in accordance with a permit issued under the Continental Shelf Act 1964 as a one-off sample of between 200 t and 1,000,000 t. Although not explicitly stated in the existing permits, practical necessity suggests these will need to occur over a period of time ranging from one day to four weeks, which we have estimated based on our understanding of probable mining approaches (Table 3-1). Because the material discharged into the environment during test pit mining is not specified in the permits issued to date, we have assumed it will resemble the original seafloor deposits in terms of particle size frequency and chemical composition, minus the ore component (Table 3-2). Although present permits specify test-pits as a one-off sample, we also evaluated the effects of release of each quantity of sediment as a series of smaller events occurring over the course of the permit period throughout the permit area (i.e. a series of smaller events of a minimum scale relevant to the testing of the mining methods of the mineral in question that in total sum to the quantity being assessed).

The discharge of sediment into surface waters, mid-water or near the seabed (defined as in the bottom 5% of the water column) was also evaluated as this will determine the size of the consequent sediment dispersal plume and the thickness and extent of the material deposited on the seafloor. Release at the sea surface maximises the spread of discharged sediment but ensures that the thickness of the deposited material is as thin as possible and potentially over a wider area than the extraction area. With small discharges, surface release may spread the sediment so thinly that the benthic impacts are negligible. However, deposition of sediment beyond a few mm is lethal to many benthic organisms, especially those from environments with naturally low levels of suspended sediments, with only the larger emergent organisms surviving, albeit with reduced condition and clearance rates (Ellis et al. 2002; Thrush et al. 2004; Lohrer et al. 2004; Lohrer et al. 2006a and b). Thus, discharge close to the seabed will smother or choke organisms directly under the release point, but ensures that the affected area is minimised. In exposed shallow water less than 50 m deep, re-suspension of sediments by wave activity may largely negate any effects of discharge depth (Hadfield 2013). Thus, we assessed surface, mid-water and near seabed release separately for single and multiple discharges of 1 t to 1,000,000 t.

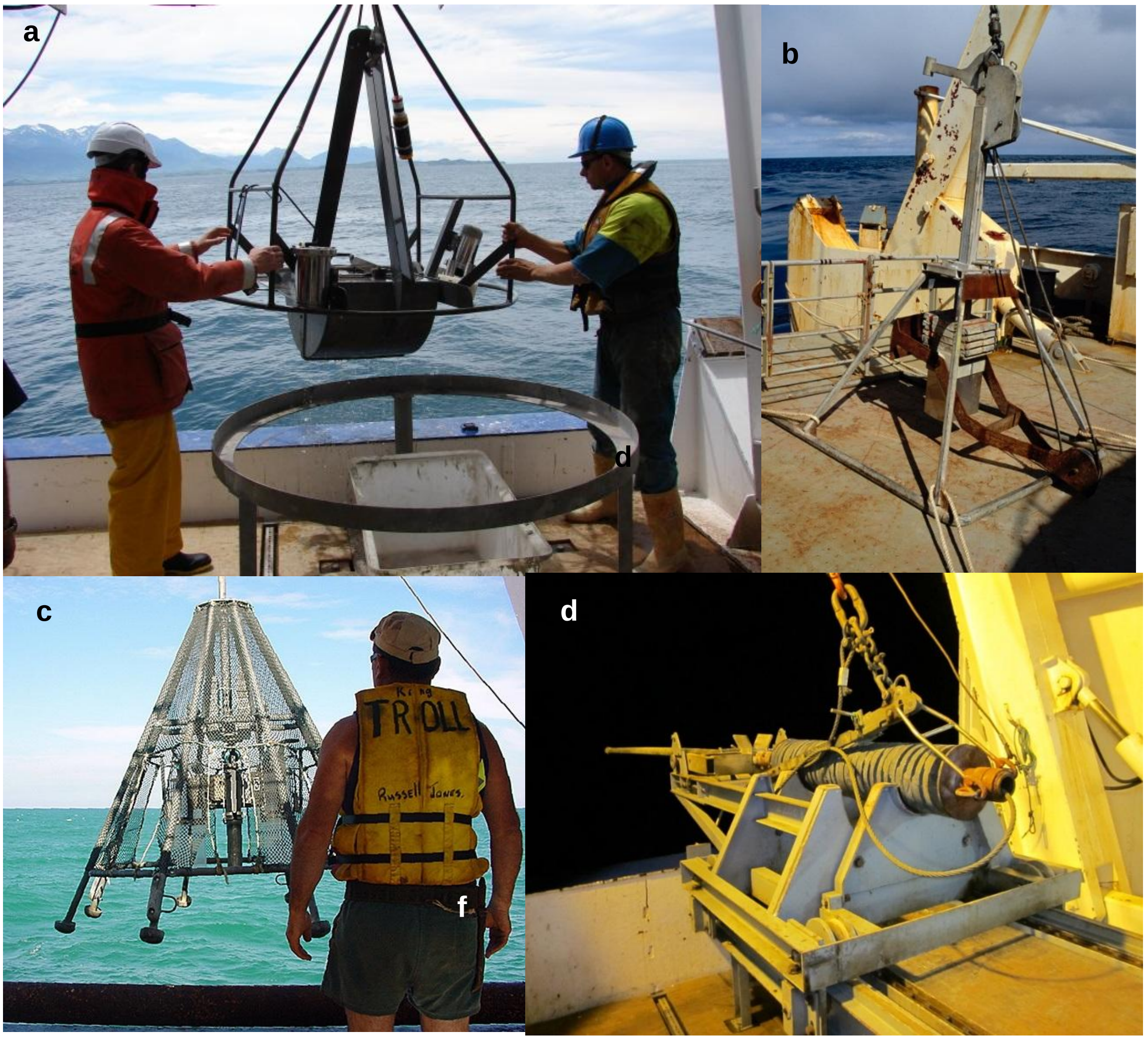

Figure 3-1: Equipment used to sample the seabed. (a) van Veen grab in closed position, (b) Reineck box corer, (c) multicorer, (d) gravity corer in its cradle, (all images NIWA).

Figure 3-2: Bulk sampling of phosphorite nodule bearing sediments on the Chatham Rise. Image courtesy of CRP.

Figure 3-3: Example of sub-sea extraction crawler demonstrating scale. From TTR Supporting Information for Marine Consent Application[2].

---

2 http://www.epa.govt.nz/eez/EEZ000004/EEZ000004_Supporting_Information_for_Marine_Consent_Application_October%202013.pdf

Table 3-1: Scales of prospecting and exploration phase mining activities.

Weight of material discharged	Type of material returned to the marine environment	Description of activity in prospecting or exploration permit/licence specifying allowable number and size. Probable time scale of activity indicated
Up to 1 t	Iron sand: Most material retained, some loss of fine silt	Shallow drill holes, surficial samples, etc. Minimum of 110 holes drilled over permit period. Conducted over 1-3 years (TTR Exploration Permit)
	Phosphorite nodules: Most material retained, some loss of fine material	> 200 samples using grabs, box corers and vibro coring over 5 month period
	SMS: Most material retained, some loss of fine material	Shallow drill holes, surficial samples, etc. Conducted over approximately 1 year.
10 t	Iron sand: Most material retained, some loss of fine silt	Up to 100 samples of 5-200 t at a maximum density of 10 bulk samples per 100,000 m^2 (i.e. 1 sample per ha). Conducted over 1 year
	Phosphorite nodules: Most material retained, small loss of fine material	50 large grab samples (500 – 2000 kg / sample) over 1 year
	SMS: Most material retained, some loss of fine material	Deeper drill holes, surficial samples, etc. E.g., a total of 111 holes were drilled to 20m depth over 1 year by Nautilus at the Solwara 1 site, PNG.
100 t	Iron sand: Most material retained, some loss of fine silt	Up to 100 samples of 5-200 t at a maximum density of 10 bulk samples per 100,000 m^2 (i.e. 1 sample per ha). Conducted over 1 year
	Phosphorite nodules: Most material retained, some loss of fine material	50 large grab samples (500 – 2000 kg / sample) taken over 1 year
	SMS: Most material retained, some loss of fine material	Bulk sampling and ship-based drilling by Nautilus at the Solwara 1 deposit, PNG
1000 t	Iron sand: Iron ores retained (~10%). Rest (90%) returned to sea	Test-pit mining – a single sample in the range of 200 -1,000,000 t (~500,000 m^3) is permitted. Probable time for extraction < 1 day
	Phosphorite Nodules: Nodules retained (9%). Rest returned to sea	No test-pit mining specified in permits. But given the size of the resource (~25 Mt) test-pit mining of 1,000 tonnes is realistic
	SMS: Sulphides retained (90% of mined deposit). Overburden (10%) returned to sea	No test-pit mining specified in Nautilus Solwara 1 EIS . But given the size of the resource (870,000 tonnes of indicated ore, 1,300 kt of inferred ore) and small proposed mining area (0.112 km^2) then test-pit mining of 1,000 tonnes is realistic
10,000 t	Iron sand: Iron ores retained (~10%). Rest (90%) returned to sea	Test-pit mining – a single sample in the range of 200 -1,000,000 t (~500,000 m^3) is

		permitted. Probable time for extraction up to 1 week
	Phosphorite Nodules: Nodules retained (9%). Rest returned to sea	No test-pit mining specified in permits. But given the size of the resource (~25 Mt) test-pit mining of 10,000 tonnes is realistic
	SMS: Sulphides retained (90% of mined deposit). Overburden (10%) returned to sea	No test-pit mining specified in Nautilus Solwara 1 EIS . But given the size of the resource (870,000 tonnes of indicated ore, 1,300 kt of inferred ore) and small proposed mining area (0.112 km^2) then test-pit mining of 10,000 tonnes is unrealistic
100,000 t	Iron sand: Iron ores retained (~10%). Rest (90%) returned to sea	Test-pit mining – a single sample in the range of 200 -1,000,000 t (~500,000 m^3) is permitted. Probable time for extraction 1-2 weeks
	Phosphorite Nodules: Nodules retained (9%). Rest returned to sea	No test-pit mining specified in permits. But given the size of the resource (~25 Mt) test-pit mining of 100,000 tonnes is the maximum realistic scale
	SMS: Sulphides retained (90% of mined deposit). Overburden (10%) returned to sea	No test-pit mining specified in Nautilus Solwara 1 EIS . But given the size of the resource (870,000 tonnes of indicated ore, 1,300 kt of inferred ore) and small proposed mining area (0.112 km^2) then test-pit mining of 100,000 tonnes is unrealistic
1,000,000 t	Iron sand: Iron ores retained (~10%). Rest (90%) returned to sea	Test-pit mining – a single sample in the range of 200 -1,000,000 t (~500,000 m^3) is permitted. Probable time for extraction 3-4 weeks
	Phosphorite Nodules: Nodules retained (9%). Rest returned to sea	No test-pit mining specified in permits. But given the size of the resource (~25 Mt) test-pit mining of 1,000,000 tonnes is unrealistic
	SMS: Sulphides retained (90% of mined deposit). Overburden (10%) returned to sea.	No test-pit mining specified in Nautilus Solwara 1 EIS (Coffey Systems 2008). But given the size of the resource (870,000 tonnes of indicated ore, 1,300 kt of inferred ore) and small proposed mining area (0.112 km^2) then test-pit mining of 1,000,000 tonnes is unrealistic

Table 3-2: Composition of three seafloor mineral deposits in the New Zealand EEZ.

Seafloor deposit	Composition
Iron sands	In South Taranaki Bight, raw iron sands, on average, comprise coarse sand (500–1000 µm, 20%), fine–medium sand (128–500 µm, 72%), very fine sand (63–128 µm, 6%), coarse silt (16–63 µm, 1.5%) and fine silt (4–16 µm, 0.5%) On average density of iron sands is 2.08 t/m^3 . Seawater suspensions of deep sediment (elutriate) contain trace metals either below detection limit (chromium, copper, lead, zinc), or, below ANZECC & ARMCANZ guidelines for the protection of 99% of species (cadmium) or 95% of species (nickel).
Phosphorite nodules	Sediments, containing phosphorite nodules from the crest of the Chatham Rise, comprise a silt/sand layer, generally less than 50 cm thick (average 30 cm), overlying a semi-consolidated ooze/chalk layer (Falconer et al. 2011; Grundlehner et al. 2012). Host sediment of phosphorite nodules is non- to lightly-cohesive. Average nodule yield is 66 kg m^{-2} . Assuming that each 1 m^2 of deposit, averaging 0.3 m thick, weighs 465 kg (density of 1.55 t/m^3) then extraction of the average yield leaves ~399 kg m^{-2} of silt and sand to be returned to the sea floor. 21 trace elements occur within the nodules including v, Cr, Co, Ni, Cu, Zn, As, Rb, Sr, Y, Zr, Nb, Mo, I, Cs, Ba, La, Hf, Pb, Th, U
Seafloor Massive Sulphides	Seafloor massive sulphides (SMS) are areas of hydrothermally formed hard substrata. Deposits can be directly exposed to the surrounding seawater or covered in a layer of unconsolidated sediment. At Nautilus' Solwara 1 site in Papua New Guinea, this unconsolidated layer of volcanic sandy silts and silty sands is generally less than 2 m thick, but can extend as deep as 6 m, with an average density of 1.2 t/m^3. Unconsolidated sediments comprise approximately 50% of overburden; the remainder comprises competent waste material, consisting of waste rock and ore below cut-off grades. SMS deposit composition varies between locations, but deposits are generally rich in base metals (Fe, Zn, Pb, Cu), sulfides, and other elements (Ca, Au, Ag, As, Co, Mo, Pt).

3.2 Iron sands

3.2.1 Background

Iron sands are the largest known reserve of metalliferous ore in New Zealand. Iron sand is a general term for sand-sized grains of heavy iron-rich minerals, principally magnetite (Fe_3O_4), titanomagnetite (Fe_2TiO_3), and ilmenite ($FeTiO_3$) (Gladsby and Wright 1990). New Zealand's iron sands occur extensively in coastal dunes and on the adjacent continental shelf of the western North Island, and have been successfully mined onshore for over 35 years.

Offshore surficial deposits of iron sand have been known since the early 1960s, but estimates of their reserves are poorly constrained and to date they remain unexploited. The coastal iron sands of the central North Island west coast are primarily derived from erosion of the Taranaki volcanics, but local fluxes of iron sand, for example off the Mokau River, suggest input from other sources, such as recycling of older, onshore dunes. The geometry of the uppermost iron sand deposits is locally influenced by paleo-topographic features on the shelf associated with the post-last glacial sea level rise. Underlying iron sand-rich deposits might also occur, reflecting older Quaternary shorelines and changes in sea level (Orpin 2013).

The marine iron sand industry is still at an early stage. Prospecting and exploration licences have been granted for large areas off the west coast of the North Island to a number of different companies, but none have yet progressed to the production phase. An application by Trans-Tasman Resources Ltd (TTR) to mine iron sands in the South Taranaki Bight is currently being considered by the Environmental Protection Agency (EPA) with a decision due in mid-2014.

A mining process has been outlined by TTR[2] in which seabed material will be excavated using a subsea sediment extraction device (referred to a “Crawler”) that will pump extracted sediment overhead to a large floating processing, storage and off-loading (FPSO) vessel. On the FPSO, extracted sediment will be processed into iron ore concentrate, with the de-ored sand deposited back onto the seabed, generally into previously worked-over areas. Although not undertaken by TTR, it is conceivable that test-pit mining using a crawler or some other large scale sampling device could be undertaken during the exploration phase to test and refine this mining process.

Sampling of iron sands during mineral exploration could make sediment-bound contaminants available to pelagic and benthic biota. We took into account the results of Vopel et al. (2013) who found a low probability of adverse effects of acid volatile sulfides and trace metals in iron sands from the South Taranaki Bight on benthic ecosystem functioning. Vopel et al. (2013) also found that for all metals except nickel, the concentration in seawater suspensions of deep sediment (elutriate) were either below detection limit (chromium, copper, lead, zinc) or, if a metal was detected (cadmium), the concentration did not exceed the ANZECC & ARMCANZ guideline for the protection of 99% of species. The nickel concentration never exceeded the guideline concentrations for the protection of 95% of species.

3.2.2 Receiving Environment

The continental shelf of North Island's west coast is subject to a vigorous wave climate driven by the prevailing westerly winds and southerly storms (MacDiarmid et al. 2011), and accordingly, the seabed of the inner and mid-shelf is naturally subjected to frequent resuspension and energetic near-bed currents, as evidenced by the extensive occurrence of sand sheets, gravels, and sediment bedforms (e.g. dunes and ripples) (Orpin 2013). The rivers inject large volumes of sediment into the near shore during floods and this is resuspended by wave activity to produce typically turbid waters inshore and clearer waters offshore (Hadfield 2013; Pinkerton et al. 2013).

Primary production along the west coast of North Island is likely to be highest nearshore, but large and relatively intense phytoplankton blooms occur offshore intermittently (Pinkerton 2013). The zooplankton community in Taranaki waters is typical of coastal waters found around North Island, but little is known of the seasonal cycle or inter-annual variability of plankton, as the existing data has been mainly collected in summer (Bradford-Grieve and Stevens 2013). It has been suggested that offshore phytoplankton blooms in the South Taranaki Bight may lead to aggregations of the euphausiid *Nyctiphanes australis*, which may be linked to the occurrence of blue whales (*Balaenoptera musculus*) in this area (Torres et al., 2013b).

Of the cetaceans along this shelf, most is known of Maui’s dolphin because of its high threat status (Du Fresne 2010). Habitat suitability modelling by Torres et al. (2013a) has identified the distributional range of this sub-species of Hector’s dolphin in the region, confirming its predominantly coastal distribution from the Kaipara Harbour through to North Taranaki. Other species occurring along this shelf include killer whales and southern right whales (Torres et al. 2013a).

The distribution and abundance of seabirds in the region is poorly known. Thompson (2013) has recently described the seabird fauna in the South Tarankai Bight as ‘relatively modest’, but noted the lack of detailed, systematic and quantitative information on the at-sea distribution of virtually all species. He commented that many of the species occurring in the area are likely to be relatively coastal in their distributions. Such species include blue penguin, shags, gulls and terns, although these latter two taxa can extend to more offshore areas.

The marine benthic habitats on the shelf in this region have been broadly described by McKnight (1969). More detailed information is available for the South Taranaki Bight. Here, the shallow exposed inner and mid-shelf rippled sand habitats, frequently disturbed by storm events, support very few visible epifauna, except on small and scattered inner shelf rocky outcrops that have a comparatively diverse epibenthic assemblage, and areas of the tube worm *Euchone* sp. (Anderson et al. 2013; Beaumont et al. 2013) (Figure 3-4, a-c). In deeper, less disturbed, areas offshore, the seabed is characterised by two types of low-relief biogenic habitat: bivalve rubble and bryozoan rubble (Figure 3-4, d-f). These broadly distributed biogenic habitats both support diverse benthic assemblages dominated by sessile suspension-feeding taxa (e.g. bryozoa, sponges, colonial ascidians, brachiopods and epiphytic bivalves), and in turn provide structure to a plethora of motile species (e.g. crabs, ophiuroids, holothurians, gastropods and nudibranchs) (Beaumont et al. 2013). These biogenic habitats meet the definitions for sensitive marine environments described by MacDiarmid et al. (2013) and are included in the Permitted Activities Regulations 2013.

Figure 3-4: Still images of benthic habitats in the South Taranaki Bight. a) Rippled sands, b) Low-lying rock outcrop, c) Wormfields, d) Bivalve/rubble, e) branching bryozoa, small foliose bryozoa & holothurian (*Australostichopus mollis*), (f) Bryozoa/rubble in muddier offshore sediments. Images from Beaumont et al. (2013).

The distribution of subtidal reefs and abundance of reef fishes along this coast have been described by Smith (2008) who found this coast has a moderately diverse fauna with just over half the 72 species he modelled nationwide present in the region. Modelling undertaken by Leathwick et al. (2006) indicates that, over a broad region of the shelf on the west coast of North Island between Whanganui and the Kaipara Harbour, demersal fish species richness is predicted to be a moderate 12-16 species per standard research bottom trawl. Slightly lower richness (8-12 species) occurs in depths less than 50 m, and slightly higher richness (16-20 species) occurs inshore in the south-east of the region north of Kapiti Island towards Whanganui. This compares with the northern flank of the Chatham Rise and continental slopes along the north-eastern flank of South Island and south-eastern flank of North Island that have predicted richness in excess of 20 species per tow. Leathwick et al. (2006) also note that generally species richness also increased with increasing primary production (via the proxy of remotely-sensed chlorophyll *a* concentrations).

Fisheries along the west coast of the North Island include bottom trawling (for a variety of species), midwater trawling (mainly for jack mackerel), and set netting (mainly for rig, warehou, and school shark) (MacDiarmid et al. 2011).

3.2.3 Assessment

Discharges of up to 1 t in total

Discharges of sediment totalling up to 1 t are most likely to arise during the taking of cores or surficial samples of sediment using corers and grabs. In both cases, most seabed material is likely to be retained for later laboratory analysis with incidental loss of finer sediments during the retrieval process. Surficial sediment samples taken for analysis of biological specimens are likely to be sieved and washed on board the research vessel with consequent loss of most sediments overboard.

Because of the small volume of sediment released, and the nature of the receiving environment, we assessed that the consequences of this discharge were negligible for all components of the ecosystem whether the sediment was released as a single or multiple event, near the surface, in mid-water or near the seafloor (Table 3-3).

Discharges of 10 t in total

Discharges of sediment totalling 10 t are most likely to arise during the taking of bulk samples to quantify the extent and quality of the resource or to obtain samples large enough to provide sufficient material to trial processing methods on land. For iron sands the bulk of the sample would be returned to shore.

Because of the reasonably small volume of sediment released as incidental discharge, and the nature of the receiving environment, we assessed that the consequences of this discharge from iron sand prospecting and exploration were negligible for all components of the ecosystem whether the sediment was released as a single or multiple event, near the surface, in mid-water or near the seafloor (Table 3-3).

Discharges of 100 t in total

Discharges of sediment totalling 100 t are most likely to arise during the taking of bulk samples to quantify the extent and quality of the resource or to obtain samples large enough to provide sufficient material to trial processing methods on land. In both cases the majority of the sample would be returned to shore and principally finer material will be incidentally lost overboard during recovery of the bulk sample.

Because of the modest volume of sediment released, and the nature of the receiving environment, we assessed that the consequences of this discharge were negligible for mobile fish and invertebrates, and for seabirds and cetaceans, as they could easily move away from the discharge point(s). Similarly, we assessed the consequences for the pelagic community and the benthic community generally to be negligible because the scale of the discharge would be too small to have detectable impacts, whether released as a single or multiple event, near the surface, in mid-water or near the seafloor (Table 3-3).

When the discharge of a total of 100 t of sediment was from multiple points within the permit area over the permit period, at the surface or mid-water, we considered the consequences for the sensitive marine environments to be negligible, as the sediment would be very widely distributed and would not form deposits sufficiently thick to impact the benthic ecosystem (Table 3-3). However, when the discharge was at single point or near the seafloor from multiple points, we considered the sediment could form deposits sufficiently thick to start to have measurable impacts on the benthic invertebrate community generally in the permit area, and on more localised sensitive marine environments, such as beds of large bivalves, bryozoans and sponges (e.g. see Beaumont et al. 2013[3]), but that the overall consequences for these components of the ecosystem would be minor.

Discharges of 1,000 t in total

Discharges of sediment totalling 1,000 t are most likely to arise during the test-pit mining when extraction, processing, and discharge methods are trialled to refine the final mining techniques. In these cases we have assumed that the discharged sediment will resemble the original seafloor deposits in terms of particle size frequency and chemical composition, minus the ore component (see Table 3-2). The coarser material will not disperse far from the discharge point, whereas the finer particles may be carried many km by ocean currents (Hadfield 2013).

We assessed that the consequences of discharges totalling 1,000 t were negligible for mobile fish and invertebrates, and for seabirds and cetaceans, as they could easily move away from the discharge point(s). Similarly, we assessed the consequences for the pelagic community to be negligible because the scale of the discharge would be too small to have detectable impacts, whether released as a single or multiple event, near the surface, in mid-water or near the seafloor (Table 3-3).

For discharges totalling 1,000 t we considered the sediment would form deposits sufficiently thick to have measurable impacts on the benthic invertebrate community in the permit area, whether released as a single or multiple event, near the surface, in mid-water or near the seafloor. However, because the total volume of sediment was still modest and likely to affect only 1-5 percent of the habitat within the permit area, we considered the overall consequences for these components of the ecosystem would be no more than minor (Table 3-3).

For more localised sensitive marine environments, such as beds of large bivalves, bryozoans and sponges, we assessed that a single point discharge of 1,000 t could have moderate consequences affecting between 5 and 20 percent of the habitat. We assessed that the same amount of sediment discharged from multiple points over the permitted sampling period would have minor consequences affecting between 1 and 5 percent of the habitat (Table 3-3).

Discharges of 10,000 t in total

Discharges of sediment totalling 10,000 t are most likely to arise during the test-pit mining when extraction, processing, and discharge methods are trialled to refine the final mining

3 http://www.epa.govt.nz/eez/EEZ000004/EEZ000004_Benthic_flora_and_fauna_of_the_Patea_Shoals_region_South_Taranaki_Bight_NIWA_October_2013.pdf)

techniques. In these cases, we have assumed that the discharged sediment will resemble the original seafloor deposits in terms of particle size frequency and chemical composition, minus the ore component (see Table 3-2). The coarser material will not disperse far from the discharge point, whereas the finer particles may be carried many km by ocean currents (Hadfield 2013).

We assessed that the consequences of discharges totalling 10,000 t would be negligible for seabirds and cetaceans and minor for demersal fish and mobile invertebrates, as they could move away from the discharge point(s). Similarly, we assessed the consequences for the pelagic community to be negligible, because the scale of the discharge would be too small to have detectable impacts whether released as a single or multiple event, near the surface, in mid-water or near the seafloor (Table 3-3).

For discharges totalling 10,000 t we considered the sediment would form deposits sufficiently thick to have ecologically important impacts on the benthic invertebrate community in the permit area, and on more localised sensitive marine environments, such as beds of large bivalves, bryozoans and sponges, whether released as a single or multiple event, near the surface, in mid-water or near the seafloor. The total volume of sediment was assessed to likely affect between 5 and 20 percent of the habitat within the permit area and the overall consequences for these components of the ecosystem would be moderate with 5-20 percent changes in in population size or community composition (Table 3-3).

Discharges of 100,000 t in total

Discharges of sediment totalling 100,000 t are most likely to arise during the test-pit mining when extraction, processing, and discharge methods are trialled to refine the final mining techniques. In these cases, we have assumed that the discharged sediment will resemble the original seafloor deposits in terms of particle size frequency and chemical composition, minus the ore component (see Table 3-2). The coarser material will not disperse far from the discharge point, whereas the finer particles may be carried many km by ocean currents (Hadfield 2013).

We assessed that the consequences of discharges in mid-water or near the seafloor totalling 100,000 t would be negligible for seabirds and cetaceans, as they could move away from the discharge point(s). When multiple discharges totalling 100,000 t were made at the sea surface over the whole of the permit area, we assessed the consequences for seabirds and cetaceans to be minor, as movement away from the affected area may result in a measurable but localised decrease in abundance but with little impact on population size or community composition (Table 3-3).

For the pelagic community, we assessed the consequences to be minor with measurable, but localised decreases in abundance, except when the discharges were near the seafloor when less of the water column would be affected and the consequences would be negligible (Table 3-3).

For discharges totalling 100,000 t, we considered the sediment would form deposits sufficiently thick to have ecologically important impacts on the benthic invertebrate community in the permit area, and on more localised sensitive marine environments, such as beds of large bivalves, bryozoans and sponges, whether released as a single or multiple event, near the surface, in mid-water or near the seafloor. The total volume of sediment was assessed to have moderate consequences for the benthic invertebrate community and major consequences for sensitive marine environments, likely affecting between 5 and 20 percent and between 20 and 60 percent , respectively (Table 3-3).

Discharges of 1,000,000 t in total

Discharges of this amount of sediment are most likely to arise during the test-pit mining when extraction, processing, and discharge methods are trialled to refine the final mining techniques. In these cases we have assumed that the discharged sediment will resemble the original seafloor deposits in terms of particle size frequency and chemical composition, minus the ore component (see Table 3-2). The coarser material will not disperse far from the discharge point whereas the finer particles may be carried many km by ocean currents (Hadfield 2013).

We assessed that the consequences of discharges in mid-water or near the seafloor totalling 1,000,000 t would be negligible for seabirds and cetaceans, as they could move away from the discharge point(s). When discharges of this size were made at the sea surface, we assessed the consequences for seabirds and cetaceans to be minor, as movement away from the affected area may result in a measurable but localised decrease in abundance but with little impact on population size or community composition (Table 3-3).

For demersal fish and mobile invertebrates, we assessed that the consequences of discharges in mid-water or near the seafloor totalling 1,000,000 t would be minor, as movement away from the affected area may result in a measurable, but localised decrease in abundance, but with little impact on population size or community composition (Table 3-3). Similarly, we assessed that the consequences for the pelagic community would be minor with measurable, but localised decreases in abundance, biomass, or composition (Table 3-3).

For discharges totalling 1,000,000 t, we considered the sediment would form deposits sufficiently thick to have ecologically important impacts on the benthic invertebrate community in the permit area, and on more localised sensitive marine environments, such as beds of large bivalves, bryozoans and sponges, whether released as a single or multiple event, near the surface, in mid-water or near the seafloor. The total volume of sediment was assessed to have major consequences for benthic invertebrate habitats and severe consequences for sensitive marine environments, likely affecting between 20 and 60 percent and between 60 and 90 percent of these habitats within the permit area respectively (Table 3-3).

Table 3-3: Expert panel assessment: iron sands. Levels of environmental consequence for seven orders of magnitude of discharge of sediment released during prospecting and exploration as a single or multiple event, near the surface, in mid-water or near the seafloor. Volumes of discharge were calculated using the sediment densities provided in Table 3-2.

Risk Assessment: Iron sand		**Benthic Invertebrate Community**		**Demersal fish and mobile invertebrates**		**Air breathing fauna (seabirds, cetaceans, turtles)**		**Sensitive Benthic Environments**		**Pelagic Community**		**Highest consequence value**
Total discharge from either a single event or multiple events Weight (volume)	**Discharge location and frequency**	Consequence	Confidence	Consequence	Confidence	Consequence	Confidence	Consequence	Confidence	Consequence	Confidence	
1 t (~0.48 m^3)	Surface- single event	1	2b	1	2b	1	2b	1	2b	1	2b	1
	Mid-water - single event	1	2b	1	2b	1	2b	1	2b	1	2b	1
	Near seafloor - single event	1	2b	1	2b	1	2b	1	2b	1	2b	1
	Surface - multiple events	1	2b	1	2b	1	2b	1	2b	1	2b	1
	Mid-water - multiple events	1	2b	1	2b	1	2b	1	2b	1	2b	1
	Near seafloor - multiple events	1	2b	1	2b	1	2b	1	2b	1	2b	1
10 t (~4.8m^3)	Surface- single event	1	2b	1	2b	1	2b	1	2b	1	2b	1
	Mid-water - single event	1	2b	1	2b	1	2b	1	2b	1	2b	1
	Near seafloor - single event	1	2b	1	2b	1	2b	1	2b	1	2b	1
	Surface - multiple events	1	2b	1	2b	1	2b	1	2b	1	2b	1
	Mid-water - multiple events	1	2b	1	2b	1	2b	1	2b	1	2b	1
	Near seafloor - multiple events	1	2b	1	2b	1	2b	1	2b	1	2b	1
100 t (~48 m^3)	Surface- single event	1	2b	1	2b	1	2b	2	2b	1	2b	2
	Mid-water - single event	1	2b	1	2b	1	2b	2	2b	1	2b	2
	Near seafloor - single event	1	2b	1	2b	1	2b	2	2b	1	2b	2
	Surface - multiple events	1	2b	1	2b	1	2b	1	2b	1	2b	1
	Mid-water - multiple events	1	2b	1	2b	1	2b	1	2b	1	2b	1

	Near seafloor - multiple events	1	2b	1	2b	1	2b	2	2b	1	2b	2
1000 t (~480 m^3)	Surface- single event	2	2b	1	2b	1	2b	3	2b	1	2b	3
	Mid-water - single event	2	2b	1	2b	1	2b	3	2b	1	2b	3
	Near seafloor - single event	2	2b	1	2b	1	2b	3	2b	1	2b	3
	Surface - multiple events	2	2b	1	2b	1	2b	2	2b	1	2b	2
	Mid-water - multiple events	2	2b	1	2b	1	2b	2	2b	1	2b	2
	Near seafloor - multiple events	2	2b	1	2b	1	2b	2	2b	1	2b	2
10,000 t (~4,800 m^3)	Surface- single event	3	2b	2	2b	1	2b	3	2b	1	2b	3
	Mid-water - single event	3	2b	2	2b	1	2b	3	2b	1	2b	3
	Near seafloor - single event	3	2b	2	2b	1	2b	3	2b	1	2b	3
	Surface - multiple events	3	2b	2	2b	1	2b	3	2b	1	2b	3
	Mid-water - multiple events	3	2b	2	2b	1	2b	3	2b	1	2b	3
	Near seafloor - multiple events	3	2b	2	2b	1	2b	3	2b	1	2b	3
100,000 t (~48,000 m^3)	Surface- single event	3	2b	2	2b	1	2b	4	2b	2	2b	4
	Mid-water - single event	3	2b	2	2b	1	2b	4	2b	2	2b	4
	Near seafloor - single event	3	2b	2	2b	1	2b	4	2b	1	2b	4
	Surface - multiple events	3	2b	2	2b	2	2b	4	2b	2	2b	4
	Mid-water - multiple events	3	2b	2	2b	1	2b	4	2b	2	2b	4
	Near seafloor - multiple events	3	2b	2	2b	1	2b	4	2b	1	2b	4
1,000,000 t (~480,000 m^3)	Surface- single event	4	2b	2	2b	2	2b	5	2b	2	2b	5
	Mid-water - single event	4	2b	2	2b	1	2b	5	2b	2	2b	5
	Near seafloor - single event	4	2b	2	2b	1	2b	5	2b	2	2b	5
	Surface - multiple events	4	2b	2	2b	2	2b	5	2b	2	2b	5
	Mid-water - multiple events	4	2b	2	2b	1	2b	5	2b	2	2b	5
	Near seafloor - multiple events	4	2b	2	2b	1	2b	5	2b	2	2b	5

3.3 Phosphorite Nodules

3.3.1 Background

Phosphorite nodules (Figure 3-5) form arguably the most economically important and well-studied marine mineral deposit in the New Zealand EEZ (Cullen 1987; Glasby and Wright 1990). These patchily distributed deposits occur in water depths of about 400 m on the crest of the Chatham Rise, especially between 179°E and 180°. The Chatham Rise phosphorites formed by the phosphatisation of fragmented hard ground chalk pebbles about 12-7 million years ago under conditions of low to no sedimentation, within a pronounced oxygen minimum zone and intensified flow and upwelling of phosphorous-rich waters over the ridge crest. Subsequent biological and iceberg activity disrupted the fragmented phosphatised hard ground and led to the patchy distribution of phosphorite nodules within the top 1 m of the surficial glauconite-rich sandy muds on the crest of the Chatham Rise. Very minor phosphorite deposits have also been reported from shallow coastal environments, such as Raglan Harbour, Hauraki Gulf and off the Northland shelf (Glasby and Wright 1990).

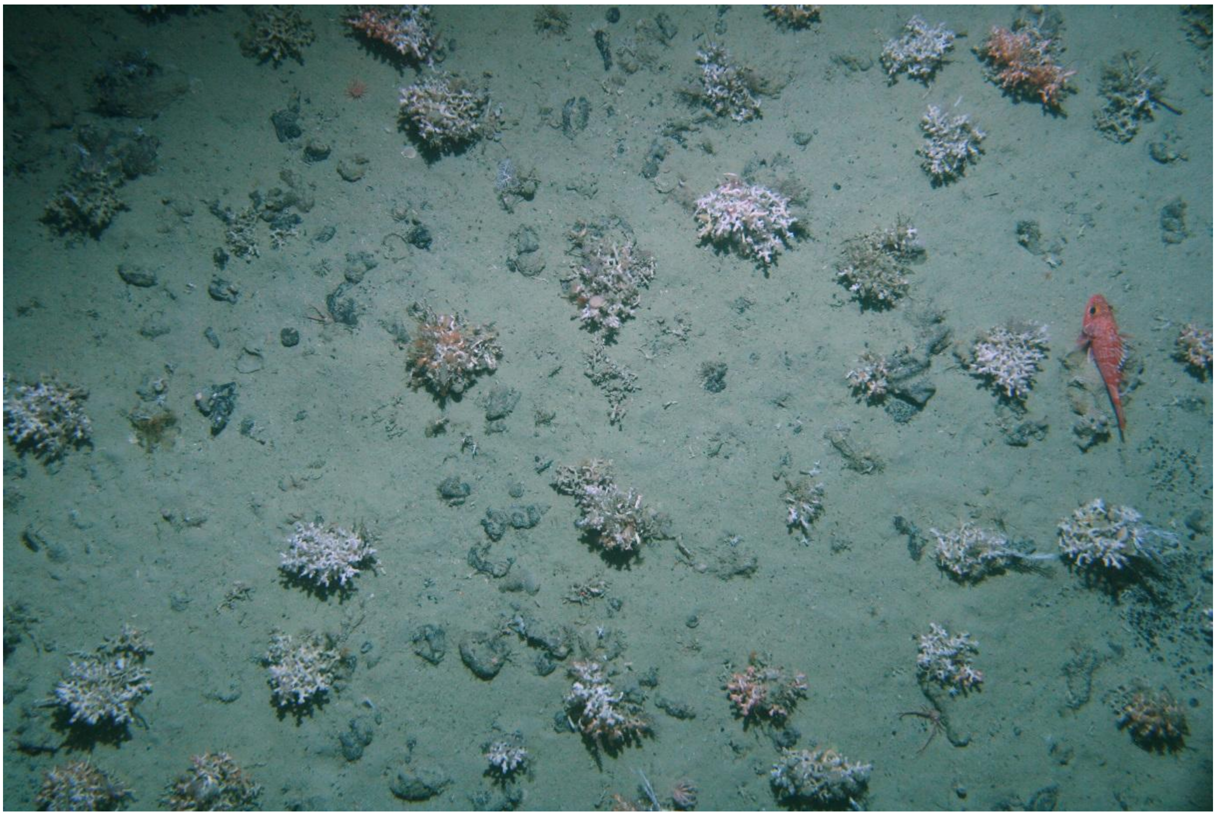

Figure 3-5: Dark, gravel-sized phosphorite nodules exposed on the Chatham Rise seafloor, some with attached deepwater corals. The fish is approximately 22 cm in length. Image: Taken during OS2020 voyage TAN1306

Potential methods to extract phosphorite deposits on the Chatham Rise include hydraulic suction dredging connected to a mining platform via a flexible hose, with a second hose transporting tailing sediments back to the seafloor (Figure 3-6). Test-pit mining during the exploration phase may be used to develop and test this technology, which has never been implemented at these water depths previously.

There is little publically available information on the potential toxicity of the seafloor sediments that would be disturbed during exploration and prospecting activities. Cullen (1987) lists the concentration of 21 trace elements, including uranium, in various sized phophorite nodules from the Chatham Rise but as the sampling regimes during exploration would target and retain these they may not contribute much to the released sediment. Consequently, we assumed that the toxicity of sediments released during exploration for phosphorite nodules was low.

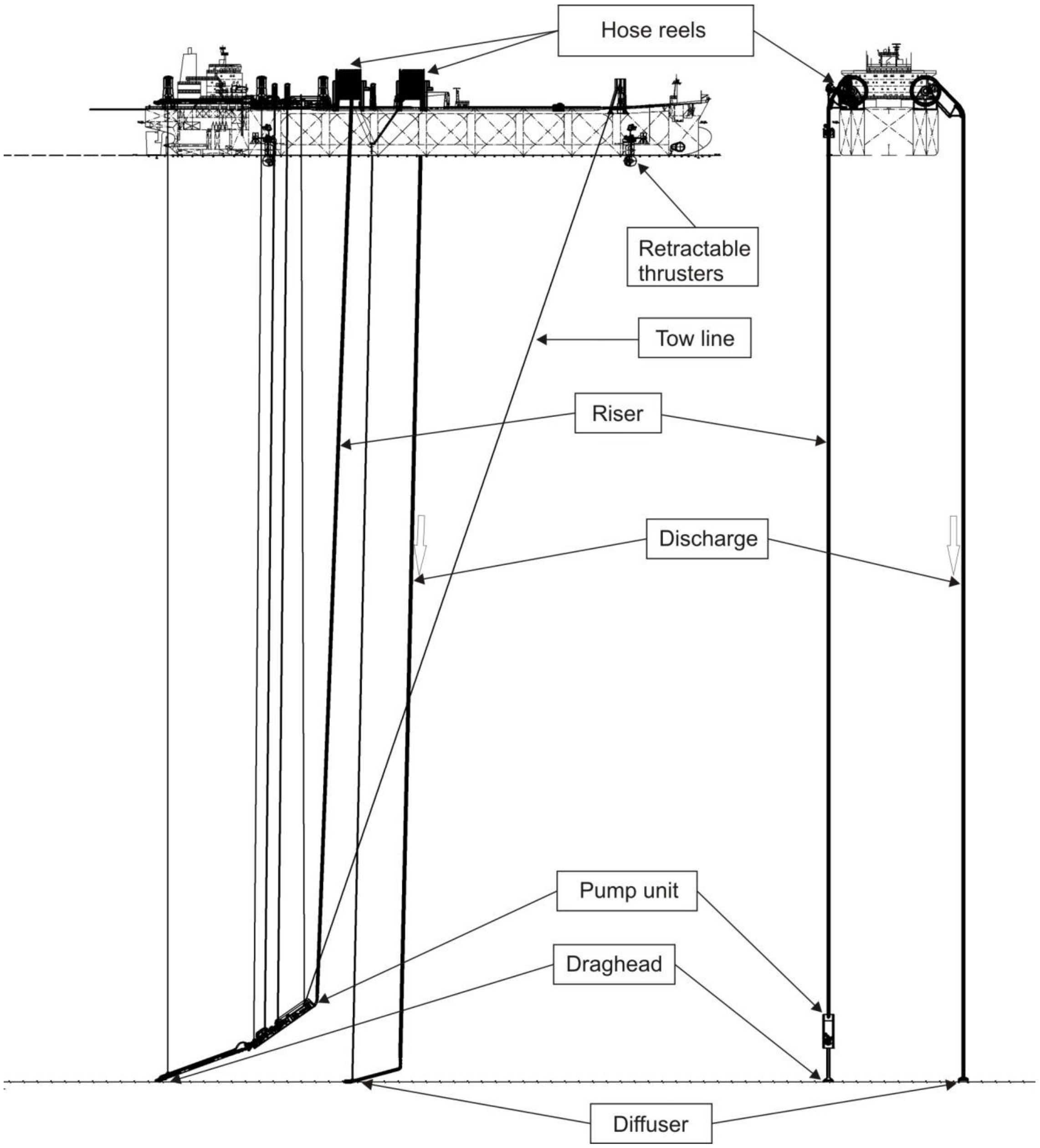

Figure 3-6: Schematic of proposed mining operations for phosphorite nodules on the Chatham Rise (from Grundlehner et al. 2012).

3.3.2 Receiving environment

The Chatham Rise is a prominent submarine feature that extends 100 km from Banks Peninsula eastwards for 1400 km. Five main areas, with depths less than 200 m, occur across the rise: Mernoo, Veryan, Reserve and Wharekauri banks and the Chatham Islands. West of the Chatham Islands, the Chatham Rise crest is generally flat-topped at 200-400 m, whilst east, north and south of the rise the water depths on the flanks increase to over 2000 m (Mackay et al. 2005; Nodder et al. 2012). Surface sediments on the rise are predominantly fine-grained sands and muds, with occasional outcrops of coarser material, including continental basement and volcanic rocks and phosphorite nodules (Nodder et al. 2012). Below 150 m water depth, the calcareous organic fraction of the sediment is composed mostly of foraminiferan tests, whereas molluscan fragments are more common above 150 m and may dominate the sediments at these shallower depths (e.g. the biogenic sediments of the Mernoo and Veryan banks) (Norris 1964).

To the north of the Chatham Rise lie warm subtropical waters, while to the south of the rise are cooler subantarctic waters. Between, and positioned variably across the rise, there is a zone of complex mixing known as the Subtropical Convergence or Front (STF) (Sutton 2001). This frontal zone is the locus for high surface primary productivity, hosting one of the most productive waters in the New Zealand EEZ (e.g. Murphy et al. 2001).

Planktonic foodwebs on the Chatham Rise are dominated by large phytoplankton (mainly diatoms), especially in spring, and year-round grazing by microzooplankton (smaller than 0.2 mm in size) and other microbial processes (e.g. Bradford-Grieve et al. 1999, Pinkerton 2013). Mesozooplankton (larger than 0.2 mm in size) biomass is often concentrated in the upper 100 m, but nocturnal vertical migration is also inferred from diurnal biomass variations (Bradford-Grieve et al. 1998). Smaller size-fractions (0.2-1 mm) of the mesozooplankton community are dominated by a combination of herbivores and omnivores, such as small calanoid copepods, appendicularians and euphausiid juveniles, with larger size-fractions containing higher numbers of carnivores, mainly amphipods, euphausiids, large adult calanoid copepods and chaetognaths (Bradford-Grieve et al. 1998). Mesopelagic fish communities on the rise are also known to actively migrate vertically from the seabed (day) to the surface (night) on a daily basis (McClatchie and Dunford 2003), and their distribution has been related to the population characteristics of one of their main predators, hoki (McClatchie et al. 1997, 2005).

The Chatham Rise is the scene of New Zealand’s major commercial deep-water fisheries, focussing primarily on hoki, ling, oreos and orange roughy, as well as being an important nursery ground for juvenile hoki. For example, in 2011-12, the Chatham Rise was the second largest hoki fishery, with 39 200 t taken from this area, almost entirely in bottom trawls (MPI/MFish 2013). Modelling undertaken by Leathwick et al. (2006) indicates that over a broad region of the Chatham Rise, species richness of demersal fish is predicted to be 16-20 species caught per standard research bottom trawl. Slightly lower richness (12-16 species) occurs on the shallower areas on the crest. Highest species richness was predicted by Leathwick et al. (2006) to occur at depths of 800 to 1000 m along the northern flank of the Chatham Rise.

The highly productive waters of the STF on the Chatham Rise hosts a rich seabird fauna of at least 14 albatross species, 11 petrel species, eight shearwater species, five prion species and five storm petrel species (Shirihai 2002). Similarly, many species of whales and dolphins occur in the area, including seven dolphins, seven toothed whales and seven baleen whales (Shirihai 2002).

Because of its depth the Chatham Rise is not subject to the high physical disturbance regime experienced by shallow areas of the shelf. Instead, the influence of the STF and the biological production that it supports are also apparent factors dictating the spatial patterns in benthic infaunal community composition observed on the Chatham Rise (e.g. Probert and McKnight 1993: Nodder et al. 2003). Probert and McKnight (1993) reported that the infauna was dominated numerically by polychaetes and peracarid crustaceans and that biomass of the sediment macroinvertebrate assemblages was greater on the south side than on the north side of the rise. Probert et al. (1996) identified two main polychaete communities, one occurring mainly on the crest of the rise (244-663 m) and a deeper one (802-1394 m) on the slopes of the rise. Community composition also differed between the north and south of the rise (i.e. on the southern flank of the rise, the station assemblages were more homogeneous in composition).

McKnight and Probert (1997) identified three epibenthic "community groups" living on the seafloor of the rise. The shallowest community, occurring on mainly sandy sediments on the crest and shallower flanks at 237-602 m, was characterised mainly by crustaceans. Two deeper water communities on muddy sediments were characterised mainly by echinoderms. Nodder et al. (2012) also considered that mobile fauna dominated the rise crest, including scampi (*Metanephrops challengeri*), squat lobsters (*Munida gracilis*), several crab species (C*arcinoplax victoriensis, Trichopeltarion fantasticum*), quill worms (*Hyalinoecia longibranchiata*), urchins (*Parametia peloria* and other spatangids) and asteroids (*Zoroaster, Astropecten, Plutonaster, Mediaster*). Where underlying rock or phosphorite nodules are exposed, sponges (*Hyalascus* sp.), stylasterid hydrocorals (*Goniocorella dumosa*) and other sessile suspension feeding fauna occur. These observations are consistent with previous findings of Dawson (1984) from areas on the rise where phosphorite mining was being contemplated. In particular, he noted that a "quite extensive epifauna" of corals (such as *G. dumosa*), bryozoans, cnidarians, bivalves and brachiopods developed on areas of hard substratum, such as exposed phosphorite nodules and crusts. Dawson considered the "*Goniocorella* clumps" as "epifaunal oases" that "undoubtedly attract small fish as feeding areas and may well be more the centre of energy dispersal than the smoother parts of the Rise". These biogenic habitats, particularly the corals and sponges, meet the definitions for sensitive marine environments described by MacDiarmid et al. (2013) and are included in the Permitted Activities Regulations 2013. These habitats are extensively, though patchily distributed over a large part of the crest of rise (Kudrass and Von Rad 1984)

3.3.3 Assessment

Note that discharges of 1,000,000 t were not assessed for phosphorite nodule deposits, as they are unrealistic during exploration phases given the likely size of the resource in existing permit areas.

Discharges of up to 1 t in total

Discharges of sediment totalling up to 1 t are most likely to arise during the taking of cores or surficial samples of sediment using corers or grabs. In both cases, most seabed material is likely to be retained for later laboratory analysis, with incidental loss of finer sediments during the retrieval process. Surficial sediment samples taken for analysis of biological specimens are likely to be sieved and washed on board the research vessel with consequent loss of most sediments overboard.

Because of the small volume of sediment released, and the nature of the receiving environment, we assessed that the consequences of this discharge were negligible for all components of the ecosystem, whether the sediment was released as a single or multiple event, near the surface, in mid-water or near the seafloor (Table 3-4).

Discharges of 10 t in total

Discharges of sediment totalling 10 t are most likely to arise during the taking of bulk samples to quantify the extent and quality of the resource or to obtain samples large enough to provide sufficient material to trial processing methods on land. If the sample is to quantify the extent of the resource, experience indicates that the sample is sieved on board the research vessel to retain those particles larger than about 1 mm with the remainder discarded overboard. If the sample was obtained for trialling processing methods, the bulk of the sample would be returned to shore.

Because of the reasonably small volume of sediment released, and the nature of the receiving environment, we assessed that the consequences of this discharge were negligible for all components of the ecosystem, whether the sediment was released as a single or multiple event, near the surface, in mid-water or near the seafloor (Table 3-4).

Discharges of 100 t in total

Discharges of sediment totalling 100 t are most likely to arise during the taking of bulk samples to quantify the extent and quality of the resource or to obtain samples large enough to provide sufficient material to trial processing methods on land.

Because of the modest volume of sediment released, and the nature of the receiving environment, we assessed that the consequences of this discharge were negligible for demersal fish and mobile invertebrates, and for seabirds and cetaceans, as they could easily move away from the discharge point(s). Similarly, we assessed the consequences for the pelagic community to be negligible because the scale of the discharge would be too small to have detectable impacts, whether released as a single or multiple event, near the surface, in mid-water or near the seafloor (Table 3-3).

When the discharge of a total of 100 t of sediment was from multiple points within the permit area, over the permit period, we considered the consequences for the benthic community to be negligible, as the sediment would probably be very widely distributed and thus would not form deposits sufficiently thick to impact the benthic ecosystem (Table 3-3). When discharged at a single point, we also considered the consequences for the benthic community to be negligible, as although deposits may be sufficiently thick to affect benthic organisms at this point, the area impacted is likely to be very small.

When the discharge was at the surface or in mid-water, at a single or multiple points, we considered the sediment could form deposits sufficiently thick over a wide enough area to have minor impacts on sensitive marine habitats, such as coral thickets, affecting between 1 and 5 percent of the habitat in the permit area. When released at the seafloor, we considered the consequences for the sensitive benthic habitats to be negligible, since, although deposits may be sufficiently thick to affect organisms, the area impacted would be very small, relative to the area occupied by the habitat as a whole in the mineral region.

Discharges of 1,000 t in total

Discharges of sediment totalling 1,000 t are most likely to arise during test-pit mining, when extraction, processing, and discharge methods are trialled to refine the final mining techniques. In these cases, we have assumed that the discharged sediment will resemble the original seafloor deposits in terms of particle size frequency and chemical composition, minus the ore component (see Table 3-2). The coarser material will not disperse far from the discharge point, whereas the finer particles may be carried many km by ocean currents over the time they may take to sink to the seafloor (McCave 1975).

We assessed that the consequences of discharges totalling 1,000 t were negligible for mobile fish and invertebrates, and for seabirds and cetaceans, as they could easily move away from the discharge point(s). Similarly, we assessed the consequences for the pelagic community to be negligible because the scale of the discharge would be too small to have detectable impacts, whether released as a single or multiple event, near the surface, in mid-water or near the seafloor (Table 3-4).

When the discharge was at the surface or in mid-water, at a single or multiple points, we considered the sediment could form deposits sufficiently thick over a wide enough area to have minor impacts on the benthic habitat, affecting between 1 and 5 percent of the habitat in the permit area. When released at the seafloor, we considered the consequences for the benthic habitat to be negligible since, although deposits may be sufficiently thick to affect organisms at this point, the area impacted would be very small. When the discharge was at the surface or in mid-water, at a single or multiple points, we considered the sediment could form deposits sufficiently thick over a wide enough area to have moderate impacts on sensitive marine environments, such as coral thickets, affecting between 5 and 20 percent of the habitat in the permit area. When released at the seafloor we considered the consequences for sensitive marine environments to be minor, since, although deposits may be sufficiently thick to affect organisms at this point, the area impacted is likely to be very small. (Table 3-4).

Discharges of 10,000 t in total

Discharges of sediment totalling 10,000 t are most likely to arise during test-pit mining, when extraction, processing, and discharge methods are trialled to refine the final mining techniques. In these cases we have assumed that the discharged sediment will resemble the original seafloor deposits in terms of particle size frequency and chemical composition, minus the ore component (see Table 3-2). The coarser material will not disperse far from the discharge point, whereas the finer particles may be carried many km by ocean currents over the time they may take to sink to the seafloor (McCave 1975).

We assessed that the consequences of discharges totalling 10,000 t would be negligible for seabirds and cetaceans if released in mid-water or near the seafloor, and minor if released at the sea surface as they could move away from the discharge point(s). Similarly, we assessed the consequences for the pelagic community to be negligible when sediment was released near the seafloor and minor when released at the surface or in mid-water, as most of the zooplankton community is in the upper half of the water column (Bradford-Grieve et al.

1998), the vision of pelagic predators and prey could be impaired, and shading of photosynthetic organisms could occur. For demersal fish and mobile invertebrates, we evaluated the consequences to be negligible for surface release of sediment and minor for discharges in mid-water or near the seafloor, as these species could move away from the discharge point(s) (Table 3-4).

For discharges totalling 10,000 t, we considered the sediment would form deposits sufficiently thick over a wide enough area to have ecologically important impacts on the benthic invertebrate community in the permit area, whether released as a single or multiple event, near the surface or in mid-water. In these circumstances, the overall consequences for these components of the ecosystem was assessed to be moderate likely affecting between 5 and 20 percent of the habitat within the permit area and with 5-20 percent changes in in population size or community composition. When released near the seafloor, we considered this same amount of sediment would be distributed less widely with likely minor consequences, affecting between 1 and 5 percent of the benthic habitat and sensitive marine environments (Table 3-4).

We assessed that for sensitive marine environments, such as coral thickets, with a more restricted distribution, a total discharge of 10,000 t, whether released as a single event or multiple events, near the surface or in mid-water, was likely to have major impacts, affecting between 20 and 60 percent of the habitat, substantially altering populations and communities and requiring a recovery period of 2-10 years. When released near the seafloor, we considered this same amount of sediment would be distributed less widely with probable moderate consequences, affecting between 5 and 20 percent of sensitive marine environments, (Table 3-4).

Discharges of 100,000 t in total

Discharges of sediment totalling 100,000 t are most likely to arise during test-pit mining, when extraction, processing, and discharge methods are trialled to refine the final mining techniques. In these cases, we have assumed that the discharged sediment will resemble the original seafloor deposits in terms of particle size frequency and chemical composition, minus the ore component (see Table 3-2). The coarser material will not disperse far from the discharge point, whereas the finer particles may be carried many km by ocean currents over the time they may take to sink to the seafloor (McCave 1975).

We assessed that the consequences of discharges totalling 100,000 t in mid-water, and near the seafloor would be minor for seabirds and cetaceans, as they could move away from the discharge point(s) causing only localised, short-term, decreases in abundance. When discharges totalling 100,000 t were made at the sea surface as either a single large event or multiple smaller events, we assessed the consequences for seabirds and cetaceans to be moderate, as movement away from the affected area could result in a measurable decrease in abundance over 5 to 20 percent of the permit area (Table 3-4).

We assessed that the consequences of discharges totalling 100,000 t at the sea surface, in mid-water, and near the seafloor, would be minor for demersal fish and mobile invertebrates, as they could move away from the discharge point(s), causing only localised, short-term, decreases in abundance (Table 3-4).

For the pelagic community, we assessed the consequences of discharges into surface waters totalling 100,000 t to be moderate with measurable decreases in abundance over 5 to 20 percent of the permit area. We considered that discharges in mid-water or near the seafloor would have less impact on the pelagic community, as less of the water column would be affected, with minor consequences (Table 3-4).

For discharges totalling 100,000 t. we considered the sediment would form deposits sufficiently thick to have ecologically important impacts on the benthic invertebrate community, whether released as a single or multiple event, near the surface, in mid-water or near the seafloor. The total volume of sediment was assessed to have moderate consequences likely affecting between 5 and 20 percent of the benthic invertebrate habitat within the permit area (Table 3-4).

We assessed that for sensitive marine environments with a more restricted distribution, a total discharge of 100,000 t, whether released as a single event or multiple events, near the surface or in mid-water, was likely to have severe impacts affecting between 60 and 90 percent of the habitat, likely to cause local extinctions, and requiring a recovery period of one to two decades. When released near the seafloor, we considered this same amount of sediment to have major consequences as it would be distributed less widely, affecting between 20 and 60 percent of sensitive marine environments (Table 3-4).

Table 3-4: Expert panel assessment: Phosphorite nodules. Levels of environmental consequence for seven orders of magnitude of discharge of sediment released during prospecting and exploration as a single or multiple event, near the surface, in mid-water or near the seafloor. Note that discharges of 1,000,000 t were not assessed as they are unrealistic during exploration phases given the likely size of the resource in permit areas. Volumes of discharge were calculated using the sediment densities provided in Table 3 2.

Risk Assessment: Phosphorite Nodules		**Benthic Invertebrate Community**		**Demersal fish and mobile invertebrates**		**Air breathing fauna (Seabirds, cetaceans, turtles)**		**Sensitive Benthic Environments**		**Pelagic Community**		**Highest consequence value**
Total discharge from either a single or multiple events Weight (volume)	**Discharge location and frequency**	**Consequence**	**Confidence**	**Consequence**	**Confidence**	**Consequence**	**Confidence**	**Consequence**	**Confidence**	**Consequence**	**Confidence**	
1 t (~0.65 m^3)	Surface- single event	1	2b	1	2b	1	2b	1	2b	1	2b	1
	Mid-water - single event	1	2b	1	2b	1	2b	1	2b	1	2b	1
	Near seafloor - single event	1	2b	1	2b	1	2b	1	2b	1	2b	1
	Surface - multiple events	1	2b	1	2b	1	2b	1	2b	1	2b	1
	Mid-water - multiple events	1	2b	1	2b	1	2b	1	2b	1	2b	1
	Near seafloor - multiple events	1	2b	1	2b	1	2b	1	2b	1	2b	1
10 t (~6.5 m^3)	Surface- single event	1	2b	1	2b	1	2b	1	2b	1	2b	1
	Mid-water - single event	1	2b	1	2b	1	2b	1	2b	1	2b	1
	Near seafloor - single event	1	2b	1	2b	1	2b	1	2b	1	2b	1
	Surface - multiple events	1	2b	1	2b	1	2b	1	2b	1	2b	1
	Mid-water - multiple events	1	2b	1	2b	1	2b	1	2b	1	2b	1
	Near seafloor - multiple events	1	2b	1	2b	1	2b	1	2b	1	2b	1
100 t (~65 m^3)	Surface- single event	1	2b	1	2b	1	2b	2	2b	1	2b	2
	Mid-water - single event	1	2b	1	2b	1	2b	2	2b	1	2b	2
	Near seafloor - single event	1	2b	1	2b	1	2b	1	2b	1	2b	1

	Surface - multiple events	1	2b	1	2b	1	2b	2	2b	1	2b	2
	Mid-water - multiple events	1	2b	1	2b	1	2b	2	2b	1	2b	2
	Near seafloor - multiple events	1	2b	1	2b	1	2b	1	2b	1	2b	1
1000 t (~650 m^3)	Surface- single event	2	2b	1	2b	1	2b	3	2b	1	2b	3
	Mid-water - single event	2	2b	1	2b	1	2b	3	2b	1	2b	3
	Near seafloor - single event	1	2b	1	2b	1	2b	2	2b	1	2b	2
	Surface - multiple events	2	2b	1	2b	1	2b	3	2b	1	2b	3
	Mid-water - multiple events	2	2b	1	2b	1	2b	3	2b	1	2b	3
	Near seafloor - multiple events	1	2b	1	2b	1	2b	2	2b	1	2b	2
10,000 t (~6,500 m^3)	Surface- single event	3	2b	1	2b	2	2b	4	2b	2	2b	4
	Mid-water - single event	3	2b	2	2b	1	2b	4	2b	2	2b	4
	Near seafloor - single event	2	2b	2	2b	1	2b	3	2b	1	2b	3
	Surface - multiple events	3	2b	1	2b	2	2b	4	2b	2	2b	4
	Mid-water - multiple events	3	2b	2	2b	1	2b	4	2b	2	2b	4
	Near seafloor - multiple events	2	2b	2	2b	1	2b	3	2b	1	2b	3
100,000 t (~ 65,000 m^3)	Surface- single event	3	2b	2	2b	3	2b	5	2b	3	2b	5
	Mid-water - single event	3	2b	2	2b	2	2b	5	2b	2	2b	5
	Near seafloor - single event	3	2b	2	2b	2	2b	4	2b	2	2b	4
	Surface - multiple events	3	2b	2	2b	3	2b	5	2b	3	2b	5
	Mid-water - multiple events	3	2b	2	2b	2	2b	5	2b	2	2b	5
	Near seafloor - multiple events	3	2b	2	2b	2	2b	4	2b	2	2b	4
1,000,000 t (~650,000 m^3)	Surface- single event	-	-	-	-	-	-	-	-	-	-	-
	Mid-water - single event	-	-	-	-	-	-	-	-	-	-	-
	Near seafloor - single event	-	-	-	-	-	-	-	-	-	-	-
	Surface - multiple events	-	-	-	-	-	-	-	-	-	-	-
	Mid-water - multiple events	-	-	-	-	-	-	-	-	-	-	-
	Near seafloor - multiple events	-	-	-	-	-	-	-	-	-	-	-

3.4 Seafloor massive Sulphides (SMS)

3.4.1 Background

Seafloor Massive Sulphide deposits (SMS) form in submarine volcanic regions where sulphur-rich magmatic and hydrothermal fluids precipitate sulphur and metals around hydrothermal vents. The hydrothermal fields typically occur on mounds that contain mineral precipitates and both high temperature 'black smoker' vents and lower temperature diffusive venting. Where mineralization is extensive SMS deposits can form, consisting of economically viable reserves of Cu, Pb and Zn, with some deposits also rich in Au and Ag (de Ronde et al. 2007) (Figure 3-7).

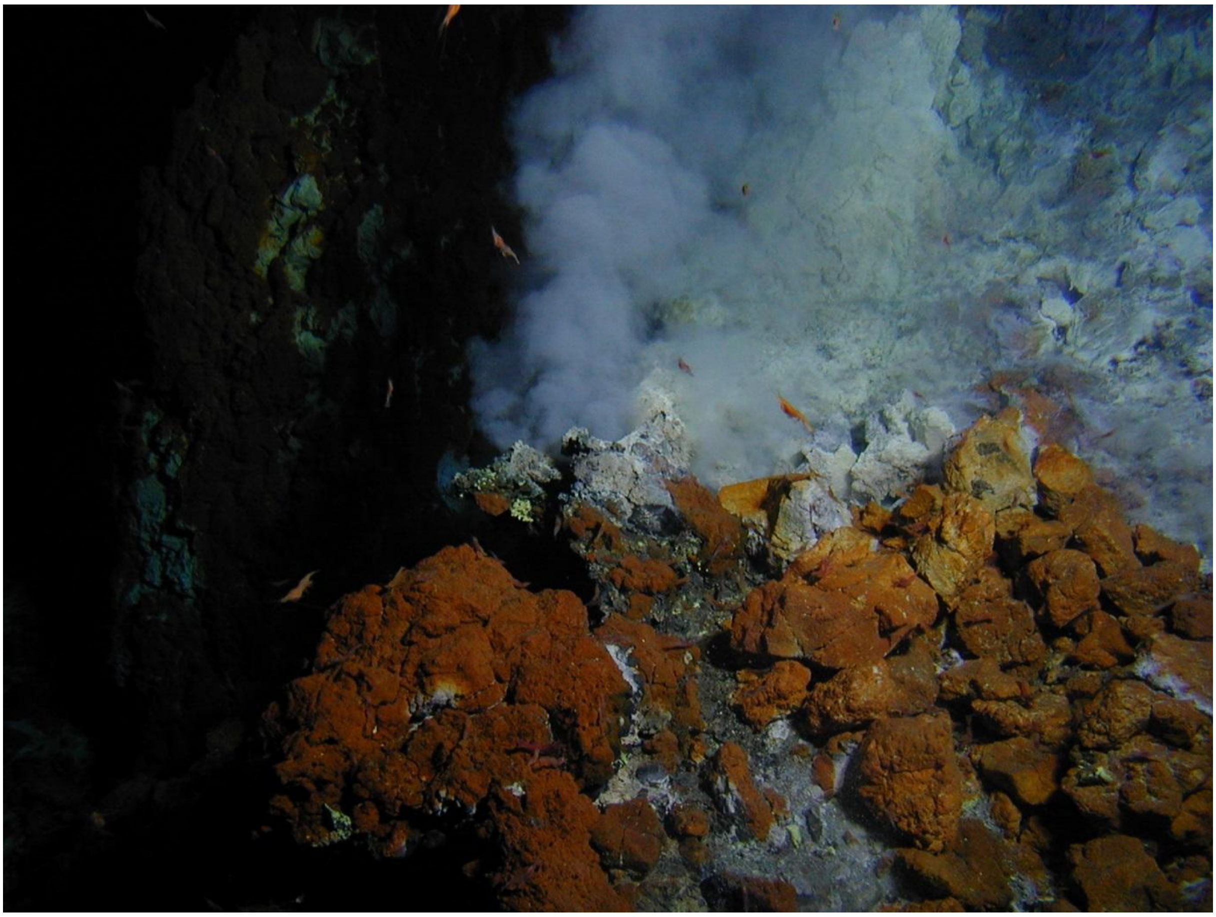

Figure 3-7: Venting on the Brothers Seamount, Kermadec Ridge. Image from the 2005 Pisces V voyage, NOAA/NIWA/GNS.

In the New Zealand EEZ and Extended Continental Shelf (ECS), hydrothermal venting is known to occur on two-thirds of the ~30 Kermadec Arc volcanoes (de Ronde et al, 2007), but only two sites, Brothers and Rumble II West, are so far reported to host SMS deposits of commercially exploitable scale. Deposits may also occur elsewhere in the Kermadec arc – Havre Trough volcanic system, although no hydrothermal activity has been found in the Havre Trough or on the Colville and Kermadec Ridges, which represent the proto-Kermadec arc (Wysoczanski and Clark 2012). However, the small number of known SMS deposits may simply be the result of limited exploration of these areas. Other Kermadec arc volcanoes, as well as the Colville and Kermadec ridges, are likely to host active or old inactive deposits, respectively. All of these areas are currently of interest to mining companies and prospecting licences have been lodged for the entire area. Extractable resources at vents are fossil in nature and non-renewable. While mineral deposits can form quickly at vents, commercial ore deposits accumulate over millennia (van Dover et al. 2011).

The technology to extract metals from SMS deposits from the ocean floor (at depths up to 4000 m) exists, but is as yet unproven. Different extraction methods are similar in that they require extraction of material from the subsurface, transportation to a large staffed mother ship, return of water and fine sediment to the ocean floor, and shipment of ore to land facilities. The most advanced proposal for exploration, by Nautilus Minerals in Papua New Guinea, involves remotely operated vehicles (ROVs), including the ocean bottom equivalent of bulldozers, and the hydraulic suctioning of ore from the seabed to the mother ship (Nautilus website).

Sampling during the exploration for SMS deposits has the potential to release toxic metals into the water column, or for these metals to be deposited down current. Toxicity testing of sediments from the Solwara 1 sulphide mound, PNG, found no observed effects on survivability of an inshore species of amphipod when ore concentrations were less than 1%, i.e., a 100-fold dilution (Coffey Natural Systems 2008). Given the likely dilutions of discharged sediment during descent through the water column, and in the context of the natural sediment fallout from plumes of volcanic or hydrothermal origin, we assessed that toxicological impacts from the scales of discharge considered are not likely to be detectable.

3.4.2 Receiving Environment

The Kermadec Volcanic Arc is comprised of two long narrow ridges that extend northeast of the North Island; the Colville Ridge towards Fiji and the Kermadec Ridge towards Tonga. Between the ridges lies the Havre Trough (maximum water depth of 4,512 m), and to the east of the Kermadec Ridge is the Kermedec Trench with a maximum depth exceeding 10 km.

The ocean currents in the region are dominated at depth (>2000 m) by the Deep Western Boundary Current that flows northward between the Kermadec Ridge and the Kermadec Trench (Wysoczanski and Clark 2012). Surface waters are strongly influenced by the East Australian Current, which flows across the northern Tasman Sea and around North Cape to form the East Auckland Current. Large warm anti-cyclonic eddies located off North Cape and East Cape further complicate surface flows in the region (Wysoczanski and Clark 2012).

The zooplankton communities are oceanic, but are poorly known with only a few studies in the region. Heinrich (1968) sampled zooplankton over a broad region of the West Pacific. She found most species to be widely distributed but abundant within part of their range. In the Kermadec region, the zooplankton is dominated by five oceanic copepods and a pelagic amphipod. The biomass for the top 500 m of the water column was broadly 3-5 g per m^2 with a few areas reaching 5-10 g per m^2 (Heinrich 1968). A synoptic overview of zooplankton biomass in the region (Bradford 1980) indicates a background in the upper 200 m of 1-25 mg per m^3, with higher biomass towards the southern end of the Kermadec Arc.

At least 42 sea bird taxa of southern, subtropical and tropical origins are known to occur with the region, generally on migration during non-breeding months, although some taxa (e.g. from northern New Zealand offshore islands) occur during breeding periods (Gaskin 2011).

Five species that nest at the Kermadec Islands are considered vulnerable; Kermadec little shearwater, white-naped petrel, white-bellied storm petrel, Tasman booby, and New Zealand sooty tern (Gaskin 2011).

According to the Department of Conservation, 35 species of whale or dolphin, including the humpback, blue whale, fin and sei whales, are thought to migrate through Kermadec waters. Five of the world's seven sea turtle species are found in the Kermadec region: hawksbill, leatherback, green, loggerhead and Pacific Ridley turtles[4].

The demersal fish fauna in the region is poorly known. Leathwick et al (2006) provide some modelling results for waters to 1,500 m water depth along both the Kermadec and Colville ridges, which indicate moderate species richness of 12-16 species per standard research bottom trawl, with a few areas of slightly higher species richness in shallow areas. However, few, if any, of the research trawls upon which the models were based are from these waters, so the data from Leathwick et al. (2006) must be used with caution.

The seamount faunal composition varies according to depth, dominant substrate type and the presence or absence of hydrothermal vents (Beaumont et al. 2012). Active vent fields are home to some of the most highly specialised marine faunas known (van Dover et al. 2011). Vent ecosystems are fueled primarily by microbial primary production through a process known as chemosynthesis. Instead of using energy from sunlight to fix inorganic carbon into organic carbon (photosynthesis), microbes in vent ecosystems use chemical energy from the oxidation of reduced chemical compounds (van Dover et al. 2011). Many species are apparently endemic to vent environments, and restricted to particular geographic regions. For example, the mussel *Gigantidas gladius* has only been recorded from hydrothermal vents along the Kermadec Arc, with the only co-genera *Gigantidas horikoshii* restricted to vents off southern Japan. Many of the vent communities in the Kermadec Arc region are dominated by bathymodiolid mussels, but there are considerable differences in the vent fauna between vents on a single seamount, and among vents on different seamounts (Wysoczanski and Clark 2012). These vent communities meet the definitions for sensitive marine environments described by MacDiarmid et al. (2013) and are included in the Permitted Activities Regulations 2013. These habitats are highly patchily distributed on seamounts (Beaumont et al. 2012).

Away from the active vents, invertebrate assemblages on hard substrates are characterised by the presence of echinoids, ophiuroids, soft corals, gastropods and asteroids (Wysoczanski and Clark 2012). The hard substrates of non-active SMS deposits have a similar faunal community (Van Dover 2011). Soft substrates are dominated by ophiuroids, asteroids and gastropods, while in coarse sediments these three groups dominate as well as anemones (Wysoczanski and Clark 2012). Ridge fauna are poorly described, but are thought to resemble those of the non-vent faunas on seamounts (Wysoczanski and Clark 2012).

3.4.3 Assessment

Note that discharges of 10,000 t, 100,000 t and 1,000,000 t were not assessed for SMS deposits, as they are unrealistic during exploration phases given the likely size of the resource in existing permit areas.

[4] http://www.doc.govt.nz/parks-and-recreation/places-to-visit/auckland/kermadec-islands/kermadec-islands/features/

Discharges of up to 1 t in total

Discharges of sediment totalling up to 1 t are most likely to arise during the taking of cores or surficial samples of sediment using corers or grabs. Core material is likely to be retained for later laboratory analysis with incidental loss of finer sediments during the retrieval process. Surficial sediment samples taken for analysis of biological specimens are likely to be sieved and washed on board the research vessel with consequent loss of most sediments overboard.

Because of the small volume of sediment released, and the nature of the receiving environment, we assessed that the consequences of this discharge were negligible for all components of the ecosystem, whether the sediment was released as a single or multiple event, near the surface, in mid-water or near the seafloor (Table 3-5).

Discharges of 10 t in total

Discharges of sediment totalling 10 t are most likely to arise during the taking of bulk samples to quantify the extent and quality of the resource or to obtain samples large enough to provide sufficient material to trial processing methods on land.

Because of the reasonably small volume of sediment released, and the nature of the receiving environment, we assessed that the consequences of this discharge were negligible for all components of the ecosystem, whether the sediment was released as a single or multiple event, near the surface, in mid-water or near the seafloor (Table 3-5).

Discharges of 100 t in total

Discharges of sediment totalling 100 t are most likely to arise during the taking of bulk samples to quantify the extent and quality of the resource or to obtain samples large enough to provide sufficient material to trial processing methods on land. Because of the modest volume of sediment released, and the nature of the receiving environment, we assessed that the consequences of this discharge were negligible for mobile fish and invertebrates, and for seabirds, cetaceans and turtles, as they could easily move away from the discharge point(s). Similarly, we assessed the consequences for the pelagic community to be negligible because the scale of the discharge would be too small to have detectable impacts whether released as a single or multiple event, near the surface, in mid-water or near the seafloor (Table 3-5).

When the discharge of a total of 100 t of sediment was at the sea surface, we considered the consequences for the benthic community to be negligible, as the sediment would be very widely distributed as it descended 1.5 km or more to the seafloor and would not form deposits sufficiently thick to impact the benthic ecosystem (Table 3-5).

However, when the discharge was in mid-water or near the seafloor, we considered the sediment could form deposits sufficiently thick to start to have measurable impacts on the benthic invertebrate community generally in the permit area. However, we assessed that the overall consequences for these components of the ecosystem would likely be minor.

When the discharge of a total of 100 t of sediment was at the sea surface, we considered the consequences for the sensitive marine environments, such as vent communities, to be minor as the sediment would be very widely distributed as it descended 1.5 km or more to the seafloor (Table 3-5). However, when the discharge was in mid-water or near the seafloor we considered the sediment could form deposits sufficiently thick to start to have measurable impacts on these species and that the consequences for these components of the ecosystem would possibly be moderate, affecting between 5 and 20 percent of the sensitive marine environments.

Discharges of 1,000 t in total

Discharges of sediment totalling 1,000 t are most likely to arise during test-pit mining when extraction, processing, and discharge methods are trialled to refine the final mining techniques. In these cases, we have assumed that the discharged sediment will resemble the original seafloor deposits in terms of particle size frequency and chemical composition, minus the ore component (see Table 3-2). The coarser material will not disperse far from the discharge point, whereas the finer particles may be carried many km by ocean currents (McCave 1975).

We assessed that the consequences of discharges totalling 1,000 t were negligible for seabirds, cetaceans, and turtles, as they could easily move away from the discharge point(s). Similarly, we assessed the consequences for the pelagic community to be negligible because the scale of the discharge would be too small to have detectable impacts, whether released as a single or multiple event, near the surface, in mid-water or near the seafloor. Discharges totalling 1,000 t are also likely to have negligible impacts on demersal fish and mobile communities, unless the discharge is near the seafloor when movement away from the discharge may cause localised short-term minor effects (Table 3-5).

When the discharge of a total of 1,000 t of sediment was at the sea surface, we considered the consequences for the benthic community to be minor, as the sediment would be very widely distributed as it descended 1.5 km or more to the seafloor and would form deposits sufficiently thick to impact between 1 and 5 percent of the benthic ecosystem. However, when the discharge was in mid-water or near the seafloor, we considered the sediment could form deposits sufficiently thick to have moderate consequences, affecting between 5 and 20 percent of the benthic invertebrate community generally in the permit area (Table 3.5).

When the discharge of a total of 1,000 t of sediment was at the sea surface, we considered the consequences for the sensitive marine environments, such as vent communities, to be moderate, as the sediment would be widely distributed as it descended 1.5 km or more to the seafloor, but might accumulate sufficient thickness to negatively impact between 5 and 20 percent of the sensitive marine environments (Table 3.5). However, when the discharge was in mid-water or near the seafloor, we considered the sediment would form deposits sufficiently thick to have major consequences, affecting between 20 and 60 percent of sensitive marine environments in the permit area.

Table 3-5: Expert panel assessment: Seafloor Massive Sulphides. Levels of environmental consequence for four orders of magnitude of discharge of sediment released during prospecting and exploration as a single or multiple event, near the surface, in mid-water or near the seafloor. Note that discharges of 10,000 t, 100,000 t and 1,000,000 t were not assessed as they are unrealistic during SMS exploration phases given the likely size of the resource in permit areas. Volumes of discharge were calculated using the sediment densities provided in Table 3 2.

Risk Assessment: Seafloor Massive Sulphides		Benthic Invertebrate Community		Demersal fish and mobile invertebrates		Air breathing fauna (Seabirds, cetaceans, turtles)		Sensitive benthic environments		Pelagic Community		Highest consequence value
Total discharge from either a single or multiple events Weight (volume)	**Discharge location and frequency**	Consequence	Confidence	Consequence	Confidence	Consequence	Confidence	Consequence	Confidence	Consequence	Confidence	
1 t (~0.83 m^3)	Surface- single event	1	2a	1	2a	1	2a	1	2c	1	2c	1
	Mid-water - single event	1	2a	1	2a	1	2a	1	2c	1	2c	1
	Near seafloor - single event	1	2a	1	2a	1	2a	1	2c	1	2c	1
	Surface - multiple events	1	2a	1	2a	1	2a	1	2c	1	2c	1
	Mid-water - multiple events	1	2a	1	2a	1	2a	1	2c	1	2c	1
	Near seafloor - multiple events	1	2a	1	2a	1	2a	1	2c	1	2c	1
10 t (~8.3 m^3)	Surface- single event	1	2a	1	2a	1	2a	1	2c	1	2c	1
	Mid-water - single event	1	2a	1	2a	1	2a	1	2c	1	2c	1
	Near seafloor - single event	1	2a	1	2a	1	2a	1	2c	1	2c	1
	Surface - multiple events	1	2a	1	2a	1	2a	1	2c	1	2c	1
	Mid-water - multiple events	1	2a	1	2a	1	2a	1	2c	1	2c	1
	Near seafloor - multiple events	1	2a	1	2a	1	2a	1	2c	1	2c	1
100 t (~83 m^3)	Surface- single event	1	2a	1	2a	1	2a	2	2c	1	2c	1
	Mid-water - single event	2	2a	1	2a	1	2a	3	2c	1	2c	3

	Near seafloor - single event	2	2a	1	2a	1	2a	3	2c	1	2c	3
	Surface - multiple events	1	2a	1	2a	1	2a	2	2c	1	2c	2
	Mid-water - multiple events	2	2a	1	2a	1	2a	3	2c	1	2c	3
	Near seafloor - multiple events	2	2a	1	2a	1	2a	3	2c	1	2c	3
1000 t (~830 m^3)	Surface- single event	2	2a	1	2a	1	2a	3	2c	1	2c	3
	Mid-water - single event	3	2a	1	2a	1	2a	4	2c	1	2c	4
	Near seafloor - single event	3	2a	2	2a	1	2a	4	2c	1	2c	4
	Surface - multiple events	2	2a	1	2a	1	2a	3	2c	1	2c	3
	Mid-water - multiple events	3	2a	1	2a	1	2a	4	2c	1	2c	4
	Near seafloor - multiple events	3	2a	1	2a	1	2a	4	2c	1	2c	4
10,000 t (~8,300 m^3)	Surface- single event	-	-	-	-	-	-	-	-	-	-	-
	Mid-water - single event	-	-	-	-	-	-	-	-	-	-	-
	Near seafloor - single event	-	-	-	-	-	-	-	-	-	-	-
	Surface - multiple events	-	-	-	-	-	-	-	-	-	-	-
	Mid-water - multiple events	-	-	-	-	-	-	-	-	-	-	-
	Near seafloor - multiple events	-	-	-	-	-	-	-	-	-	-	-
100,000 t (~83,000 m^3)	Surface- single event	-	-	-	-	-	-	-	-	-	-	-
	Mid-water - single event	-	-	-	-	-	-	-	-	-	-	-
	Near seafloor - single event	-	-	-	-	-	-	-	-	-	-	-
	Surface - multiple events	-	-	-	-	-	-	-	-	-	-	-
	Mid-water - multiple events	-	-	-	-	-	-	-	-	-	-	-
	Near seafloor - multiple events	-	-	-	-	-	-	-	-	-	-	-
1,000,000 t (~830,000 m^3)	Surface- single event	-	-	-	-	-	-	-	-	-	-	-
	Mid-water - single event	-	-	-	-	-	-	-	-	-	-	-
	Near seafloor - single event	-	-	-	-	-	-	-	-	-	-	-
	Surface - multiple events	-	-	-	-	-	-	-	-	-	-	-
	Mid-water - multiple events	-	-	-	-	-	-	-	-	-	-	-
	Near seafloor - multiple events	-	-	-	-	-	-	-	-	-	-	-

4 Summary and Conclusions

MfE has identified that more detailed and comprehensive information is needed to fully inform policy decisions relating to the discharge of sediments during prospecting and exploration for seabed minerals. Consequently, NIWA was engaged by MfE to undertake a qualitative assessment, using expert opinion, of the environmental risk of sediment discharges arising during exploration and prospecting for iron sands, phosphorite nodules and seafloor massive sulphide (SMS) deposits.

There are a number of approaches and methods that have been applied around the world to conduct ecological risk assessments. Where the activity is deliberate and programmed to take place, regularly and repeatedly in an area, such as in seabed exploration or prospecting, an exposure-effects approach (e.g. Smith et al. 2007; Sharp et al. 2009) is the most suitable. In this case, risk is the sum of all the effects on the ecosystem, as the likelihood of the event occurring is unity (1). The approach adopted for this assessment was a Level 1 Scale, Intensity, and Consequence Analysis (SICA) (Hobday et al 2007). Level 1 assessments are generally used in data-poor situations where the scale of activity or its impacts on particular species, habitats or the ecosystem are uncertain or only partially described (Hobday et al. 2007). This was the case for this assessment where the scale of possible discharges during exploration and prospecting is poorly described for SMS deposits in a New Zealand context, and the distribution of benthic species is also not yet described in any detail for most areas with seafloor mineral deposits, with the exception of areas in the immediate vicinity of the proposed mining of iron sands in the South Taranaki Bight, phosphorite nodules on part of the Chatham Rise, and on the Kermadec volcanic arc where SMS deposits are presently known to occur.

The scale of discharges that could potentially arise from the prospecting and exploration phases of seabed mining ranges from 1 t or less to, in the case of iron sands, close to one million tonnes. To indicate where thresholds may occur, whereby the risk of adverse effects to the environment would be minor or less, we assessed discharges of sediment of 1 t, 10 t, 100 t, 1,000 t, 10,000 t, 100,000 t and 1,000,000 t, except for SMS deposits, where the three largest scales of discharge were considered to be unrealistic during exploration phases given the likely restricted size of the resource in permit areas. The discharge of sediment into surface waters, mid-water or near the seabed (defined as in the bottom 5% of the water column) was also evaluated since this will determine the size of the consequent sediment dispersal plume and the thickness and extent of the material deposited on the seafloor. We also assessed the consequences of the discharge being from a single point at one time or from multiple points over the permit period that sum to the same total discharge under consideration.

The ecosystem components evaluated were the benthic invertebrate community in the discharge environment, the demersal (bottom- associated) fish and mobile invertebrate (squid, octopus, scallops, large crabs) community, the air- breathing fauna, comprising marine mammals, seabirds and turtles, sensitive benthic environments, as defined in the Permitted Activities Regulations 2013, and the pelagic community, including phytoplankton, zooplankton, fish, and larger invertebrates. The effects taken into account were clogging of respiratory surfaces and feeding structures of marine organisms, shading of photosynthetic organisms, diminished capacity for vision by predators and prey, known toxic effects, noise, avoidance of the discharge area by mobile species, and smothering of organisms on the seafloor.

Using this qualitative approach, our assessment indicates that, at the scale of sampling undertaken to-date by mining companies prospecting and exploring for seabed minerals, the consequences are likely to be negligible or minor. However, we also concluded that discharges of sediment during exploration and prospecting for seabed minerals can reach major or severe levels of consequence for the most sensitive marine benthic habitats occurring in each of the seabed mineral areas, depending on the size of the discharge, but that catastrophic consequences were never reached over the scales of discharge considered.

Severe consequences indicate extensive impacts, with between 60 and 90 percent of a habitat affected within the area being assessed, causing local extinctions of some species if the impact continues, with a major change to habitat and community structure. Recovery is likely to take one or two decades (see Table 2-1). Severe consequences for sensitive marine environments were reached at a discharge scale of 1,000,000 t on the shelf along the west coast of North Island (iron sands region) and at a discharge scale of 100,000 t on the crest of the Chatham Rise (phosphorite nodule regions). Major consequences were reached at a discharge scale of 1,000 t along the Kermadec volcanic arc (SMS region). The smaller scale of the sensitive habitats in these latter two regions is why they were assessed as being more vulnerable to a lower level of discharge than on the west coast North Island.

Moderate or greater consequences indicate an important transition in ecological significance (e.g. Hobday et al. 2007). Impacts that have minor consequences may be detectable, but are likely to have little impact on population size or community composition and are not expected to have any impact on the dynamics of any population or the ecosystem. Recovery from this level of impact is expected to occur within one to eight weeks. Moderate consequences are ecologically significant, affecting between 5 and 20 percent of the habitat or community in question, with measurable changes in populations abundance, or biomass, or community composition of between 5 and 20 percent (although there is unlikely to be a major change in function). Recovery from this level of impact is expected to take up to 1-2 years. Moderate consequences for sensitive marine environments were reached at a discharge scale of 1,000 t on the shelf along the west coast of North Island (iron sands region), at a discharge scale of 1,000 t on the crest of the Chatham Rise (phosphorite nodule region), and a discharge scale of 100 t along the Kermadec volcanic arc (SMS region) (see Table 4-1).

Over the range of discharges considered, seabirds, cetaceans and turtles were assessed as being the least vulnerable, principally because they can rapidly move away from the discharge point(s) and are less affected by discharges in mid-water or near the seafloor. The pelagic community was the next least affected by sediment discharge, principally because the scale of pelagic habitats is so large compared to even the largest discharge considered, and in deep water, seabed discharges are unlikely to have much impact on the upper part of the water column where most of the pelagic biomass occurs, although in areas of strong vertical migration (e.g., McClatchie and Dunford 2003) some pelagic species could be periodically exposed. Demersal fish and mobile invertebrates will probably be little impacted by discharges of sediment over the scales of discharge assessed, as they can rapidly move away from the discharge point(s). Seafloor discharge of sediment, however, had the largest impact on the dermersal component of the ecosystem.

Table 4-1: Levels of sediment discharge when consequences become moderate or greater for five ecosystem components. - indicates a moderate consequence was not reached for this component of the ecosystem over the scales of discharge assessed.

Mineral deposit	Benthic Invertebrate Community	Demersal fish and mobile invertebrates	Air breathing fauna (seabirds, cetaceans, turtles)	Sensitive Benthic Environments	Pelagic Community
Iron sands	10,000 t	-	-	1,000 t	-
Phosphorite nodules	10,000 t	-	100,000 t	1,000 t	100,000 t
SMS deposits	1,000 t	-	-	100 t	-

Benthic communities, aside from sensitive environments, showed varying levels of impact across the three mineral regions assessed. Most sensitive to the scales of sediment discharge assessed were the non-vent faunas along the Kermadec volcanic arc, as these include invertebrate assemblages on hard substrates characterised by the presence of echinoids, ophiuroids, soft corals, gastropods and asteroids. Slightly less sensitive were the faunas of non-sensitive environments on the crest of the Chatham Rise, as these naturally occur in areas of soft sediment and are believed to be resilient to the low levels of suspended sediment (Nodder et al. 2007). We assessed the benthic community along the relatively shallow, wave-swept west coast of the North Island to be least impacted by the levels of sediment discharge considered. Each major storm event re-suspends sediments in this region (Hadfield 2013) and the benthic species present are resilient to this type of natural disturbance.

Our risk assessments were carried out without taking into account possible strategies by the mining companies to avoid or mitigate impacts, other than the depth of release. Ellis (2008) reviewed the role of deep submarine tailings placement (STP) in the mitigation of pollution from coastal terrestrial mines. He stated that the best practice for STP is for the tailings to be placed in a targeted area of sandy or muddy seafloor in deepwater, below the photic zone, in areas with low rates of resuspension, of low fisheries use, low biodiversity, and away from sensitive marine habitats and feeding or staging areas for marine mammals and birds. Ellis (2008) suggests that the final desposition site should have the potential for recovery within 1-3 years. Similarly, Johnson et al. (2008) in their review of conservation measures and best management practices for offshore mineral mining recommended avoiding discharging sediment in areas containing sensitive or unique marine benthic habitats. Boschen et al. (2013) have proposed two general mitigation strategies for mining of SMS deposits. The first should aim at maximising the potential for recolonisation of areas impacted by mining from surrounding populations by the preservation of undisturbed communities similar to the impacted community. The second mitigation strategy should aim at reducing the concentration and toxicity of particles in sediment plumes associated with various mining activities.

While designed to mitigate the impact of mining itself, these best-practice principles could be applied to the discharge of sediment during exploration and prospecting phases of mining. In some circumstances restricting the discharge of sediments during exploration activities to the point of extraction might also mitigate the effects of the discharge as it is likely to minimise impacts on adjacent habitats that may be sensitive. However, a legitimate focus of smaller scale sampling during exploration phases, with consequent discharges of material of up to 1 t, is to sample the benthos and describe the distribution of sensitive communities. Although in these cases discharges over the point of extraction could be over a sensitive community we assessed discharges of this scale to have negligible consequences. The scale at which discharge over the point of extraction may provide a meaningful level of mitigation is 100 t and above where consequences are minor or greater for exploration of all three mineral deposits. This scale of discharge is associated with bulk sampling or test pit mining of the mineral deposit.

Our assessments indicate that there is a trade-off in mitigation between release of the sediment near the surface thereby spreading a thinner layer over a wide area or discharging near the seabed which result in a thicker deposit but may assist in minimising the extent of the area affected by the discharge. The strategy undertaken will depend on the depth of water, the type of sediment and the expected dispersal of sediment from the release point. However, release near the seabed may be impractical for all sampling undertaken during exploration other than test-pit mining when non-ore sediments could be discharged close to the seabed at, or near, the point of sampling.

Effective employment of these strategies requires good knowledge of the spatial distribution of the different benthic habitats with respect to the distribution of the mineral resource within the permit area, as well as the function of the marine ecosystems in the area. Thus, the compilation of available data or a degree of sampling effort to obtain this basic information will be required prior to undertaking prospecting and exploration activities that will involve the discharge of sediment above 100 t for iron sand and phophorite nodule regions and 10 t for SMS deposit regions, because only below this scale are the impacts of discharges assessed to be negligible or minor.

5 Acknowledgements

We thank Ashley Rowden (NIWA), Rosie Parry and Joshua McLennan-Deans (both MfE) and Conrad Pilditch (University of Waikato) for helpful comments on an earlier draft of this report.

6 References

Anderson, T.; MacDiarmid, A.; Stewart, R. (2013). Benthic habitats, macrobenthos and surficial sediments of the nearshore South Taranaki Bight. NIWA Client Report No: NEL2013-012

Baird, S.J.; Gilbert, D.J. (2010). Initial assessment of risk posed by trawl and longline fisheries to selected seabird taxa breeding in New Zealand waters. New Zealand Aquatic Environment and Biodiversity Report No. 50. 99 p.

Beaumont, J.; Rowden, A.A.; Clark, M.R. (2012). Deepwater biodiversity of the Kermadec Islands Coastal Marine Area. Science for Conservation 319. New Zealand Department of Conservation. 60p.

Beaumont, J.; Anderson, T.; MacDiarmid, A. (2013). Benthic flora and fauna of the Patea Shoals region South Taranaki Bight, NIWA Client Report No: WLG2012-55;

Boschen, R.E.; Rowden, A.A.; Clark, M.R.; Gardner, J.P.A. (2013). Mining of deep-sea seafloor massive sulfides: a review of the deposits, their benthic communities, impacts from mining, regulatory frameworks and management strategies. Ocean & Coastal Management 84: 54-67.

Bradford, J.M. (1980). New Zealand region, zooplankton biomass (0-200 m). New Zealand Oceanographic Institute Chart, Miscellaneous Series 41.

Bradford-Grieve, J.; Murdoch, R.; James, M.; Oliver, M.; McLeod, J. (1998). Mesozooplankton biomass, composition, and potential grazing pressure on phytoplankton during austral winter and spring 1993 in the Subtropical Convergence region near New Zealand. Deep-Sea Research I 45: 1709-1737.

Bradford-Grieve, J.M.; Boyd, P.W.; Chang, F.H.; Chiswell, S.; Hadfield, M.; Hall, J.A.; James, M.R.; Nodder, S.D.; Shushkina, E.A. (1999). Pelagic ecosystem structure and functioning in the Subtropical Front region east of New Zealand in austral winter and spring 1993. Journal of Plankton Research 21(3): 405-428.

Bradford-Grieve, J.; Stevens, C. (2013). Zooplankton and the processes supporting them in Greater Western Cook Strait. NIWA Client Report No: WLG2013-9, 22 p.

Coffey Natural Systems (2008). Environmental impact statement: Nautilus Minerals Niugini Ltd, Solwara 1 project, Volume 1 Main report, 226 p.

Cullen, D.J. (1987). The submarine phosphate resource on central Chatham Rise. DMFS Report 2, DSIR-Division of Marine & Freshwater Science, Wellington, New Zealand: 22p.

Dawson, E. (1984). The benthic fauna of the Chatham Rise: an assessment relative to possible effects of phosphorite mining. Geologisches Jahrbuch D65: 209-231.

de Ronde, C.E.J.; Baker, E.T.; Massoth, G.J.; Lupton, J.E.; Wright, I.C.; Sparks, R.J.; Bannister, S.C.; Reyners, M.E.; Walker, S.L.; Greene, R.R.; Ishibashi, J.; Faure, K.; Resing, J.A.; Lebon, G.T. (2007). Submarine hydrothermal activity along the mid-Kermadec Arc, New Zealand: large-scale effects on venting: Geochemistry, Geophysics, Geosystems, v. 8, p. Q07007.

Du Fresne, S. (2010). Distributionof Maui's dolphin (*Cephalorhynchus hectori maui*) 2000-2009. DOC Research & Development Series 322.

Ellis, D. (2008). The role of deep submarine tailings placement (STP) in the mitigation of marine pollution for coastal and island mines. In: Marine Pollution: New Research, T.N. Hofer (ed), 23-51.

Ellis, J.I.; Cummings, V.; Hewitt, J.; Thrush, S.; Norkko, A. (2002). Determining effects of suspended sediment on condition of a suspension feeding bivalve *(Atrina zelandica)*: results of a survey, a laboratory experiment and a field transplant experiment. Journal of Experimental marine Biology and Ecology 267:147–174.

Gaskin, C.P. (2011). Seabirds of the Kermadec region: their natural history and conservation. Science for Conservation 316. Department of Conservation, Wellington. 71 p.

Glasby, G.P.; Wright, I.C. (1990). Marine mineral potential in New Zealand's Exclusive Economic Zone. Marine Mining 9: 403-427.

Grundlehner, G.; Castle, C.; Falconer, R.K.H. (2012). Phosphate mining offshore New Zealand. Offshore Technology Conference, Houston, Texas.

Hadfield, M. (2013). South Taranaki Bight Iron Sand Extraction Sediment Plume Modelling Phase 3 studies. NIWA Client Report No: WLG2013-36, 86 p. Available at http://www.epa.govt.nz/eez/EEZ000004/EEZ000004_NIWA_sediment_plume_modelling_report.pdf

Heinrich, A.K. (1968). Quantitative distribution of the plankton animals in the west Pacific. In H.J. Semina (ed) Plankton of the Pacific Ocean. Nauka, Moscow. [In Russian with English abstract].

Hobday, A. J.; Smith, A.; Webb, H.; Daley, R.; Wayte, S.; Bulman, C.; Dowdney, J.; Williams, A.; Sporcic, M.; Dambacher, J.; Fuller, M.; Walker, T.. (2007). Ecological risk assessment for the effects of fishing: methodology. Report R04/1072 for the Australian Fisheries Management Authority, Canberra.

Hobday, A.J.; Smith, A.D.M.; Stobutzki, I.C.; Bulman, C.; Daley, R.; Dambacher, J.M.; Deng, R.A.; Dowdney, J.; Fuller, M.; Furlani, D.; Griffiths, S.P.; Johnson, D.; Kenyon, R.; Knuckey, I.A.; Ling, S.D.; Pitcher, R.; Sainsbury, K.J.; Sporcic, M.; Smith, T.; Turnbull, C.; Walker, T.I.; Wayte, S.E.; Webb, H.; Williams, A.; Wise, B.S.; Zhou, S. (2011). Ecological risk assessment for the effects of fishing. Fisheries Research 108 (2-3): 372-384.

Johnson, M.R.; Boelke, C.; Chiarella, L.A.; Colosi, P.D.; Greene, K.; Lellis-Dibble, K.; Ludemann, H.; Ludwig, M.; McDermott, S; Ortiz, J.; Rusanowsky, D.; Scott, M.; Smith, J. (2008). Impacts to marine fisheries habitat from non-fishing activities in the North-eastern United States. NOAA Technical Memorandum NMFS-NE-209, http://www.nefsc.noaa.gov/nefsc/publications/tm/tm209/

Kudrass, H-R.; Von Rad, U. (1984). Underwater television and photpgraphy observations, side-scan sonar and acoustic reflectivity measurements of phosphorite-rich areas of the Chaham Rise (New Zealand). Geologisches Jahrbuch D65: 69-89.

Leathwick, J.R.; Elith, J.; Francis, M.O.; Hastie, T.; Taylor, P. (2006). Variation in demersal fish species richness in the oceans surrounding New Zealand: an analysis using boosted regression trees. Marine Ecology Progress Series 321:267-281.

Lohrer, A.M.; Thrush, S.F.; Hewitt, J.E.; Berkenbusch, K.; Ahrens, M.; Cummings, V.J. (2004). Terrestrially derived sediment: response of marine macrobenthic communities to thin terrigenous deposits. Marine Ecology Progress Series 273:121–138

Lohrer, A.M.; Thrush, S.F.; Lundquist, C.J.; Vopel, K.; Hewitt, J.E.; Nicholls, P.E. (2006). Deposition of terrigenous sediment on subtidal marine macrobenthos: response of two contrasting community types. Marine Ecology Progress Series 307: 115–125.

Loher, A.M.; Hewitt, J.E.; Thrush, S.F. (2006). Assessing far-field effects of terrigenous sediment loading in the coastal marine environment. Marine Ecology Progress Series 315: 13–18.

MacDiarmid, A.; Anderson, O.; Beaumont, J.; Gorman, R.; Hancock, N.; Julian, K.; Schwarz, J.; Stevens, S.; Sturman, J.; Thompson, D.; Torres, L. (2011). South Taranaki Bight factual baseline environmental report. NIWA Client Report WLG2010-43, 391 pp. (see http://www.epa.govt.nz/eez/EEZ000004/EEZ000004_South_Taranaki_Bight_Baseline_Evironmental_Report_final_No_Appendices.pdf)

MacDiarmid, A.B.; Beaumont, J.; Bostock, H.; Bowden, D.; Clark, M.; Hadfield, M.; Heath, P.; Lamarche, G.; Nodder, S.; Orpin, A.; Stevens, C.; Thompson, D.; Torres, L.; Wysoczanski, R. (2011). Expert risk assessment of activities in the New Zealand Exclusive Economic Zone and Extended Continental Shelf. NIWA Client Report No: WLG2011-39, 145 p.

Mackay KA, Wood BA, Clark MR (2005) Chatham Rise Bathymetry. NIWA Miscellaneous Chart Series 82. NIWA.

McCave, I.N. (1975). Vertical flux of particles in the ocean. Deep Sea Research and Oceanographic Abstracts 22: 491–502.

McClatchie, S.; Millar, R.B.; Webster, F.; Lester, P.J.; Hurst, R.; Bagley, N. (1997). Demersal fish community diversity off New Zealand: Is it related to depth, latitude and regional surface phytoplankton? Deep Sea Research Part I: Oceanographic Research Papers 44: 647–667.

McClatchie, S.; Dunford, A. (2003). Estimated biomass of vertically migrating mesopelagic fish off New Zealand. Deep-Sea Research I 50: 1263–1281.

McClatchie, S.; Pinkerton, M.; Livingsston, M.E. 2005: Relating the distribution of a semi-demersal fish, Macruronus novaezelandiae, to their pelagic food supply. Deep-sea Research I 52: 1489-1501.

McKnight, D.G. (1969). Infaunal benthic communities of the New Zealand Continental shelf. New Zealand Journal of Marine and Freshwater Research 3: 409-444.

McKnight, D.G.; Probert, P.K. (1997). Epibenthic communities on the Chatham Rise, New Zealand. New Zealand Journal of Marine and Freshwater Research 31:505-513.

Ministry of Primary Industries/Ministry of Fisheries 2013: Fisheries Assessment Plenary May 2013: Stock Assessments and Yield Estimates – Hoki, 428p

Murphy, R. J.; Pinkerton, M. H.; Richardson, K. M.; Bradford-Grieve, J. M.; Boyd, P.W. (2001). Phytoplankton distributions around New Zealand derived from SeaWiFS remotely-sensed ocean colour data. New Zealand Journal of Marine and Freshwater Research 35, 343-362.

Nodder, S.D.; Pilditch, C.A.; Probert, P.K.; Hall, J.A. (2003). Variability in benthic biomass and activity beneath the Subtropical Front, Chatham Rise, SW Pacific Ocean. Deep-Sea Research I 50: 959-985.

Nodder, S.D.; Bowden, D.A.; Pallentin, A.; Mackay, K. (2012). Seafloor habitats and benthos of a continental ridge: Chatham Rise, New Zealand (Chapter 56). Seafloor Geomorphology as Benthic Habitat: GeoHab Atlas of seafloor geomorphic features and benthic habitats, edited by P.T. Harris and E.K. Baker. Elsevier Insights: 763-776.

Norris, R.M. (1964). Sediments of Chatham Rise. New Zealand Oceanographic Institute Memoir No. 26.

Orpin, A. (2013). Geological Desktop Summary Active Permit areas 50753 (55581), 54068 and 54272, South Taranaki Bight. NIWA Client Report No: WLG2013-44, 42 p. (See http://www.epa.govt.nz/eez/EEZ000004/EEZ000004_Geological_Desktop_Summary_Active_Permit_areas_50753_(55581)_54068_and_54272_South_Taranaki_Bight_NIWA_August_2013.pdf)

Pinkerton, MH (2013). Ecosystem Modelling of the Chatham Rise. Research report prepared for Chatham Rock Phosphate, April 2013. NIWA Client Report No: WLG2013-17. Pp 183.

Pinkerton, M.; Schwarz, J.; Gall, M.; Beaumont, J. (2013). Satellite ocean-colour remote sensing of the South Taranaki Bight from 2002 to 2012. NIWA Client Report No: WLG2013-14 Rev 1, 74 p. (see http://www.epa.govt.nz/eez/EEZ000004/EEZ000004_Satellite_ocean_colour_remote_sensing_of_the_South_Taranaki_Bight_from_2002_to_2012_NIWA_October_2013.pdf)

Probert, PK, McKnight DG (1993) Biomass of bathyal macrobenthos in the region of the Subtropical Convergence, Chatham Rise, New Zealand. Deep-Sea Research I 40: 1003-1007.

Probert P.K.; Grove, S.L.; McKnight, D.G.; Read, G.B. (1996). Polychaete distribution on the Chatham Rise, Southwest Pacific. Internationale Revue der Gesamten Hydrobiologie 81: 577-588.

Shirihai, H. (2002). The complete guide to Antarctic wildlife: birds and marine mammals of the Antarctic continent and the Southern Ocean. Princeton University Press, Princeton and Oxford, 510 p.

Smith, A.N.H. (2008). Predicting the distribution and relative abundance of fishes on shallow subtidal reefs around New Zealand. NIWA Client Report WLG2008-9, 175 pp.

Smith, A.D.M.; Fulton, E.J.; Hobday, A.J.; Smith, D.C.; Shoulder, P. (2007). Scientific tools to support the practical implementation of ecosystem-based fisheries management. ICES Journal of Marine Science 64: 633–639.

Sutton, P. (2001). Detailed structure of the Subtropical front over Chatham Rise, east of New Zealand. Journal of Geophysical Research. C. Oceans 106(C12): 31,045-031,056.

Thrush, S.F.; Hewitt, J.E.; Cummings, V.J.; Ellis, J.I.; Hatton, C.; Lohrer, A.M.; Norkko, A. (2004) Muddy waters: elevating sediment input to coastal and estuarine habitats. Frontiers in Ecology and the Environment 2:299–306.

Thompson, D. (2013). Seabirds of the South Taranaki Bight. NIWA Client Report No: WLG2013-15, 9 p. see http://www.epa.govt.nz/eez/EEZ000004/EEZ000004_Seabirds_of_the_South_Taranaki_Bight_NIWA_March_2013.pdf

Torres, L.; Compton, T.; Fromant, A. (2013a). Habitat models of southern right whales, Hector's dolphin, and killer whales in New Zealand. NIWA Client Report No: WLG2012-28, 61 p. see http://www.epa.govt.nz/eez/EEZ000004/EEZ000004_Habitat_models_of_southern_right_whales_Hector’s_dolphin_and_killer_whales_in_New_Zealand_NIWA_October_2013.pdf

Torres, L.; Pinkerton, MH; Sutton, P (2013b). Blue whales and green water: Describing trophic links of a foraging ground in New Zealand’s South Taranaki Bight. Poster. The 20th Biennial Conference on Marine Mammals’, Dunedin, New Zealand, Dec. 9-13.

Van Dover, C.L. (2011). Mining seafloor massive sulphides and biodiversity: what is at risk? ICES J. Mar. Sci. 68, 341-348.

Van Dover, C.L.; Smith, C.R.; Ardron, J.; Arnaud, S.; Beaudoin, Y.; Bezaury, J.; Boland, G.; Bille, D.; Carr, M.; Cherkashov, G.; Cook, A.; DeLeo, F.; Dunn, D.; Fisher, C.R.; Godet, L.; Gjerde, K.; Halpin, P.; Levin, L.; Lodge, M.; Menot, L.; Miller, K.; Milton, D.; Naudts, L.; Nugent, C.; Pendleton, L.; Plouviez, S.; Rowden, A.; Santos, R.; Shank, T.; Smith, S.; Tao, C.; Tawake, A.; Thurnherr, A.; Treude, T. (2011). Environmental management of deep-sea chemosynthetic ecosystems: justificaton of and considerations for a spatially-based approach. ISA Technical study; No. 9. International Seabed Authority, Kingston, Jamaica, 90 p. (http://www.isa.org.jm/files/documents/EN/Pubs/TS9/index.html)

Vopel, K.; Robertson, J.; Wilson, P.S. (2013). Iron sand extraction in South Taranaki Bight: effects on trace metal contents of sediment and seawater. AUT Client report: TTRL 20138, 59 p. (http://www.epa.govt.nz/Publications/Sediment_Toxicology_study.pdf)

Wysoczanski, R.J.; Clark, M.R. (2012). Southern Kermadec Arc- Havre Trough geohabitats and biological communities. In: Seafloor geomorphology as benthic habitat. DOI: 10.1016/B978-0-12-385140-600063-3

7 Appendix A: Panellists and areas of expertise

Panellist	Expertise
Dr David Bowden	Benthic ecology of shelf ecosystems including the Chatham Rise
Dr Malcolm Clark	Deepsea ecology including Kermadec Arc seamounts, deepsea fisheries, seabed mining, risk assessment
Dr Mark Hadfield	Oceanography, sediment plume modelling including for proposed mining for iron sands and phosphorite nodules
Dr Geoffroy Lamarche	Seabed geology including Chatham Rise and Kermadec Arc
Dr Alison MacDiarmid	Reef ecology, fisheries, benthic ecology of iron sands , risk assessment
Dr Scott Nodder	Sedimentology and seabed geology including the south Taranaki Bight and Chatham Rise
Dr Matt Pinkerton	Remote sensing, primary production, plankton ecology, trophic functioning, and ecosystem dynamics with recent experience along the east coast North Island and Chatham Rise
Dr David Thompson	Seabirds and marine mammals in the NZ EEZ
Ms Rachel Boschen	PhD student assessing impacts of proposed SMS mining on deep-sea communities