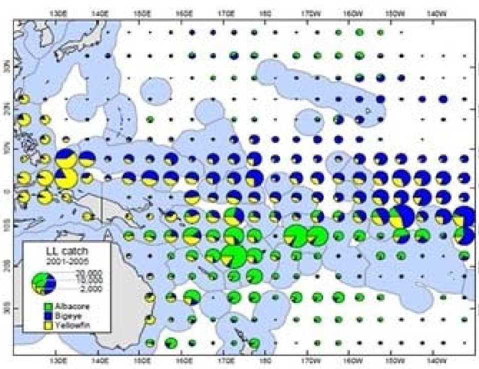
Assessment of the potential impacts of deep seabed mining on Pacific Island fisheries

Prepared for Pacific Community

November 2016



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List of Abbreviations

ACP	Africa-Caribbean-Pacific
AUV	Autonomous Underwater Vehicle
CPUE	Catch Per Unit Effort
CRC	Cobalt-rich ferromanganese crusts
DSM	Deep Sea Minerals
ECS	Extended Continental Shelf
EEZ	Exclusive Economic Zone
EIA	Environmental Impact Assessment
ERA	Ecological Risk Assessment
FAD	Fish Aggregating Device
FAME	Fisheries Aquaculture and Marine Ecosystems
GEBCO	General Bathymetric Chart of the Oceans
GIS	Geographic Information System
GOBI	Global Ocean Biodiversity Initiative
IEC/ISO	International Electrotechnical Commission / International Organization for Standardization
MIDAS	Managing impacts of deep sea resource exploitation
MN	Manganese nodules
NIWA	National Institute of Water and Atmospheric Research Ltd
OBIS-SEAMAP	Ocean Biogeographic Information System Spatial Ecological Analysis of Megavertebrate Populations
P-ACP	Pacific ACP States
PIS	Pacific Island State
ROV	Remote Operated Vehicle
SMS	Seafloor massive sulphides
SPC	Pacific Community (previously South Pacific Commission)
SPC-EU DSM	An SPC-EU funded project entitled: *Deep Sea Minerals (DSM) in the Pacific Islands Region: A Legal and Sustainable Framework for Sustainable Resource Management*
SPREP	Secretariat of the Pacific Regional Environment Programme
WCPFC	Western and Central Pacific Fisheries Commission

Executive summary

NIWA was contracted by the Pacific Community (SPC) to undertake a study and prepare a report that identifies and assesses the impacts of deep-sea mining on existing and potential fisheries in the Pacific islands region, with particular emphasis on the 15 Pacific-ACP States[1] which are a part of the SPC-European Union EDF 10 Regional Deep Sea Minerals Project.

The approach taken by NIWA has been to carry out an expert Ecological Risk Assessment (ERA), which is a "Level 1" assessment in line with accepted New Zealand and Australian risk assessment standards.

A panel of NIWA experts progressed through 3 main steps:

- the examination of sources of risk, their magnitudes, frequencies and intensities;
- an assessment of the potential consequences of those risks; and
- the likelihood of a particular level of consequence occurring from the various activities.

Scores were given to the potential consequence (6 levels from negligible to catastrophic) of an activity and to the likelihood of that consequence (6 levels from remote to likely/certain) occurring. Risk for each activity was then calculated as the product of consequence and likelihood, and scores of ecological risk can range from a minimum of 0 to a maximum of 30. Ecological risk scores were further binned into 4 relative categories of risk: low (0-6), moderate (8-12), high (15-20) and extreme (24-30).

Levels of risk were established using a precautionary approach, taking into account the worst case scenario for environmental risks. We have not taken into account how any mitigation measures might reduce environmental risk when recommending classifications. These recommendations should not be taken as a comprehensive assessment, but they serve as an indicator of the activities that might require special attention for further data collection, assessment, operational or regulatory conditions and close monitoring.

Assessments were carried out for three mineral resources:

- Seafloor massive sulphides (SMS)
- Manganese nodules (MN)
- Cobalt-rich crusts (CRC)

Exploration and Mining (Exploitation) stages were considered separately. Prospecting activities were included in exploration. Decommissioning was not considered necessary to evaluate at this stage because not enough is known about the nature of mining operations, equipment to be used, and possible seabed installations.

The four main fishery "types" of the Pacific islands region were considered:

- Tuna (longline, pole and line, purse-seine), including billfish

[1] The 15 Countries are: Cook Islands, Federated States of Micronesia, Fiji, Kiribati, Nauru, Niue, Palau, Papua New Guinea, Republic of the Marshall Islands, Samoa. Solomon Islands, Timor Leste, Tonga, Tuvalu, and Vanuatu

- Deepwater snapper (longline)
- Coastal fisheries (various)
- Mariculture

For each fishery/mineral combination, 10 activities were assessed for exploration, and eight for the mining phase. Each activity was scored for its potential impact on population size, geographical range, genetic structure, and biological parameters of the fish species. An assessment was also made where it was felt that aspects of the fishery operation (catching or marketing of product) could be affected.

Tuna fisheries were classified as low risk during both exploration and mining phases for the three mineral types. This was largely due to a depth separation of most mining operations from the tuna fisheries, with DSM activities deeper than the fisheries, as well as the widespread distribution and mobility of most tuna stocks. There could be localised effects, but it was judged none would have substantial effects at the population or stock level. Ecotoxicity was scored as a low risk for tuna species, but it was noted that any toxic accumulation or contaminant presence from crushed mineral release could have a high impact on the fishery through a negative market reaction. Billfish and shark species, caught as bycatch or in target fisheries, were also classified as low risk during both exploration and mining phases for the three mineral types.

Deepwater snapper fish and fisheries are often focussed on seamounts, and if there are resident populations, these will be vulnerable to SMS and CRC activities. Risks were low during exploration, but during the mining phase scored moderate for seafloor extraction and overburden deposition where habitat can be affected. The sediment plumes (both from extraction and wastewater returns at SMS and CRC sites) were a source of high risk potentially affecting population size, geographic range and biological parameters if the sediment reduced visibility or forced the fish to move away. The risk from toxic release or bioaccumulation through the food chain at SMS sites were also high, as this could affect the suitability of the environment for the fish or their prey. Risks to snapper were highest for SMS, lower for CRC, and lower again for MN mining.

For coastal fisheries, risk was assessed under two situations: one where the mining operation was distant from the islands, and one where it was near. The latter may be unlikely, but mineral distribution occurs close to some islands. Scores were presented as a range to indicate the variability in risk depending on location of the operation relative to the coast. Risk during exploration was low, but a mining operation close to the islands or coast posed a high risk to coastal fisheries through habitat modification during seafloor extraction. Overburden deposition (for community links) and sediment plumes posed a moderate risk for both coastal and reef fisheries. Toxicity was a high risk for coastal and reef fisheries for near operations.

Risks to mariculture operations were also assessed by provision of a score range reflecting distant and near mine sites respectively. Shellfish, shrimp, fish and seaweed farming were considered separately. Exploration activities were generally low risk, but a sediment plume from seafloor sampling, even if small, could have a localised and moderate impact if it drifted across a confined mariculture location. During mining, risks from extraction and wastewater plumes were high, and there was a moderate risk score for underwater noise for some operations.

None of the activities or threats assessed in this report returned a risk level of extreme. The activities which could have a high risk from a mining operation are summarised below by mineral and fishery type (L=low, M=medium, H=high).

Activity	Mineral type	Tuna fishery	Deepwater snapper fishery	Coastal fisheries	Mariculture
Seafloor extraction	CRC		M-H		
	All DSM			L-H	
Sediment plume	CRC		M-H		
	SMS		H		
	All DSM				L-H
Wastewater discharge	SMS		H		
	All DSM				L-H
Toxic chemical release	SMS	H*	H	L-H	L-H
	CRC			L-H	L-H

*Risk to fishery market

For many of the activities associated with potential seabed mining there is insufficient information or detail available at this time to determine the risk with any certainty. Gaps in knowledge are raised throughout the text, and four key issues are expanded in the discussion:

- Sedimentation effects
- Ecotoxicity effects
- Fish species life history
- Seamount affinities of fish species

It is stressed that environmental risk assessments are required on a site-specific basis, and need to consider the broader ecosystem rather than just fisheries, and include considering the nature of the actual mining operation, as well as social, cultural and economic factors that were beyond the scope of this report. Potential mining interactions with marine mammals were, however, briefly considered, and noise and light generation are potential impact factors that will warrant more detailed evaluation.

1 Introduction

1.1 Background

This report has been prepared by the National Institute of Water and Atmospheric Research Ltd (NIWA) in response to the Pacific Community (SPC) call for proposals to conduct an independent assessment of the potential impacts of Deep Seabed Minerals Mining on Pacific island fisheries (request for proposal no: RFP 16/017). This forms part of the work programme of the SPC Project: *Deep Sea Minerals (DSM) in the Pacific Islands Region: A Legal and Sustainable Framework for Sustainable Resource Management* (termed the "SPC-EU DSM Project"). This Project has been designed to strengthen Pacific Island State (PIS) institutions and their capacity to assess, regulate, manage, and monitor DSM development and industry, and to optimise sustained benefits with minimal negative impacts for PISs.

During the course of the SPC-EU DSM Project, a number of countries and other stakeholders have raised significant concerns about the potential impacts of DSM activities on fisheries and fishery resources (commercial, artisanal and subsistence) and the impact that this could have on Pacific Island economies, societies and cultural identities. This assessment was conducted to provide an independent assessment of the potential impacts of DSM exploration and mining on Pacific Island fisheries, with a view to supporting a number of objectives:

1) Make recommendations as to what fisheries-related issues should be included in Environmental Impact Assessments (EIAs) of DSM proposals;

2) Inform government legislators, policy makers, decision makers and regulators, the fisheries industry, the fishing community and civil society of the key fisheries-related issues that need to be considered when assessing whether or not to approve proposals to undertake DSM activities in the Pacific Islands region;

3) Identify critical knowledge and data gaps with respect to the impacts of DSM activities on Pacific Island fisheries and fishery resources, considering the Precautionary Principle as defined under Principle 15 of the 1992 Rio Declaration on Environment and Development; and

4) Make recommendations as to what further studies and research need to be carried out in order to address the critical knowledge and data gaps identified under point 3.

This assessment was commissioned as a desk-top study based on a literature search and review of relevant, available and accessible information and data from national, regional and global sources, and involved consultation and input from key relevant national, regional and global agencies concerned with DSM and fishing activities. The original Request for Proposals specified a very wide range of aspects to be included, but the assessment reported here was reduced given budget constraints (see section 1.3).

1.2 The risk assessment approach

A number of national and international Ecological Risk Assessment (ERA) frameworks and methodologies have been developed in recent years, and there is extensive literature on ERA (Suter

2006, Smith et al. 2007, Astles 2015). While the ERA approach is increasingly being applied across a range of marine threats and habitats (e.g., Halpern et al. 2008), it is a field in which a number of methods have been developed to assess the impacts of fisheries in the deep sea such as a consequence-likelihood approach (Fletcher 2005) and the Ecological Risk Assessment for the Effects of Fishing (Hobday et al. 2011). Such frameworks have been used to determine the risk posed to deep-sea habitats around New Zealand from a range of human activities, including deep-sea mining (MacDiarmid et al. 2012), and more specifically, the risk commercial fishing poses to deep-sea corals on New Zealand seamounts (Clark et al. 2011, 2014a). Such approaches broadly fit into three categories (after Hobday et al. 2011):

- Level 1: Qualitative expert based risk assessments which are used for a broad scoping of risk, or in "data limited" situations.
- Level 2: Semi-quantitative risk assessments, where more data are available, but not enough to complete a quantitative assessment.
- Level 3: Quantitative risk assessments, where enough data are available to complete a fully quantitative assessment including species or ecosystem modelling.

Given the wide breadth of fisheries and mineral resources in the Pacific region, this assessment is a Level 1 assessment that involves an expert panel evaluating compilations of available data and information. This type of assessment is in line with accepted New Zealand and Australian fisheries risk assessments, as well as international standards (Australia/New Zealand Standards 2009, IEC/ISO 2009). It has been applied in a number of fisheries or mining situations in New Zealand (e.g., Campbell & Gallagher 2007, Baird & Gilbert 2010, MacDiarmid et al. 2012 and Ford et al. 2015).

1.3 Scope of the report

The original Request for Proposals (RfP) was very extensive, specifying three mineral types polymetallic manganese nodules (MN), seafloor massive sulphides (SMS), cobalt-rich ferromanganese crusts (CRC), four fishery types (offshore pelagic, deep seabed, nearshore-coastal, mariculture – many with subdivisions by species and gear type), five to six assessment types (environmental, ecological, (operational), economic, social, cultural), for each of the 15 P-ACP countries.

Such an extensive assessment as originally proposed by NIWA was beyond the available SPC budget, but the proposal included a simplified and scaled-down risk assessment that did not include the full scope of the RfP, but could potentially still satisfy the core issues identified in it. The simplified assessment approach:

- retains the three DSM types (important given the very different environments they occur in);
- retains the four fishery types (but with less subdivision by species except where essential, and more emphasis placed on the offshore activities closer to prospective mining areas). Different fishery types are retained where that is important in relation to differential impacts from mining activities;

- reduces the assessment types to one (mainly ecological), but attempts to incorporate elements of environmental, social, and cultural assessments where they have a clear link with the ecological threat parameters; and
- does not consider every country separately. Assessments are more regional for each mineral and fishery type. However, particular issues relevant to individual countries are addressed by highlighting risk issues for particular minerals that relate to countries with a certain spatial distribution of types of DSM and fisheries.

2 Methods

2.1 Consequence-likelihood approach

The assessment used a “consequence-likelihood” methodology refined at NIWA in recent years from the original method developed for Australian fisheries by Fletcher (2005). This method evaluates the consequences for aspects of fisheries from a particular impact, and then assesses the likelihood of this level of consequence occurring. Risk is summarised as the product of the expected likelihood and consequence.

The methodology includes the following steps:

1) Collate and review relevant existing data and information on deep-sea mining, fisheries, and environmental conditions in the region to inform the risk assessment.

2) Determine the likely activities associated with DSM (prospecting-exploration and mining phases), such as surface activities, resource assessment surveys (swath, seismic, ROV, direct sampling), and describe the components of these activities (see Table 2-1).

3) Determine the probable distributions of these activities, to enable spatial overlap and proximity to be evaluated between sites of DSM potential and fisheries. This stage was informed by collating available published and unpublished material from a range of sources (in particular the SPC-EU DSM Project for minerals, and the Fisheries Aquaculture and Marine Ecosystems (FAME) Division of SPC for fisheries). A series of GIS layers and maps were produced to inform the expert workshop.

4) Establish the likely environmental effects of the activities identified in step 1. This was based on existing team knowledge of the impacts of mining activities, especially the work done under NIWAs “Enabling the Management of Offshore Mining” project and a literature review of New Zealand and international studies (e.g., Ellis et al. 2014) and mining studies for the Ministry for the Environment (e.g., MacDiarmid et al. 2013, 2015), knowledge of international studies, research done for Chatham Rock Phosphate and Trans-Tasman Resources by NIWA, and reports from the DSM Project (e.g., SPC 2013a,b,c). These sources supported a broad scale definition of likely magnitude and frequency of environmental effects of certain activities on the ocean environment.

5) Convene an Ecosystem Risk Assessment (ERA) Panel of experts to assess the impacts from mining activities on the various fisheries of interest. These experts are

experienced in ERA, and have a strong knowledge of mining effects, and their impacts on fisheries.

Table 2-1: List of typical DSM activities used in the assessment.

Exploration (includes prospecting)	Mining
Ship presence	Ship presence
Surface lights and noise	Surface lights and noise
ROV and other imaging surveys	Sea floor extraction
Acoustic swath mapping	Sediment plumes
Seismic surveys (e.g., air gun, boomer)	Deposition of overburden in stock piles or pits
Spot sampling (e.g., ROV/AUV/dredge/coring)	Underwater lights and noise
Drilling	Wastewater return
Bulk sampling	Toxic chemical release from crushed substrate
Sediment plume	
Underwater lights and noise	

Most of these are self-explanatory, and only a brief description is given below.

Ship presence: The physical location of a vessel from which the DSM activities are being carried out. During mining, there may be additional regular traffic of support vessels (but probably still a single "mother-ship") and transport of material in barges. We focus on the physical presence of a vessel or vessels, and how this could displace or impact local fishing craft. We do not include potential for carriage of non-indigenous species, grey water discharge, oil spill, garbage etc.

Surface lights and noise: Ships will use lights at night, and have thrusters, generators, winches, etc. running.

Imaging surveys: Towed cameras, Remote Operated Vehicles (ROVs), Autonomous Underwater Vehicles (AUVs) will be deployed for visual surveys, covering wide areas during exploration, and possibly more restricted operational observations during mining.

Acoustic swath mapping: Typically this is hull-mounted transducers operating at 12 kHz or 38 kHz.

Seismic surveys: These are potentially more disturbing than swath mapping, using air guns, boomer systems, and sub-bottom profiling.

Spot sampling: Small-scale or limited sampling of rocks for geological testing or fauna for identification. Sampling would impact a small area by ROV, coring, dredges, or sleds etc.

D**rilling:** Small-scale drilling or rock-coring to establish the geological composition

Bulk sampling: Extraction of a greater volume of material to test extraction methods, and processing. It is equivalent to "test mining" but on a smaller scale. The latter has not been considered separately.

Sediment plume: During exploration, drilling and spot sampling will generate a small plume, which will be greater during bulk sampling. Mining operations will generate a much larger plume, as heavy machinery or large dredges will be deployed. The extent of coverage is larger than the physical footprint, as defined in the "Mining phase assumptions" section (2.2.1).

Underwater lights and noise: ROVs, towed camera gear etc will generate both noise and light disturbance. This will be small-scale during exploration, but more extensive during mining. Direct sampling with dredges and sleds will make noise moving over rough ground or hard substrate.

Seafloor extraction: The physical disturbance of the seafloor by mining vehicles, digging or dredging areas of mineral deposits.

Deposition of overburden: For SMS and CRC mining operations may involve clearing access for mining machinery to the main deposit area. This material will likely be deposited in adjacent areas on the seafloor. It is not expected to occur with MN.

Wastewater returns: Material transported to the surface will be largely retained. It is likely to be sieved or screened, and the residual water and fine particles (up to 10 um) will be discharged back into the water column. We assume this is below the thermocline, but it could be anywhere from about 250 m to the seafloor. It is effectively a fine sediment plume, although water will also be of a different temperature and density to the receiving environment.

Toxic chemical release: The physical breaking and crushing of the DSM could release, to the surrounding water, heavy metals or toxic elements that are contained within the rocks/nodules. These elements can be dispersed in the sediment plume at the extraction point on the seafloor and/or in the wastewater returns.

2.1.1 Scoring of risk factors

The assessment is qualitative, but quantitative data, scientific reports and other information collated during steps 2 and 3 above were used to support and inform the risk assessments. The method sequentially progressed through three main steps: (i) examining sources of risk; (ii) assessing the potential consequences of these risks and; (iii) evaluating the likelihood of a particular level of consequence occurring from the various activities. Scores were given to the potential consequence (6 levels from negligible to catastrophic) and to the likelihood of that consequence (remote to likely) using a set of standard tables that describe each level (see Table 2-2, and Table 2-3 after Fletcher 2005). Risk for each activity was then calculated as the product (multiplication) of consequence and likelihood. A confidence score was also made, to reflect the certainty of the risk classification (see Table 2-4). This process was repeated for each identified activity (see Table 2-1).

Where data or information did not exist, a precautionary approach was adopted to reflect the uncertainty in the effects of the activity. A low confidence score highlights such an activity as warranting more information or research in future.

Table 2-2: Description of consequence scoring.

Consequence Level	Score	Description
Negligible	0	Impact unlikely to be detectable at the scale of the stock/habitat/community
Minor	1	Minimal impact on stock/habitat/community structure or dynamics
Moderate	2	Maximum impact that still meets an objective (e.g. sustainable level of impact such as full exploitation rate for a target species).
Major	3	Wider and longer term impacts (e.g. long-term decline in stock size)
Severe	4	Very serious impacts occur, with relatively long time period likely to be needed to restore to an acceptable level (e.g. serious decline in spawning biomass limiting population increase).
Catastrophic	5	Widespread and permanent/irreversible damage or loss will occur-unlikely to ever be fixed (e.g. local extinction/ extirpation)

Table 2-3: Description of likelihood scoring criteria.

Likelihood level	Score	Description
Remote	1	No known examples, but not impossible
Rare	2	May occur in exceptional circumstances
Unlikely	3	Uncommon, but has been known to occur elsewhere
Possible	4	Some evidence exists indicating this is could occur
Occasional	5	May occur from time to time
Likely-certain	6	It is expected to occur

Table 2-4: Description of confidence scoring.

Confidence rating	Score	Rationale for confidence score
Low	1a	No data exist and no consensus among experts
	1b	Data exist, but are considered poor or conflicting
	1c	Agreement among experts, with low confidence
High	2a	Consensus among experts, with high confidence, even though data may be lacking
	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)

The scoring process described above for each activity, for each fishery, was applied to a number of fishery factors that could be affected by the mining activity: these included population size, geographic range, genetic composition of the stock, and general biology (e.g., age or size structure, behaviour, spawning activity). Criteria for scoring the threat components are already in place from previous Australian and New Zealand risk assessments, and were adapted for this study (Table 2-5).

Table 2-5: Criteria used for assessing consequence scores for the various fish/fishery factors (modified from Hobday et al. 2007).

	0 Negligible	1 Minor	2 Moderate	3 Major	4 Severe	5 Catastrophic
Population size	Insignificant change to population size. Unlikely to be detectable	Possible detectable change but minimal impact on population size or dynamics.	Full exploitation rate but long-term recruitment dynamics not adversely damaged.	Affecting recruitment state of stocks and/or their capacity to increase.	Likely to cause local extinctions if continued in longer term.	Local extinctions are imminent or immediate.
Geographic range	No detectable change in geographic range.	Possible detectable change in geographic range (5%) but no impact on dynamics.	Change in geographic range up to 10 % of original.	Change in geographic range up to 25 % of original.	Change in geographic range up to 50 % of original.	Change in geographic range > 50 % of original.
Genetic structure	No detectable change in genetic structure against background variability.	Possible detectable change in genetic structure. Any change in frequency of genotypes, up to 5%.	Change in frequency up to 10%.	Change in frequency of genotypes, up to 25%.	Change up to 50%.	Change > 50%.
Biological parameters	No detectable change in age/size/sex structure, reproductive capacity, or behaviour or movement.	Possible detectable changes, but minimal impact on population dynamics.	Some impact on population dynamics, within sustainable limits, recovery weeks to months.	Long-term changes, adverse effects on population dynamics, recovery to normal months to years.	Long-term recruitment dynamics affected, recovery years to decades, or 10 generations.	Population unlikely to return to original conditions.

The resulting matrices lay out in a transparent form the scoring reached by the panel, with explanatory text accompanying them. The tables contain the scores of consequence, likelihood, risk and confidence, for each of the threat elements. The risk scores can range from 0 to 30. Following the approach of MacDiarmid et al. (2012), risk scores are classified into four risk levels (Table 2-6). It should be noted that this classification should not be translated into firm recommendations about how the activities should be ultimately regulated. They are based purely on a relative assessment of environmental risk, with increased risk meaning the activity will need to be more closely controlled.

The matrix-table summaries allow an easy-to-understand assessment of relative risks, as well as identification of high and extreme risk activities that will warrant more detailed assessment, or the collection of data and further study, to inform a robust EIA, and reduce such risks.

Table 2-6: Risk level classes based on the product of likelihood and consequence scores.

Risk Level	Risk score range	Consequence level	Likelihood levels
Low	0-6	0 – negligible	1-6 (remote to likely)
		1 – minor	1-6 (remote to likely)
		2 – moderate	1-3 (remote, rare or unlikely)
		3 – severe	1-2 (remote or rare)
		4 – major	1 (remote)
		5 – catastrophic	1 (remote)
Moderate	8-12	2 – moderate	4-6 (possible, occasional, likely)
		3 – severe	3-4 (unlikely, possible)
		4 – major	2-3 (rare, unlikely)
		5 – catastrophic	2 (rare)
High	15-20	3 – severe	5-6 (occasional, likely)
		4 – major	4-5 (possible, occasional)
		5 – catastrophic	3-4 (unlikely, possible)
Extreme	24-30	4 - major	6 (likely)
		5 – catastrophic	5-6 (occasional or likely)

2.1.2 Risk assessment panel

The risk assessment process outlined in the previous section involved expert input from a wide range of NIWA staff, outlined in the following table, (Table 2-7).

Table 2-7: NIWA staff involved in the ERA expert assessment (* workshop participant).

Key Panellist	Expertise
Dr Malcolm Clark*	Deep-sea ecology including seamounts, deep sea fisheries, seabed mining, risk assessment
Dr Kim Goetz*	Marine mammal distribution and ecology.
Dr Stuart Hanchet	Fisheries stock assessment, deep-sea snapper Tonga
Dr Simon Hoyle*	Pacific fisheries, tuna stock assessment
Mr Peter Horn*	Fisheries stock assessment, deepwater longline fisheries
Mr Vijay Paul*	GIS specialist
Dr Matt Pinkerton*	Remote sensing, primary production, plankton ecology, trophic functioning, and ecosystem dynamics
Dr Phil Sutton*	Oceanographer, deep-sea water mass and current flows, convergence zones.
Ms Di Tracey*	Deep-sea ecology including seamounts, corals, and deep sea fisheries

2.2 Key mining impacts

The method description above lists the key mining activities, and the threats to various structural or functional components of fishery ecosystems. The expert panel considered also the likely water column location of the impact source when evaluating the risks (Figure 2-1).

At the surface there is the physical presence of ships and platforms, with accompanying light, and noise. In the midwater, there is the physical presence of riser pipes, potential discharges of processing waters/returned sediment fines, etc., and various equipment moving between the surface and seafloor. The seafloor itself will experience physical disruption by seafloor production tools, and there could be sediment plume generation, overburden disposal etc.

Surface impacts

- Changes in primary production through shading by, or nutrient levels in, discharges (if near-surface discharges occur in photic zone)
- Effects on behaviour of surface fish, marine mammals, turtles and birds through changes in water composition or clarity, and lighting/noise/vibrations from vessel activity

Water column impacts:

- Sediment plume through water column
- Depending on discharge depth:
  - potential oxygen depletion

- nutrient and trace metal enrichment
- change in pH

- Effects on fish and deep-diving marine mammals behaviour from the plume and noise
- Bioaccumulation of toxic metals though the food chain to higher predators
- Toxic effects in early life stages (embryos, larvae, juveniles)
- Plankton/mesopelagic fish mortality and behavioural avoidance of contaminants (e.g., high turbidity, chemically enriched plumes)

Seafloor:

- Benthic organism mortality from direct physical impact of mining gear
- Smothering/burying of animals by deposited sediment
- Change in seafloor sediment characteristics by mining
- Clogging of suspension feeder's feeding structures
- Toxic effects with metal release (and other contaminants), and accumulation through the food chain

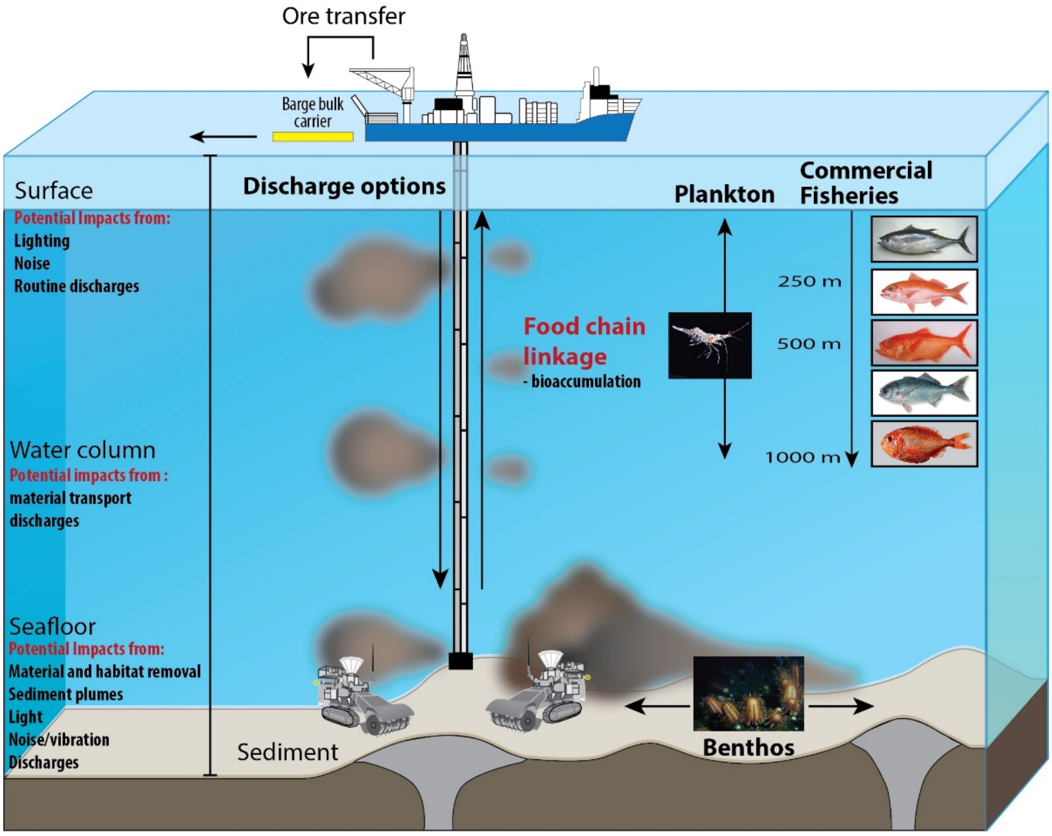


Figure 2-1: Summary illustration of the variety of sources and environmental impacts to be considered in evaluating a deep-sea mining operation (NIWA).

2.2.1 Mining phase assumptions

There is no current deep-sea mining operation against which to compare the likely nature and extent of impacts if DSM started in the western Pacific Ocean. However, the three part report published by the SPC in 2013 gives some idea of likely mining technologies, and consistent with a recent international risk assessment questionnaire for a MIDAS (Managing Impacts of Deep-Sea Resource Exploitation) and GOBI (Global Ocean Biodiversity Initiative) project, the following definitions were adopted to give some context for evaluating how large a mining operation might be. The assessment is made on the assumption that a single DSM mine is under operation, and does not take into account cumulate effects of multiple concurrent mining operations.

Seafloor Massive Sulphides: A single SMS mining event is similar to 'open pit mining', and is expected to have a duration of 3 to 10 years. Direct impacts will be on the order of <0.2 km^2 (Coffey Natural Systems 2008), with an indirect impact from seabed vehicles potentially 2-5 fold larger in scale due to sediment plume effects. Where deposits are closely spaced (within a few km of one another), a mining event may involve a cluster of sites (Petersen et al. 2016). Ore delivered from the seabed to the ship through a lifting system is dewatered on the ship; wastewater is released below the thermocline or near the seabed and contains only fine particles (~10 µm). The recovered material will be shipped offsite to a concentrating facility.

Manganese Nodules: A single nodule-mining event is similar to 'strip-mining' on land, with a dedicated seabed vehicle using a hydraulic system to recover nodules. The seabed vehicle will generate an exhaust sediment plume in its wake. The mining event in this scenario will not occur on slopes of greater than 3 to 5% and will have a duration of ~30 years. Direct impacts will be on the order of 300-800 km^2 per year (Oebius et al. 2001) and indirect impacts are 2-5 fold larger due to sediment plume effects from the seabed vehicle activity (Smith et al. 2008). Ore delivered from the seabed to the ship through a lifting system is dewatered on the ship; wastewater is released below the thermocline or near the seabed. In this mining scenario, the wastewater 'plume' contains only fine particles (~10 µm). The recovered material will be shipped offsite to a concentrating facility.

Cobalt-rich Crusts: A cobalt-crust mining event is similar to stripping rock off rock, and to have a duration of 3 to 5 years. Direct impacts will be on the order of ~20 to 200 km^2 (Hein et al. 2009) with an indirect impact potentially 2-5 fold larger due to sediment plume effects. While multiple seamounts may be mined in a given lease area, we evaluated only a single seamount or small cluster mining scenario. Ore delivered from the seabed to the ship through a lifting system is dewatered on the ship and wastewater containing fine particles (likely also ~10 µm) is released below the thermocline or near the seabed. The recovered material will be shipped offsite to a concentrating facility.

2.3 Data sources

2.3.1 Deep-sea minerals distribution

The Pacific region has substantial potential for DSM resources (Figure 2-2). This assessment focuses on the three main types: Seafloor Massive Sulphides, Manganese Nodules, and Cobalt-rich Crusts. Many Pacific States have such deposits within their Exclusive Economic Zones (EEZ) and on their Extended Continental Shelves (ECS), and/or are interested in sponsoring DSM activities in the international seabed area, 'the Area' (see SPC 2013a, b, c; Swaddling 2016).

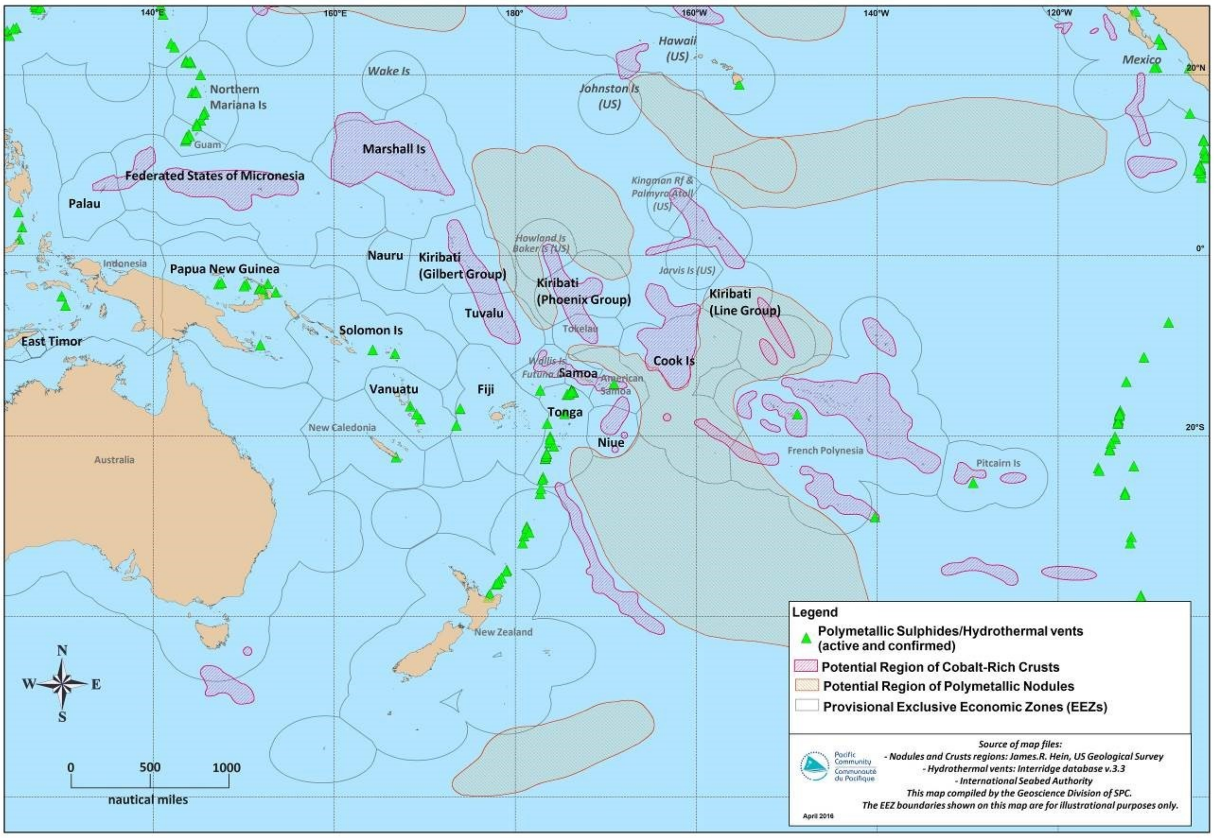


Figure 2-2: The distribution of mineral resources within the western South Pacific Ocean (image courtesy of SPC).

Seafloor Massive Sulphides

Seafloor Massive Sulphides (SMS), also known as polymetallic sulphides, form at active hydrothermal vent sites at depths commonly ranging from 1,000 to 3,500 m. These vents often occur at locations of undersea volcanic activity, most commonly associated with tectonic plate boundaries (mid-ocean ridges, or back-arc volcanoes). At these sites, super-heated seawater containing high levels of dissolved metals is expelled through cracks in the seafloor, where the minerals are deposited into chimney and mound structures rich in iron, copper, lead, zinc, gold, and silver. The likely depths of mining activity range from 1,000 to 3,000 m depth.

Amongst PISs, known locations of SMS deposits include Fiji, Papua New Guinea, Solomon Islands, Tonga, and Vanuatu.

Manganese Nodules

Polymetallic ferro-manganese nodules, commonly referred to as ‘manganese nodules’ (MN), are potato-shaped nodules composed largely of manganese and iron oxides that occur over extensive areas of the abyssal plains at depths of 4,000 to 6,500 m. They contain a variety of commercially significant metals, including nickel, copper, cobalt, manganese, molybdenum, with small amounts of rare-earth elements. Nodules accrete slowly, at rates of a few mm per million years.

MN are known to be abundant in the national jurisdiction of the Cook Islands and Kiribati, and to a lesser extent in Niue and Tuvalu.

Cobalt-rich Crusts

Cobalt-rich ferro-manganese crusts (CRC) form on the summits and flanks of seamounts, ridges, and plateaux, especially large flat-topped seamounts (guyots), at depths of between 600 and 7,000 m. They form on bare rock and therefore occur mainly where strong oceanic currents keep the seafloor free of sediment. The minerals take millions of years to form a crust, which can be up to about 250 mm. The thickest (economic) crusts are generally found at 800 – 2,500 m along the upper flanks and summit region of guyots. CRC deposits include valuable metals such as cobalt, nickel, and manganese, but they are also a potential source of rare-earth elements (e.g., tellurium, niobium, platinum) that are used in advanced and green technology industries.

Known locations of CRC deposits include the waters of Kiribati, Samoa, Tuvalu, Niue, Marshall Islands, Palau, and Federated States of Micronesia.

Figure 2-2 shows the general areas covered by the three mineral types. The extent to which the PIS EEZs might contain mineral deposits was estimated by the area of the mineral polygons (excluding SMS which are just point locations) that are within an EEZ (Table 2-8).

Table 2-8: The approximate proportion of EEZs covered by CRC and MN potential, and number of SMS sites recorded by the EU-SPC DSM project.

Country	% CRC	%MN	No. SMS
Cook Islands	20.8	69.1	0
Federated States of Micronesia	20.6	0	0
Fiji	0	0	3
Kiribati (Gilbert Group)	22.9	7.3	0
Kiribati (Line Group)	13.4	45.7	0
Kiribati (Phoenix Group)	26.8	31.3	0
Marshall Islands	45.3	0	0
Nauru	0	0	0
Niue	24.6	4.7	0
Palau	7.1	0	0
Papua New Guinea	0	0	11
Samoa	37.6	3.8	0
Solomon Islands	0	0	2
Timor Leste	0	0	0

Tonga	0.4	10.7	20
Tuvalu	26.9	4.3	0
Vanuatu	0	0	2

2.3.2 Tuna fisheries

The Pacific region hosts major fisheries for tunas. Tuna is one of the most important world marine fish resources, accounting at times for nearly 10% of the global marine fisheries catches by landed weight and double this by value (FAO 2016). There are four main species targeted: Skipjack (*Katsuwonus pelamis*), yellowfin (*Thunnus albacares*), bigeye (*Thunnus obesus*) and albacore (*Thunnus alalunga*). The western and central Pacific Ocean fisheries are the largest tuna fisheries, and are managed by the Western and Central Pacific Fisheries Commission (WCPFC). In 2014, the most recent year with readily available statistics, the annual catch in the WCPFC area was about 2.9 million t (WCPFC 2014), which comprised 60% of the total global tuna catch. This has a value of about US 5 billion dollars.

The largest fishery, by weight uses purse-seine gear, and operates predominately between 10°N to 10°S in latitude and 120° E to 165° W longitude, and accounts for 75% of the annual catch (Table 2-9). The longline and pole and line fisheries, however, occur over a wider range of the region, operating between 35°N to 50°S in latitude and from 120°E to 110°W in longitude and account for 10% and 7% of the annual catch respectively. The remainder of the annual catch is taken by troll gear and a variety of artisanal gears.

Table 2-9: Summary of tuna catches in 2014, by species (left panels) and by gear type (right panels) for the full WCPFC area. From WCPFC 2014.

Species	2014 catch (t)	Fishery type	2014 catch (t)
Albacore	128,050	Purse-seine	2,036,968
Bigeye	160,755	Longline	263,462
Skipjack	1,982,578	Pole and Line	215,324
Yellowfin	611,876	Troll	103,177
		Other	264,328
TOTAL	2,883,259	TOTAL	2,883,259

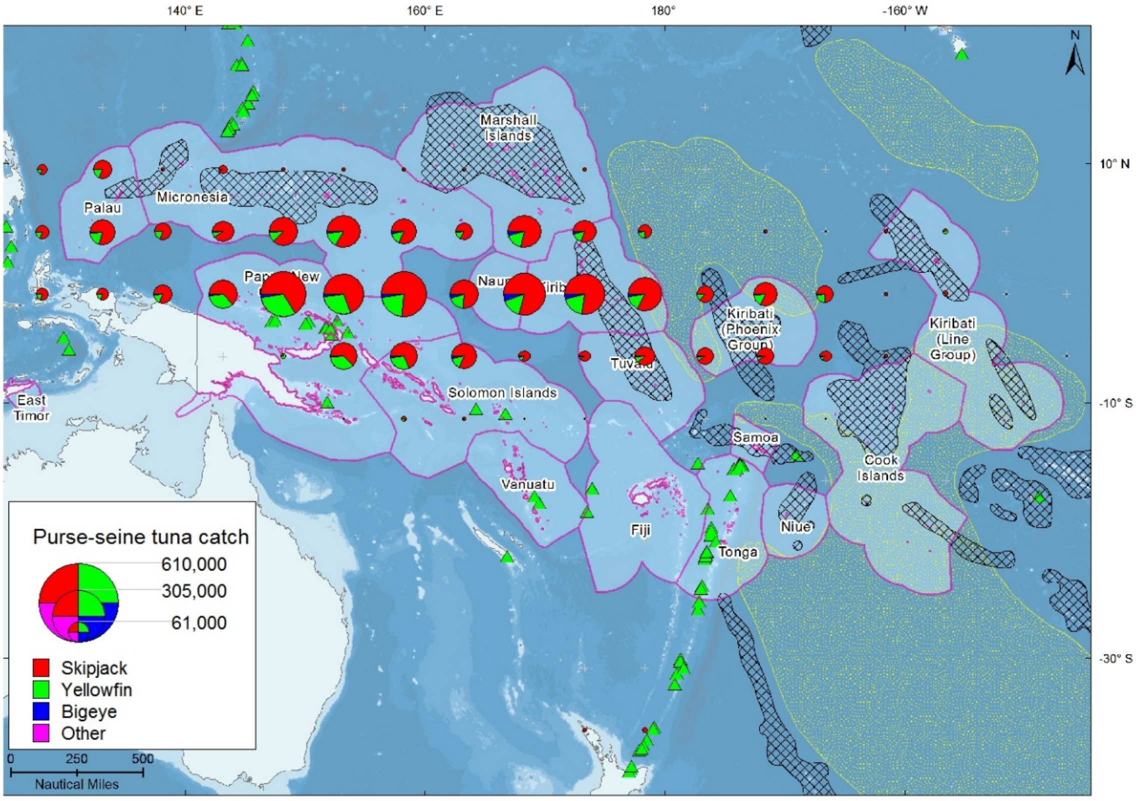
Catches by vessels flagged to the various PISs are summarised in Table 2-10. These are high for many countries, emphasising the importance of the oceanic tuna fisheries for a number of economies, as well as local communities (Bell et al. 2011).

Table 2-10: Total reported tuna catches (t) by country fleet in 2014 (from WCPFC 2014).

Country	2014 catch (t)
Cook Islands	2,181
Federated States of Micronesia	40,870
Fiji	13,663
Kiribati	114,156
Marshall Islands	75,887
Nauru	19
Niue	0
Palau	0
Papua New Guinea	236,823
Samoa	1,102
Solomon Islands	61,151
Timor Leste	0
Tonga	250
Tuvalu	10,561
Vanuatu	32,343

A number of billfish species are also targeted or caught in association with the tuna. These include black marlin (*Makaira indica*), blue marlin (*Makaira nigricans*), striped marlin (*Tetrapturus audax*) and swordfish (*Xiphias gladius*). In addition, a number of oceanic sharks are taken as bycatch in longline fisheries: blue shark (*Prionace glauca*), silky shark (*Carcharhinus falciformis*), oceanic whitetip shark (*Carcharhinus longimanus*) and mako sharks (*Isurus* spp.). Billfish catches in 2014 totalled over 47,000 t (WCPFC 2014).

The spatial overlap of tuna fisheries by gear type is an important consideration for the ERA. Public domain catch and effort data were downloaded from the WCPFC website (https://www.wcpfc.int/science-and-scientific-data-functions-0). In Figure 2-3 below, the distributions of current catch by the three main fishery types of the key tuna species (last 5 years, 2010–2014) are plotted, overlaid on the mineral distribution.



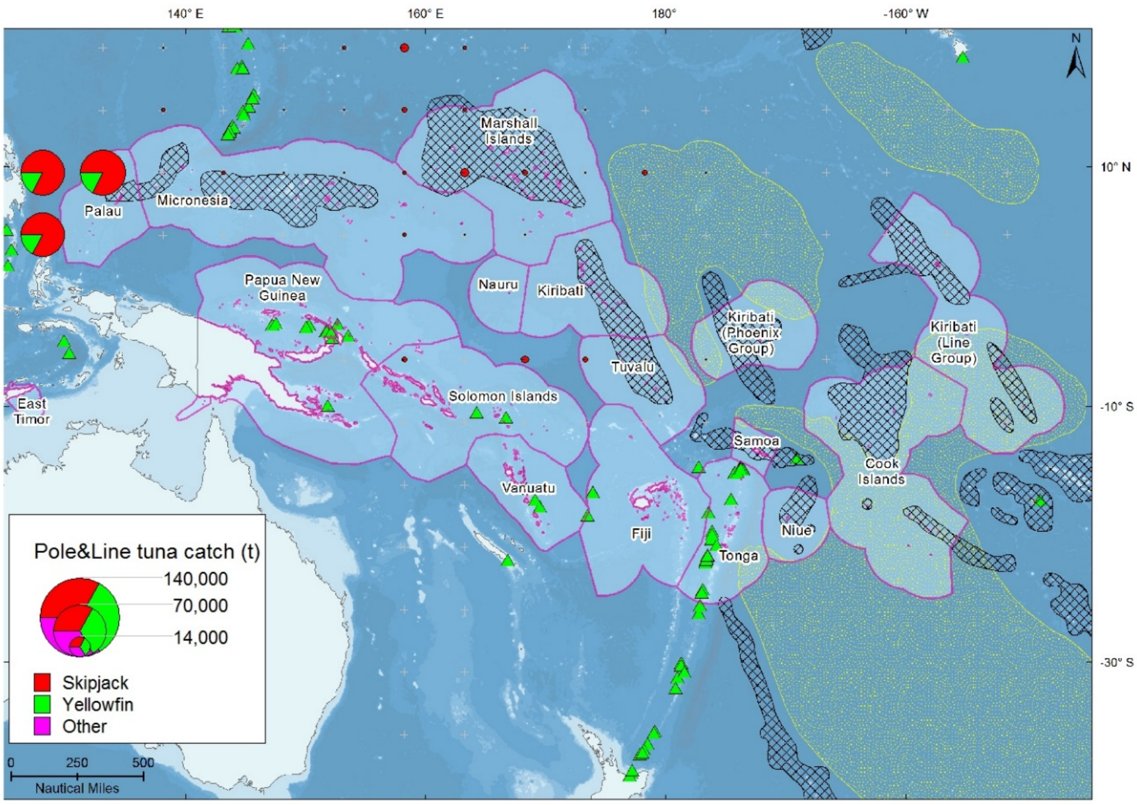


Figure 2-3: Distribution of tuna catch for the purse-seine (top) and pole and line (bottom) fisheries for 2010-14 (SPC data) relative to mineral type (SMS=green triangle, CRC= dark hatch, MN=yellow speckle).

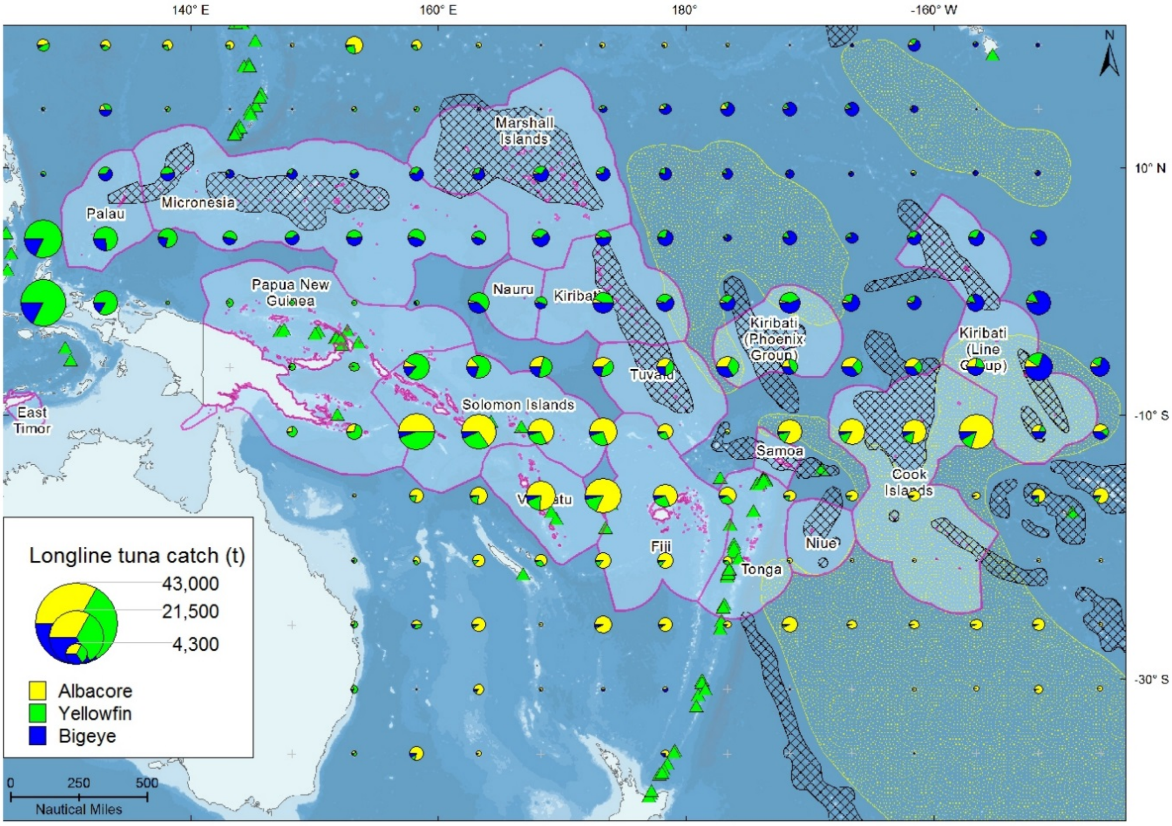


Figure 2-3 (cont): **Distribution of tuna catch in the longline fishery for the period 2010-14 (SPC data).**

The data are amalgamated into 5° by 5° squares, and hence the absolute degree of spatial overlap is unknown. However, as a relative measure, the number of such squares with more than 1% catch that overlap the mineral polygons, or point locations of CRC, SMS, and MN are given in Table 2-11.

Table 2-11: The degree of spatial overlap between 5 degree square catches of tuna, and distribution of mineral resources within the PIS EEZs (number of 5 degree squares given in parentheses)

Mineral type	Longline	Purse-seine	Pole & Line
CRC	High (22)	Low (7)	Very low (2)
SMS	Medium (10)	Medium (9)	Very low (0)
MN	Medium (14)	Low (5)	Very low (0)

Given the importance of tuna fisheries to PIS, the panel considered aspects of their biology as well. Skipjack are relatively short lived (generally 2-3 yr), mature young, and are highly fecund. Spawning occurs in the central Pacific throughout the year, near the equator. Skipjack move long distances, but movements are not well understood. Some skipjack, particularly in areas where they may be entrained by islands, are thought to not be highly mobile, with median movement distances in the hundreds of km (Kleiber and Hampton 1994). Depth distribution is surface to 300 m, with occasional deeper dives (Schaefer and Fuller 2007), but are caught mostly near the surface in purse seine fisheries.

Albacore vary in depth, with juveniles occurring in surface waters at higher latitudes, while adults are deeper (down to 400 m) in subequatorial waters (Nikolic et al. 2016). A South Pacific stock is distributed between 10° and 50° S, and spawns between 10° and 25° S in the western central Pacific in the austral summer (Nikolic et al 2016). They mature at 4-5 years (Farley et al 2014), and may live for up to 20 years. Adults appear to move seasonally, south during the early summer and north in winter (Langley 2004).

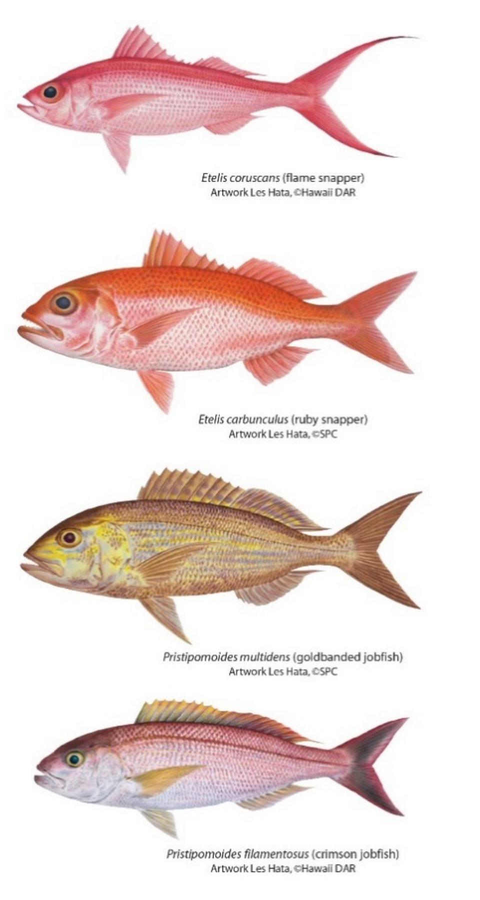
Bigeye also have a geographical pattern associated with life history stages. Juveniles are largely caught in tropical latitudes at the surface in association with floating objects. Adults are caught deeper using longlines (to 450 m), and taken mainly in the longline fishery. They mature at 2-3 years, and may live for up to 16 years (Farley et al 2006). There is widespread spawning, throughout most months of the year. Stock structure and movements are poorly known, but adults are relatively mobile, with tagged fish moving up to 1,800 km (SPC data).

Yellowfin juveniles are also caught mostly in association with floating objects, with larger adults caught by purse seines in unassociated schools and by longlines. There is widespread spawning, throughout the year, with seasonal peaks at different times by location (Itano 2000). They mature at about 2 years, and may live for 7 years. Adults may be less mobile than skipjack and bigeye, although tag recapture displacements of up to 1,800 km have been observed. Recent evidence suggests there may be several genetically distinct stocks in the Pacific (Grewe et al 2015).

Yellowfin, bigeye and albacore can show a preference for aggregating over seamount features, with a study by Morato et al. (2010a) identifying over 600 seamounts in the region where tuna catches in the longline fishery were higher than in coastal or oceanic waters.

2.3.3 Deepwater snapper fisheries

Deepwater snapper are an important fisheries resource for many PISs, where they support important domestic and export markets (SPC 2013d). Line fishing for these species has been carried out commercially around Pacific islands for several decades. Over 20 west-central Pacific countries and territories have active deepwater snapper fisheries, have participated in deepwater snapper historically, or have expressed some interest in developing this capacity (Williams & Nicol 2014). The fish caught in these fisheries are mainly from the families Serranidae, Lutjanidae, and Lethrinidae (McCoy 2010) (Figure 2-4). However, a range of over 100 species is landed, including those in the families Gempylidae and, more recently, Centrolophidae (the latter primarily bluenose and blue warehou from the seamounts of southern Tonga and the international waters between Tonga and New Zealand) (SPC 2013e). Currently, there is little information available to determine the distribution of deepwater snapper habitat throughout the Pacific. Williams & Nicol (2014) and Gomez et al. (2015) estimated the distribution of 14 deepwater snapper, grouped by the three genera *Etelis*, *Pristipomoides* and *Aphareus* using available fisheries and oceanographic data. Of the three predictors used (depth, slope and temperature), depth was the most influential, and there were strong regional patterns in the predicted distributions of snapper. The highest proportion of suitable habitat was predicted in waters between approximately 15 and 25°S, especially in the EEZ of Tonga.



Scientific name	Common Name
SNAPPERS	
Etelis carbunculus	Ruby snapper
Etelis coruscans	Long tailed red/flame snapper
Aphareus rutilans	Small-tooth jobfish
Pristipomoides filamentosus	Rosy/crimson jobfish
Pristipomoides flavipinnis	Yellow-finned jobfish
Pristipomoides multidens	Purple-cheeked/goldbanded jobfish
Pristipomoides amoenus	Flower snapper
Pristipomoides auricilla	Gold-tailed jobfish
Pristipomoides zonatus	Banded flower snapper
OTHERS	
Seriola rivoliana	Amberjack
Promethichthys prometheus	Snake mackerel
Ruvettus pretiosus	oilfish

Figure 2-4: The main deepwater snapper species taken in deep longlining operations (from McCoy 2010).

The fisheries occur on the outer reef slope and around seamounts (mainly in depths from 100 to 400 m), with the most active fisheries in Guam, New Caledonia, Northern Mariana Islands, Tonga, and Vanuatu (SPC 2013e). The main gear used in the Pacific region for deepwater snappers is hand-reels and powered reels, with some commercial bottom longlining and trotlining.

The dataset on all known deepwater snapper location records compiled by Gomez et al. (2015) was plotted to enable overlays against the mineral resource distributions (Figure 2-5).

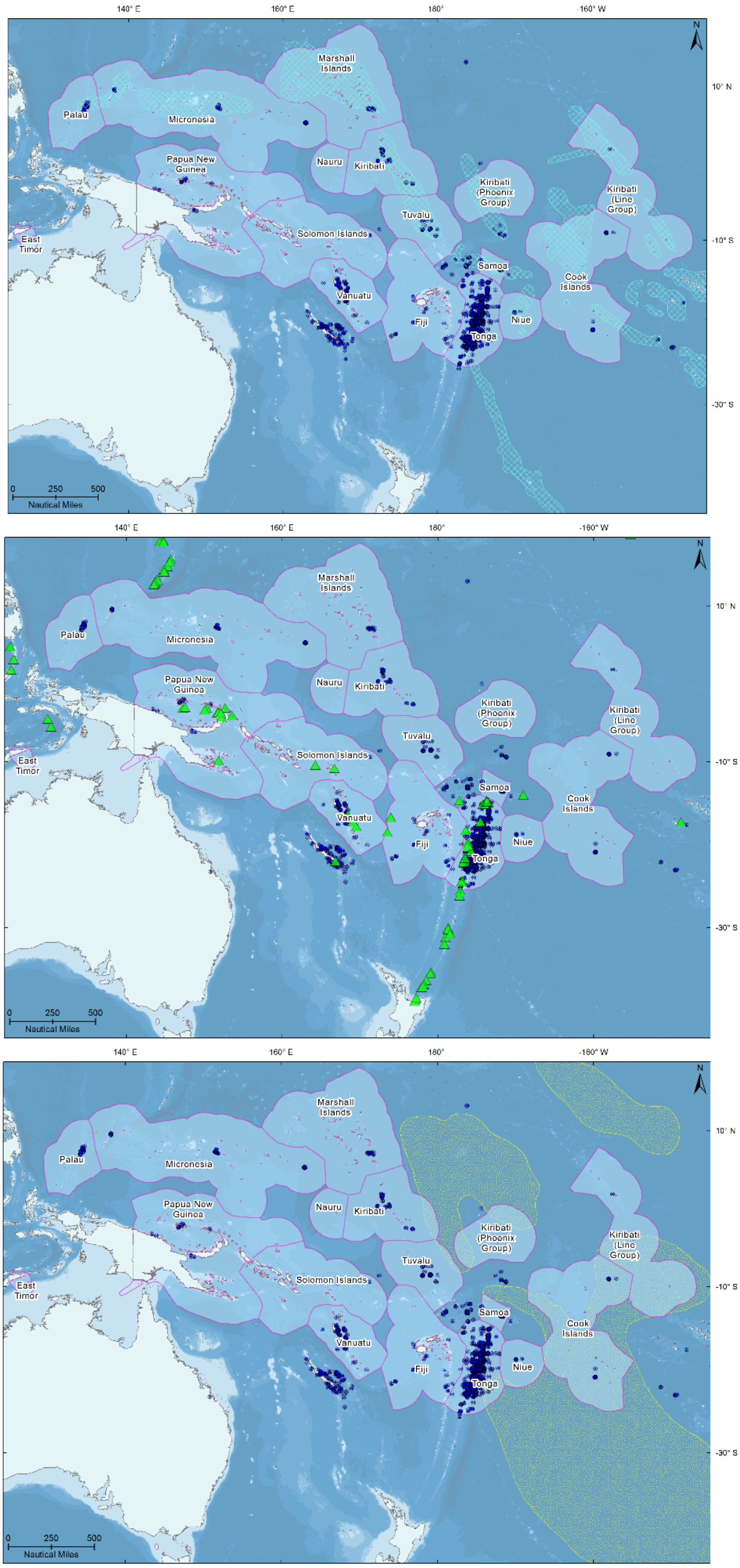


Figure 2-5: The distribution of deepwater snappers and mineral resources (top to bottom CRC dark hatch, SMS green triangle, MN yellow speckle).

In many states the deepwater snapper resource was found to be more limited than had been first thought (McCoy 2010). Localised depletions have raised concerns about the sustainability of current fishing rates. These stocks are also considered vulnerable to fishing due to their seamount distribution, high longevity, late maturity, and slow growth (Williams et al. 2013). There are currently no reliable estimates of sustainable levels of catch and effort, and a poor understanding of stock structure.

2.3.4 Coastal fisheries

A diverse range of demersal fish and invertebrate species are harvested from inshore waters around Pacific Island nations (Pratchett et al. 2011). The exploited habitats are mainly coral reefs, but also include mangroves, seagrass meadows, estuaries, and sandflats. The catches are taken for both subsistence and local trade.

A list of estimated catch by State in 2014 (Table 2-12) indicates an annual harvest of around 150 000 t, which has increased since 2007. Since 1999, coastal fisheries production has been largely stable despite an increase in fishing effort by most Pacific nations (Gillett 2016). The main families of demersal reef fishes that are harvested comprise the carnivorous emperors (Lethrinidae), snappers (Lutjanidae) and groupers (Serranidae), as well as herbivorous parrotfish (Scaridae), surgeonfish (Acanthuridae) and rabbitfish (Siganidae) (Pratchett et al. 2011). The composition of catches varies between States, but in ways that are not always related to availability, i.e., there is regional variation in fishing techniques, and cultural preferences for different fish as food. The invertebrate catch comprises molluscs, crustaceans, and echinoderms, with giant clams, sea cucumbers and gastropods being the most harvested groups by weight (Pratchett et al. 2011). Catch statistics, particularly for the invertebrate species that constitute an important part of subsistence fisheries, are poorly known (SPC 2013e). It is also considered likely that many reef fisheries that are based on finfish and invertebrates are operating at an unsustainable level (SPC 2013e).

Table 2-12: Estimated catches (t) of inshore demersal fishes and invertebrates in coastal commercial and subsistence fisheries for 2007 and 2014 (from Gillet 2016). Note for Timor-Leste the catch data are from 2009.

Country	2007	2014
Cook Islands	400	426
Federated States of Micronesia	12,600	5,270
Fiji	27,000	26,900
Kiribati	20,700	19,000
Marshall Islands	3,750	4,500
Nauru	650	373
Niue	150	165
Palau	2115	2,115
Papua New Guinea	35,700	41,500
Samoa	8,624	10,000
Solomon Islands	18,250	26,468
Timor-Leste	3,500*	?
Tonga	6,500	6,900
Tuvalu	1,215	1,435
Vanuatu	3,368	3,906

2.3.5 Mariculture

Marine aquaculture occurs at a relatively low intensity throughout the southwest Pacific Ocean (SPC 2013e, 2014).In most Pacific States, the economic value of marine and freshwater culture production is less than 5% of the value of coastal fisheries (Gillett 2016). Between 2007 and 2014, production decreased in value by about one-third, mainly attributable to the fall in value of pearls produced mainly in the Cook Islands and French Polynesia (Gillett 2016).

A list of mariculture operations by State and species indicates, that there is a relatively large number of small operations widespread throughout the PISs covered by this assessment (Table 2-13). Difficulties in obtaining up-to-date information on the status of Pacific aquaculture means that this list may be incomplete, or that some of the operations listed are no longer functional or are only at the developmental hatchery stage. However, the list demonstrates the diversity of the aquaculture sector, its local importance, and gives an idea of the likely impacts from DSM that could be important.

Table 2-13: List of mariculture activities and species occurring PIS (excludes exclusively freshwater). Countries listed alphabetically.

Country	Aquaculture species	Farming system
Cook Islands	Black-lip pearl oyster (*Pinctada margaritifera*)	Floating longlines
	Giant clams (mainly *Tridacna gigas*)	Floating & submerged cages
	Milkfish (*Chanos chanos*)	Earthen ponds
Federated States of Micronesia	Sea snail (*Trochus niloticus*)	Land-based, for restocking
	Black-lip pearl oyster (*Pinctada margaritifera*)	Floating longlines
	Giant clams (*Tridacna gigas*)	Floating & submerged cages
	Sea cucumber “sandfish” (*Holothuria scabra*)	Earthen ponds & sea ranching
	Corals	Submerged cages
	Sponges	Floating long-line
Fiji	Black-lip pearl oyster (*Pinctada margaritifera*)	Floating longlines
	Whiteleg shrimp (*Litopenaeus vannamei*)	Earthen ponds
	Giant tiger prawn (*Penaeus* sp.)	Earthen ponds
	Carrageenan seaweed (*Kappaphycus alvarezii*)	Off-bottom & floating long-line
	Sea grapes (*Caulerpa racemosa*)	Floating & submerged cages
	Giant clams (*Tridacna gigas*)	Floating & submerged cages
	Sea snail (*Trochus niloticus*)	Land-based, for restocking
	Sea cucumber “sandfish” (*Holothuria scabra*)	Earthen ponds & sea ranching
Kiribati	Milkfish (*Chanos chanos*)	Earthen ponds
	Giant clams (*Tridacna gigas*)	Floating & submerged cages
	Carrageenan seaweed (*Kappaphycus alvarezii*)	Off-bottom & floating long-line
	Sea cucumber “sandfish” (*Holothuria scabra*)	Earthen ponds & sea ranching
	Sea snail (*Trochus niloticus*)	Land-based, for restocking
Marshall Islands	Sea snail (*Trochus niloticus*)	Land-based, for restocking
	Black-lip pearl oyster (*Pinctada margaritifera*)	Floating longlines

Country	Aquaculture species	Farming system
	Giant clams (*Tridacna gigas*) Corals	Floating & submerged cages Submerged cages
Nauru	Milkfish (*Chanos chanos*)	Earthen ponds
Palau	Giant clams (*Tridacna gigas*) Milkfish (*Chanos chanos*)	Floating & submerged cages Earthen ponds
	Milkfish (*Chanos chanos*)	Earthen ponds
	Giant tiger prawn (*Penaeus monodon*)	Earthen ponds
Papua New Guinea	Barramundi (*Lates calcarifer*)	Floating cages
	Carrageenan seaweed (*Kappaphycus alvarezii*)	Off-bottom & floating long-line
	Sea snail (*Trochus niloticus*)	Land-based, for restocking
	Sea cucumber “sandfish” (*Holothuria scabra*)	Earthen ponds & sea ranching
Samoa	Giant clams (*Tridacna gigas*)	Floating & submerged cages
	Sea grapes (*Caulerpa racemosa*)	Floating & submerged cages
Solomon Islands	Milkfish (*Chanos chanos*) Carrageenan seaweed (*Kappaphycus alvarezii*) Corals Giant clams (*Tridacna gigas*)	Earthen ponds Off-bottom & floating long-line Submerged cages Floating & submerged cages
Tonga	Corals Giant clams (*Tridacna gigas*) Black-lip pearl oyster (*Pinctada margaritifera*)	Submerged cages Floating & submerged cages Floating longlines
Vanuatu	Barramundi (*Lates calcarifer*) Giant clams (*Tridacna gigas*) Sea snail (*Trochus niloticus*) Green snails Corals Whiteleg shrimp (*Litopenaeus vannamei*) Giant tiger prawn (*Penaeus monodon*)	Floating cages Floating & submerged cages Land-based, for restocking Hatchery Submerged cages Earthen ponds Earthen ponds

This list does not include the following exclusively freshwater species that are also cultured by Pacific nations:

- Tilapia (Nile and Red)
- Giant prawn (*Macrobrachium rosenbergii*)
- Rainbow trout (*Macrobrachium lar*)
- Grass carp (*Ctenopharyngodon idella*)
- Silver carp (*Hypophthalmichthys molitrix*)
- Silver barb (*Puntius javanicus*)
- Red claw crayfish (*Cherax quadricarinatus*).

2.3.6 Oceanography and bathymetry

Oceanographic data were not directly used in the assessment, but enable a general evaluation of where in the region as a whole stronger currents at depth might be expected, and hence where dispersal of sediment plumes, for example, could be greater.

Oceanographic data were extracted from a number of sources, but especially Argo floats as these give the most accurate indication of current direction and flows between the surface and 1,000 m depth. Combining mean data from Argo with the satellite anomaly information allows for estimation of the time-varying surface currents (Figure 2-6).

The mean currents at both the surface and depth show the gyre-scale circulation: westward flows both sides of the equator, and then western boundary currents heading poleward. Eastward flows occur north of the Subtropical Front and strong eastward flows are notable in the Southern Ocean, especially associated with the Subantarctic Front.

As a general rule, the variability in deep currents is almost as large as the mean. In the strong flow regimes (equator, western boundary currents, subantarctic front) it would be very unusual for the flows to reverse, but in weaker, but still significant, flows like the East Auckland Current the flows occasionally reverse. Anywhere with mean flows of less than 5-10 cm/s it could be expected that variability could be larger than the mean.

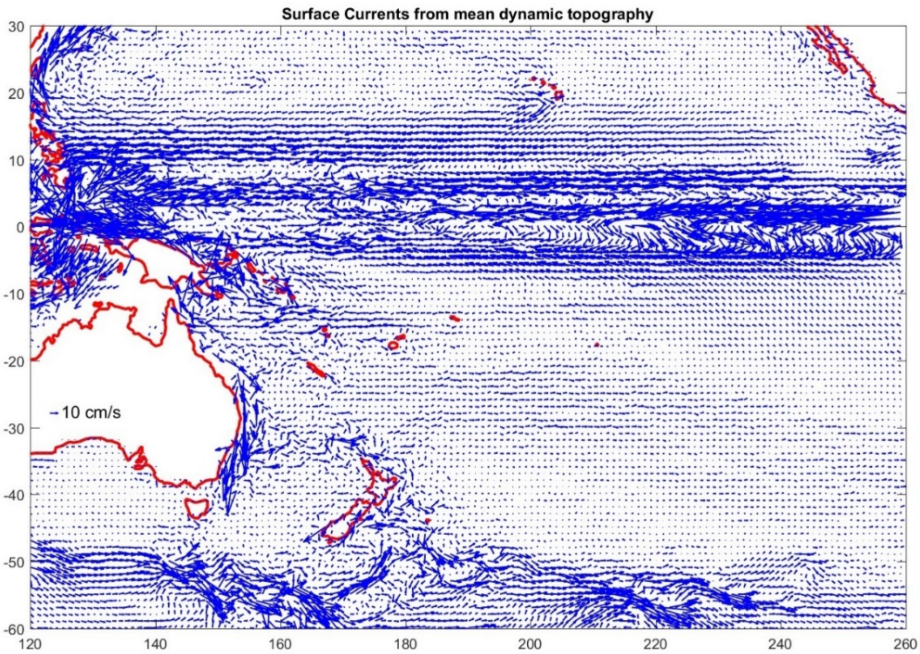


Figure 2-6: Dynamic current flow representation at the surface. Derived from Rio et al. (2011).

The 1,000 m plot (Figure 2-7) is based solely on Argo trajectories. The vectors indicate an average of all float trajectories in each 1 degree square for 2015; where there were no data, there is no vector.

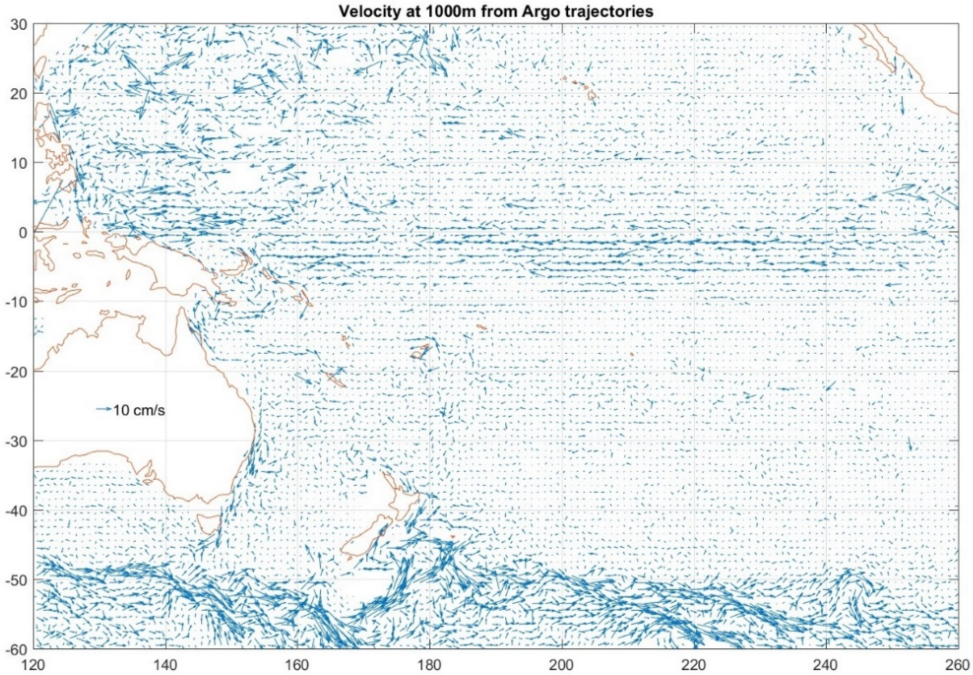


Figure 2-7: The average velocity field of currents at 1,000 m for 2015 as estimated from Argo float trajectories. http://apdrc.soest.hawaii.edu/projects/Argo/data.

Additional information was also extracted for bathymetry (from GEBCO 2008) and seamount features. MN resources generally occur deeper than about 4,000 m, and so this was used as a reference contour to further interpret the SPC polygons. CRC and SMS generally occur on seamounts, and hence the validated dataset for the region derived by Allain et al. (2008) was plotted (Figure 2-8). At a regional level, this plot shows a large number of features.

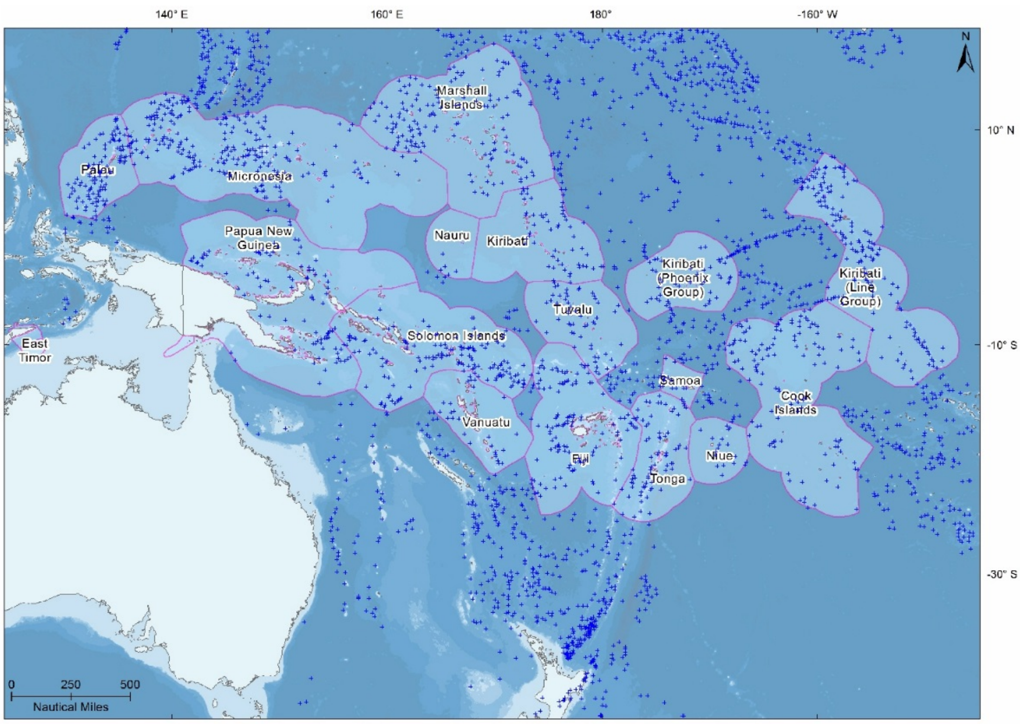


Figure 2-8: Distribution of large seamount features (blue crosses) in the region (from Allain et al. 2008).

2.3.7 Proximity estimation

For coastal and aquaculture fisheries, it is difficult to assess how close to land a mining operation could occur. If it was very close (several km) then effects could be severe, whereas they would be potentially minor if the mining was much further away (10s to 100s km). Site-specific conditions need to be assessed in this situation, and distances of potential mining operations to islands can vary considerably between countries. An indication of this was gained by estimating the distance between the nearest seamount (CRC), vent (SMS) or 4000 m contour (MN) to the main island in each of the groups (Table 2-14). For some of the mineral types, such as SMS, vents are not known from near the country, but the values have been left in to give an idea of whether resource operations in neighbouring countries should be considered. The dispersal potential of indirect effects (e.g., sediment plume) from a major mining activity are poorly known, ranging from several km (SMS) to up to 100 km or more (MN) depending on the site characteristics (see SPC 2013a,b,c for a description of the extent of effects).

Table 2-14: Nearest distances (km) of the main island by country (listed alphabetically) to known vent and seamount locations, and the abyssal plains 4000 m contour.

Country	Vent (SMS)	Seamount (CRC)	4000 m (MN)
Cook Islands	407	17	4
Fiji	347	75	138
Kiribati (Gilbert Group)	1,473	31	32
Kiribati (Phoenix Islands group)	1,090	80	45
Kiribati (Line Is Group)	2,130	62	40
Marshall Islands	1,589	53	5
Nauru	866	17	4
Niue	422	28	10
Palau	844	32	2
Papua New Guinea	20	200	100
Samoa	151	30	48
Solomon Islands	351	71	34
Timor Leste	460	103	38
Tonga	41	32	80
Tuvalu	470	12	91
Vanuatu	173	28	45

3 Results

3.1 Tuna fisheries

3.1.1 Tuna longline fishery

CRC and SMS mineral operations

The main assessment was for the interaction between the longline fishery and CRC (Tables 3-1 and 3-2) for exploration and mining phases respectively. However, it was felt that any differences for fisheries overlying SMS sites would be very minor. Hence the tables apply to both CRC and SMS, reflecting the seamount environment of the two mineral types.

During exploration, the expected impacts from the range of activities were generally minor. None of the assessed activities were thought likely to have any effect on tuna, billfish, or bycatch species, and no trophic linkage community impacts. Hence the fisheries would be unaffected.

During a mining operation on a seamount feature (whether a smaller volcanic cone with venting, or a large guyot), there would be a limited surface effect (probably a single vessel with barges for transhipping) with impacts of the ship presence or surface lights and noise on the tuna being negligible. However, this would depend upon the “footprint” of the operation on the surface, as it could potentially limit fishing vessel operation or cause fish behaviour to alter (avoidance or attraction). The panel was confident that the seafloor activities in general would have no direct impact on the fish species or fisheries.

The depths of a CRC or SMS mining operation at 800 m or greater are several hundred m below the deepest fish (typically shallower than 500 m). The main concern for the fishery would be the processing return water. It is likely that this could be returned close to the seafloor (as proposed by Nautilus Minerals for their permitted Solwara 1 project for SMS) but this is not certain. Returns will also certainly be below the thermocline, but at 200-300 m this could have a possible effect on the tuna, billfish and shark species if visibility is reduced for such visual predators. However, although this was regarded as having a possible effect on geographic range (fish moving to another location), the consequence was scored as minor because of the very widespread distribution of all the species. It may make a particular location less favourable, but the fish will be available elsewhere, and the effect on the fishery is also likely to be small.

The main impact on the fishery could be through any release of heavy metals or toxic contaminants. This could work through the food chain, which is signalled by the scoring of 3 (not thought to be a common event, although a possible score (4) was also considered) reflecting a moderate likelihood of having an effect on stock dynamics-but if it did, the consequence could be moderate. Ecotoxicity effects could, however, be important on the market perception of the health of the fish. Tuna have been shown to take up radioactive isotopes (e.g., Cesium following the Fukushima nuclear incident: Reuters 2012). Although this has been used as a migratory tracker (Madigan et al. 2013) the presence of radioactive elements has also raised concerns about the safety of eating contaminated fish (Natural News 2015). Where the fish are highly migratory, any contamination of fish through the food chain on one seamount will likely percolate through the wider stock distribution.

MN operations

There were some changes from the above baseline scores for CRC and SMS mining operations when considering MN activities (Table 3-3). It was felt unlikely that there would be a shift caused by seafloor extraction or the extraction plume in the geographic range of any fish, whether tuna, billfish, or bycatch species. Processing return impacts would also be less, because they would not have an influence on seamount conditions, where catch rates and pelagic diversity can be high. Note the uncertainty changes a small amount in the MN assessment compared to the assessments for mineral operations on seamounts where depths of extraction and species encountered are more variable. Similarly, toxic chemical release would be less in MN operations, on account of the mining operation being more a dredging of nodules, rather than a physical crushing or breaking of crust (CRC) or seafloor rock/chimneys (SMS). In MN operations any release at the seafloor would be too deep for an effect on fisheries, and release through processing returns could be more widely dispersed than if done over a seamount. The assessment for MN mining operations is given in Table 3-3.

The final difference between MN and other seafloor mineral operations is the reduced overall effect of toxicity on fishery operations, where toxicity could affect market value of the tuna. However, over the abyssal plains the fleet is more dispersed, and less reliant on seamount targeting for their catch.

Table 3-1: Expert panel assessment scores: Tuna longline fishery. CRC and SMS. Exploration activities. Lik = likelihood, Cons = consequence, Conf = confidence

ACTIVITY	Threat	Spatial overlap	Tuna				Billfish				Bycatch				Community-links			
			Lik	Cons	Risk	Conf	Lik	Cons	Risk	Conf	Lik	Cons	Risk	Conf	Lik	Cons	Risk	Conf
Ship presence	Population size	Low	1	0	0	2a	1	0	0	2a	1	0	0	2a	1	0	0	2a
	Geographic range		1	0	0	2a	1	0	0	2a	1	0	0	2a	1	0	0	2a
	Genetic structure		1	0	0	2a	1	0	0	2a	1	0	0	2a	1	0	0	2a
	Biological parameters		1	0	0	2a	1	0	0	2a	1	0	0	2a	1	0	0	2a
Surface lights and noise	Population size	Low	1	0	0	2a	1	0	0	2a	1	0	0	2a	1	0	0	2a
	Geographic range		1	0	0	2a	1	0	0	2a	1	0	0	2a	1	0	0	2a
	Genetic structure		1	0	0	2a	1	0	0	2a	1	0	0	2a	1	0	0	2a
	Biological parameters		1	0	0	2a	1	0	0	2a	1	0	0	2a	1	0	0	2a
ROV/other imaging surveys	Population size	Low	1	0	0	2a	1	0	0	2a	1	0	0	2a	1	0	0	2a
	Geographic range		1	0	0	2a	1	0	0	2a	1	0	0	2a	1	0	0	2a
	Genetic structure		1	0	0	2a	1	0	0	2a	1	0	0	2a	1	0	0	2a
	Biological parameters		1	0	0	2a	1	0	0	2a	1	0	0	2a	1	0	0	2a
Acoustic swath mapping	Population size	Low	1	0	0	2a	1	0	0	2a	1	0	0	2a	1	0	0	2a
	Geographic range		1	0	0	2a	1	0	0	2a	1	0	0	2a	1	0	0	2a
	Genetic structure		1	0	0	2a	1	0	0	2a	1	0	0	2a	1	0	0	2a
	Biological parameters		1	0	0	2a	1	0	0	2a	1	0	0	2a	1	0	0	2a

ACTIVITY	Threat	Spatial overlap	Tuna				Billfish				Bycatch				Community-links			
			Lik	Cons	Risk	Conf	Lik	Cons	Risk	Conf	Lik	Cons	Risk	Conf	Lik	Cons	Risk	Conf
Seismic survey	Population size	Low	1	0	0	1c	1	0	0	1c	1	0	0	1c	1	0	0	1c
	Geographic range		1	0	0	1c	1	0	0	1c	1	0	0	1c	1	0	0	1c
	Genetic structure		1	0	0	1c	1	0	0	1c	1	0	0	1c	1	0	0	1c
	Biological parameters		1	0	0	1c	1	0	0	1c	1	0	0	1c	1	0	0	1c
Spot sampling	Population size	Low	1	0	0	2a	1	0	0	2a	1	0	0	2a	1	0	0	2a
	Geographic range		1	0	0	2a	1	0	0	2a	1	0	0	2a	1	0	0	2a
	Genetic structure		1	0	0	2a	1	0	0	2a	1	0	0	2a	1	0	0	2a
	Biological parameters		1	0	0	2a	1	0	0	2a	1	0	0	2a	1	0	0	2a
Drilling	Population size	Low	1	0	0	1c	1	0	0	1c	1	0	0	1c	1	0	0	1
	Geographic range		1	0	0	1c	1	0	0	1c	1	0	0	1c	1	0	0	1
	Genetic structure		1	0	0	1c	1	0	0	1c	1	0	0	1c	1	0	0	1
	Biological parameters		1	0	0	1c	1	0	0	1c	1	0	0	1c	1	0	0	1
Bulk sampling	Population size	Low	1	0	0	1c	1	0	0	1c	1	0	0	1c	1	0	0	1c
	Geographic range		1	0	0	1c	1	0	0	1c	1	0	0	1c	1	0	0	1c
	Genetic structure		1	0	0	1c	1	0	0	1c	1	0	0	1c	1	0	0	1c
	Biological parameters		1	0	0	1c	1	0	0	1c	1	0	0	1c	1	0	0	1c
Sediment plume	Population size	Low	1	0	0	2a	1	0	0	2a	1	0	0	2a	2	1	2	1c
	Geographic range		1	0	0	2a	1	1	1	1c	1	1	1	1c	2	1	2	1c

ACTIVITY	Threat	Spatial overlap	Tuna				Billfish				Bycatch				Community-links			
			Lik	Cons	Risk	Conf	Lik	Cons	Risk	Conf	Lik	Cons	Risk	Conf	Lik	Cons	Risk	Conf
	Genetic structure		1	0	0	2a	1	0	0	2a	1	0	0	2a	1	0	0	1c
	Biological parameters		1	0	0	2a	1	0	0	2a	1	0	0	2a	2	1	2	1c
Underwater lights and noise	Population size	Low	1	0	0	2a	1	0	0	2a	1	0	0	2a	1	0	0	2a
	Geographic range		1	0	0	2a	1	0	0	2a	1	0	0	2a	1	0	0	2a
	Genetic structure		1	0	0	2a	1	0	0	2a	1	0	0	2a	1	0	0	2a
	Biological parameters		1	0	0	2a	1	0	0	2a	1	0	0	2a	1	0	0	2a

Table 3-2: Expert panel assessment scores. Tuna longline fishery. CRC and SMS. Mining phase. Lik = likelihood, Cons = consequence, Conf = confidence; -, indicates a range of scores.

ACTIVITY	Threat	Spatial overlap	Tuna				Billfish				Bycatch				Community-links			
			Lik	Cons	Risk	Conf	Lik	Cons	Risk	Conf	Lik	Cons	Risk	Conf	Lik	Cons	Risk	Conf
Ship presence	Population size	Low	1	0	0	2a	1	0	0	2a	1	0	0	2a	1	0	0	2a
	Geographic range		1	0	0	2a	1	0	0	2a	1	0	0	2a	1	0	0	2a
	Genetic structure		1	0	0	2a	1	0	0	2a	1	0	0	2a	1	0	0	2a
	Biological parameters		2	1	2	2a	2	1	2	2a	1	0	0	2a	1	0	0	2a
Surface lights and noise	Population size	Low	1	0	0	2a	1	0	0	2a	1	0	0	2a	1	0	0	2a
	Geographic range		1	0	0	2a	1	0	0	2a	1	0	0	2a	1	0	0	2a
	Genetic structure		1	0	0	2a	1	0	0	2a	1	0	0	2a	1	0	0	2a
	Biological parameters		2	1	2	2a	2	1	2	2a	1	0	0	2a	1	0	0	2a
Seafloor extraction	Population size	Low-Medium	1	0	0	2a	1	0	0	2a	1	0	0	2a	2	1	2	1c
	Geographic range		2	1	2	2a	2	1	2	2a	2	1	2	2a	2	1	2	1c
	Genetic structure		1	0	0	2a	1	0	0	2a	1	0	0	2a	1	0	0	1c
	Biological parameters		1	0	0	2a	1	0	0	2a	1	0	0	2a	2	1	2	1c
Sediment plume	Population size	Low-medium	1	0	0	2a	1	0	0	2a	1	0	0	2a	2	1	2	1c
	Geographic range		2	1	2	2a	2	1	2	1c	2	1	2	1c	2	1	2	1c
	Genetic structure		1	0	0	2a	1	0	0	2a	1	0	0	2a	1	0	0	1c
	Biological parameters		1	0	0	2a	1	0	0	2a	1	0	0	2a	2	1	2	1c
Deposition of	Population size	Low	1	0	0	2a	1	0	0	2a	1	0	0	2a	1	0	0	2a

ACTIVITY	Threat	Spatial overlap	Tuna				Billfish				Bycatch				Community-links			
			Lik	Cons	Risk	Conf	Lik	Cons	Risk	Conf	Lik	Cons	Risk	Conf	Lik	Cons	Risk	Conf
overburden	Geographic range		1	0	0	2a	1	0	0	2a	1	0	0	2a	1	0	0	2a
	Genetic structure		1	0	0	2a	1	0	0	2a	1	0	0	2a	1	0	0	2a
	Biological parameters		1	0	0	2a	1	0	0	2a	1	0	0	2a	1	0	0	2a
Underwater lights and noise	Population size	Low-medium	1	0	0	2a	1	0	0	2a	1	0	0	2a	1	0	0	2a
	Geographic range		1	0	0	2a	1	0	0	2a	1	0	0	2a	1	0	0	2a
	Genetic structure		1	0	0	2a	1	0	0	2a	1	0	0	2a	1	0	0	2a
	Biological parameters		1	0	0	2a	1	0	0	2a	1	0	0	2a	1	0	0	2a
Wastewater return	Population size	Low-Medium	1	0	0	1c	1	0	0	1c	1	0	0	1c	3	1	3	1c
	Geographic range		4	1	4	1c	4	1	4	1c	4	1	4	1c	3	1	3	1c
	Genetic structure		1	0	0	1c	1	0	0	1c	1	0	0	1c	1	0	0	1c
	Biological parameters		1	0	0	1c	1	0	0	1c	1	0	0	1c	2	1	2	1c
Toxic chemical release	Population size	Low-medium	1	0	0	1c	1	0	0	1c	1	0	0	1c	3	2	6	1c
	Geographic range		1	0	0	1c	1	0	0	1c	1	0	0	1c	1	0	0	1c
	Genetic structure		1	0	0	1c	1	0	0	1c	1	0	0	1c	1	0	0	1c
	Biological parameters		2	2	4	1c	2	2	4	1c	2	2	4	1c	3	2	6	1c
	Fishery operation		4	2-4	8-16	1c	4	2-4	8-16	1c								

Table 3-3: Expert risk assessment scores. Tuna longline. MN. Mining phase. Only threats where the risk score differed from SMS/CRC are shown. Lik = likelihood, Cons = consequence, Conf = confidence; -,indicates a range of scores

ACTIVITY	Threat	Spatial overlap	Tuna				Billfish				Bycatch				Community-links			
			Lik	Cons	Risk	Conf	Lik	Cons	Risk	Conf	Lik	Cons	Risk	Conf	Lik	Cons	Risk	Conf
Seafloor extraction	Population size	Low-Medium	1	0	0	2a	1	0	0	2a	1	0	0	2a	2	1	2	1c
	Geographic range		1	0	0	2a	1	0	0	2a	1	0	0	2a	2	1	2	1c
	Genetic structure		1	0	0	2a	1	0	0	2a	1	0	0	2a	1	0	0	1c
	Biological parameters		1	0	0	2a	1	0	0	2a	1	0	0	2a	2	1	2	1c
Sediment plume	Population size	Low-Medium	1	0	0	2a	1	0	0	2a	1	0	0	2a	2	1	2	1c
	Geographic range		1	0	0	2a	1	0	0	1c	1	0	0	1c	2	1	2	1c
	Genetic structure		1	0	0	2a	1	0	0	2a	1	0	0	2a	1	0	0	1c
	Biological parameters		1	0	0	2a	1	0	0	2a	1	0	0	2a	2	1	2	1c
Wastewater return	Population size	Low-Medium	1	0	0	1c	1	0	0	1c	1	0	0	1c	3	1	3	1c
	Geographic range		3	1	3	1c	3	1	3	1c	3	1	3	1c	3	1	3	1c
	Genetic structure		1	0	0	1c	1	0	0	1c	1	0	0	1c	1	0	0	1c
	Biological parameters		1	0	0	1c	1	0	0	1c	1	0	0	1c	2	1	2	1c
Toxic chemical release	Population size	Low-medium	1	0	0	1c	1	0	0	1c	1	0	0	1c	3	2	6	1c
	Geographic range		1	0	0	1c	1	0	0	1c	1	0	0	1c	1	0	0	1c
	Genetic structure		1	0	0	1c	1	0	0	1c	1	0	0	1c	1	0	0	1c
	Biological parameters		2	1	3	1c	2	1	3	1c	2	1	3	1c	3	2		1c
	Fishery operation		3	2-4	6-12	1c	3	2-4	6-12	1c								

3.1.2 Tuna pole and line and purse-seine fisheries

Initially it was intended to carry out separate assessments for each fishery method, because of differences in the geographical extent of each, the target species, and the depth at which the fisheries operate. Some of the key points discussed were:

- The purse seine fishery works at depths from the surface to about 200 m, with the key target species being skipjack – a smaller-bodied species than bigeye or yellowfin tuna. However, size of fish varies, with free schools including large yellowfin, whereas around fish aggregating devices (FADs) the fish tend to be smaller.
- There may be some site-association with species and size of fish over seamounts. However, unlike the relationship on some seamounts for tuna density of yellowfin and bigeye (Morato et al. 2010a) and higher oceanic species diversity (Morato et al. 2010b), it is uncertain how consistent patterns may be.
- Despite differences in how fisheries operate, effects of mining on the depth-specific biology of the fish species are not as clear. Both adult and juvenile fish cover a wide depth range, and although adults are typically deeper, it varies by species and location. It also varies by time, with an example being swordfish in the upper 200 m during the night, but greater than 500 m in the daytime (Dewar et al. 2011)
- The pole and line fishery is also shallow, like purse seine operations, working on surface fish. In contrast, longline fleets can operate down to 400 m.
- Depth-specific effects were felt unlikely to greatly change fish behaviour. The assumption made here is that fish are free to move, but are less likely to change their depth distribution compared with altering their horizontal spatial distribution.
- The likelihood of bioaccumulation from any toxic release might be lower for the smaller species or juveniles in the purse-seine or pole and line fisheries (a 3 rather than a 4), but the range of consequences from 2 to 4 would be the same.

Overall, it was resolved that differences in the risk profiles by fishery type would be subtle, and unlikely to change the overall scoring. Hence separate tables are not presented.

3.1.3 Billfish and other bycatch species (tuna longline fishery)

Although there is a targeted billfish fishery, the majority is taken as bycatch with the longline tuna fishery. Billfish and other pelagic bycatch species were covered under the tuna longline assessment, and it was agreed that the general risk scoring would not change by considering target versus bycatch billfish. There may be differences in certain areas, but this was beyond the scope of the current project.

3.2 Deepwater snapper fishery

The fishery is located on island slopes, and on offshore seamounts. The main focus of the expert panel was on assessing the risks from SMS mining, for which there are exploration licences granted within the EEZs of Tonga, the Solomon Islands, Vanuatu and Fiji. CRC habitats are also included, but they are more associated with larger guyot features (Hein et al. 2009) which are not common in these waters compared with the volcanic seamounts that are typically smaller and more conical in shape.

3.2.1 Exploration for SMS deposits

Exploration activities were assessed for snapper and community links (trophic interactions supporting the snapper populations) (Table 3-4). There are a number of species taken in this type of bottom longline fishery, but the panel felt it was unnecessary to divide the species into smaller groups (such as groupers, warehou, etc.). Nevertheless, other species were borne in mind when scores were agreed for the snappers, in case they might not be appropriate for all species.

All exploration activities scored a remote likelihood, and negligible consequence, with the exception of the sediment plume generated during seabed sampling. This would be a small plume, and typically deeper than the distribution of the fish. However, upwelling can be strong on seamounts, and hence sediment could be transported to depths where snapper occur. It was felt to be a rare event, and would have a minor effect, if any, on population size, range, or biology (with behaviour affected rather than any core life history parameter). Any effect through community linkages would also be unlikely, but could occur given the particular set of oceanographic conditions on a seamount, which can localise effects.

Table 3-4: Expert panel risk assessment. Deepwater snapper longline fishery. SMS. Exploration phase. Lik = likelihood, Cons = consequence, Conf = confidence

ACTIVITY	Threat	Spatial overlap	Snapper				Community-links			
			Lik	Cons	Risk	Conf	Lik	Cons	Risk	Conf
Ship presence	Population size	Low	1	0	0	2a	1	0	0	2a
	Geographic range		1	0	0	2a	1	0	0	2a
	Genetic structure		1	0	0	2a	1	0	0	2a
	Biological parameters		1	0	0	2a	1	0	0	2a
Surface lights and noise	Population size	Low	1	0	0	2a	1	0	0	2a
	Geographic range		1	0	0	2a	1	0	0	2a
	Genetic structure		1	0	0	2a	1	0	0	2a
	Biological parameters		1	0	0	2a	1	0	0	2a
ROV/other imaging surveys	Population size	Medium	1	0	0	1c	1	0	0	1c
	Geographic range		1	0	0	1c	1	0	0	1c
	Genetic structure		1	0	0	2a	1	0	0	1c
	Biological parameters		1	0	0	2a	1	0	0	1c
Acoustic swath mapping	Population size	Medium-High	1	0	0	2a	1	0	0	2a
	Geographic range		1	0	0	2a	1	0	0	2a

ACTIVITY	Threat	Spatial overlap	Snapper				Community-links			
			Lik	Cons	Risk	Conf	Lik	Cons	Risk	Conf
	Genetic structure		1	0	0	2a	1	0	0	2a
	Biological parameters		1	0	0	2a	1	0	0	2a
Seismic survey	Population size	Medium	1	0	0	1c	1	0	0	1c
	Geographic range		1	0	0	1c	1	0	0	1c
	Genetic structure		1	0	0	1c	1	0	0	1c
	Biological parameters		1	0	0	1c	1	0	0	1c
Spot sampling	Population size	Low	1	0	0	2a	1	0	0	2a
	Geographic range		1	0	0	2a	1	0	0	2a
	Genetic structure		1	0	0	2a	1	0	0	2a
	Biological parameters		1	0	0	2a	1	0	0	2a
Drilling	Population size	Low	1	0	0	1c	1	0	0	1c
	Geographic range		1	0	0	1c	1	0	0	1c
	Genetic structure		1	0	0	1c	1	0	0	1c
	Biological parameters		1	0	0	1c	1	0	0	1c
Bulk sampling	Population size	Low	1	0	0	1c	1	0	0	1c
	Geographic range		1	0	0	1c	1	0	0	1c
	Genetic structure		1	0	0	1c	1	0	0	1c
	Biological parameters		1	0	0	1c	1	0	0	1c
Sediment plume	Population size	Low-medium	2	1	2	2a	2	1	2	1c
	Geographic range		2	1	3	1c	2	1	2	1c
	Genetic structure		1	0	0	2a	1	0	0	1c
	Biological parameters		2	1	2	2a	2	1	2	1c
Underwater lights and noise	Population size	Low-medium	1	0	0	2a	1	0	0	2a
	Geographic range		1	0	0	2a	1	0	0	2a
	Genetic structure		1	0	0	2a	1	0	0	2a
	Biological parameters		1	0	0	2a	1	0	0	2a

3.2.2 Mining of SMS deposits

The mining phase assessment for SMS saw a considerable increase in risk to snapper fish and fisheries (Table 3-5). Ship presence, and surface lights and noise were still considered remote possibilities. However, seafloor activities were more likely to have an impact, and these would have greater consequences. Seafloor extraction of SMS is possibly small on an individual seamount, depending on whether chimney features, or larger mounds, were the target of mining. In both cases the seafloor characteristics could be affected and influence the suitability of habitat for the snappers. In a similar way, deposition of overburden to clear access for machinery could alter the seafloor shape or benthic communities. Again, this is deeper than the fishery, and the consequences are uncertain (agreement amongst experts, but with low confidence). Risk is greater from the sediment plume, which could extend several hundred metres above the seafloor, especially with potential upwelling by currents on a seamount or area of island slope. Impacts on population size, geographic range, and biological/behavioural aspects may occur (5), with potentially major consequences reducing population size and range on a seamount. The stock structure and affinity of snapper species for a particular area is uncertain. Although the species are widely distributed, there may be resident populations on individual seamounts, and if affected would cause a reduction in abundance and CPUE in the fishery.

Similarly high risk was assigned to impacts from the return of wastewater return plumes, which, depending on release depth, could also reduce the suitability of a seamount for the snapper population. The overall stock might not be greatly affected by mining on a single seamount, but the level of population affinity to a feature was recognised as an important information gap and hence confidence was low. Large amounts of fine returns could also affect the zooplankton and mesopelagic fish and squid, which could reduce prey availability for the fish. The release of heavy metals/toxic elements contained in the rocks at the SMS site was also thought to be possible. If this occurred, it would have a definite effect on the fishery, through food-safety concerns for local landing or export markets. The potential effects of sedimentation from the direct mining operation, as well as wastewater discharge, can only be confirmed when test mining is undertaken, with the sort of equipment that would likely be used in actual mining. It may be possible to mitigate sedimentation effects, but because these impacts can extend beyond the direct area being mined, they are high priority for studies and good data for an EIA.

Hence, compared with tuna fisheries, there are several possible threats to deepwater snapper fish and fisheries that make SMS mining a high risk in certain seamount situations. The latter include seamounts with a summit depth of less than 500 m, and those that are important feeding or spawning sites for snapper populations.

Table 3-5: Expert panel risk assessment scoring. Deepwater snappers. Longline fishery. SMS. Mining phase. Lik = likelihood, Cons = consequence, Conf = confidence

ACTIVITY	Threat	Spatial overlap	Snapper				Community-links			
			Lik	Cons	Risk	Conf	Lik	Cons	Risk	Conf
Ship presence	Population size	Low	1	0	0	2a	1	0	0	2a
	Geographic range		1	0	0	2a	1	0	0	2a
	Genetic structure		1	0	0	2a	1	0	0	2a
	Biological parameters		1	0	0	2a	1	0	0	2a
Surface lights and noise	Population size	Medium	1	0	0	2a	1	0	0	2a
	Geographic range		1	0	0	2a	1	0	0	2a
	Genetic structure		1	0	0	2a	1	0	0	2a
	Biological parameters		1	0	0	2a	1	0	0	2a
Seafloor extraction	Population size	Medium	4	2	8	1c	3	2	6	1c
	Geographic range		4	1	4	1c	3	2	6	1c
	Genetic structure		1	1	1	2a	1	0	0	1c
	Biological parameters		3	2	6	2a	3	2	6	1c
Sediment plume	Population size	Medium-High	6	3	18	1c	4	2	8	1c
	Geographic range		6	3	18	1c	4	2	8	1c
	Genetic structure		2	1	2	1c	1	0	0	1c
	Biological parameters		6	3	18	1c	4	2	8	1c
Deposition of overburden	Population size	Low-Medium	4	2	8	1c	3	2	6	1c
	Geographic range		4	1	4	1c	3	2	6	1c
	Genetic structure		1	0	0	2a	1	0	0	1c
	Biological parameters		1	1	1	2a	3	2	6	1c
Underwater lights and noise	Population size	Medium	1	0	0	2a	3	1	3	1c
	Geographic range		4	1	4	2a	3	1	3	1c
	Genetic structure		1	0	0	2a	1	0	0	1c
	Biological parameters		1	0	0	2a	3	1	3	1c
Wastewater return	Population size	Medium-	6	3	18	1c	4	2	8	1c

ACTIVITY	Threat	Spatial overlap	Snapper				Community-links			
			Lik	Cons	Risk	Conf	Lik	Cons	Risk	Conf
	Geographic range	High	6	3	18	1c	4	2	8	1c
	Genetic structure		2	1	2	1c	1	0	0	1c
	Biological parameters		6	3	18	1c	4	2	8	1c
Toxic chemical release	Population size	Medium	6	3	18	1c	4	2	8	1c
	Geographic range		6	3	18	1c	4	2	8	1c
	Genetic structure		2	1	2	1c	1	0	0	1c
	Biological parameters		6	3	18	1c	4	2	8	1c
	Fishery operation		6	3	18	1c				

3.2.3 CRC mining operations

The majority of the assessment scores for SMS operations were the same for CRC, which is also a seamount-feature mineral. However, there were a number of differences. Rather than present duplicate tables, below we tabulate solely the differences for the assessments of impacts with CRC mining (Table 3-6).

For CRC, there is typically a lower expected spatial overlap of the snapper species distributions, and the CRC habitat. Although snappers are widely distributed on seamount features, it is likely that they are less abundant on the large guyot features where CRC is likely to be targeted (Hein et al. 2009). The distribution modelling work by Gomez et al. (2015) indicated that snapper habitat was most likely to occur between latitudes 15° and 25° S, which is south of the main distribution of CRC as indicated in Figure 2-2, and also south of the larger guyot features in the EEZs of countries like Tuvalu and Kiribati. Hence, the likelihood of some impacts is lower, although the consequences if CRC mining occurs on a feature with snapper species would be the same. During exploration, the sediment plume from small-scale activities on a larger seamount is unlikely to cause a change in geographical distribution. However during mining a larger area of seafloor is impacted (compared to a SMS site), which would have a high likelihood of driving fish away from the seamount. The sediment plume is likely to be larger, but because the guyot is much larger than a ridge seamount peak, it is less clear that a mining operation would force snapper away from the feature entirely, and hence the likelihood of an impact is slightly lower, although the consequences are the same.

Toxic element release from the crushed rock is very site specific, but in general it would be expected that ecotoxic releases from a CRC operation would be more “diluted” over the area of a large guyot, and hence have a lower likelihood of impact, and reduced consequence. The lower densities of heavy metals or contaminants mean that the overall effects of ecotoxicity on the fishery would potentially be lower than at a SMS site.

Table 3-6: Expert risk assessment scoring. Deepwater snapper. CRC. Only activities with differences in risk scores from SMS are given (Tables 3-4 and 3-5). Lik = likelihood, Cons = consequence, Conf = confidence; - indicates a range of scores

ACTIVITY	Threat	Spatial overlap	Snapper				Community-links			
			Lik	Cons	Risk	Conf	Lik	Cons	Risk	Conf
Exploration										
Sediment plume	Population size	Low-medium	2	1	2	2a	2	1	2	1c
	Geographic range		2	1	3	1c	2	1	2	1c
	Genetic structure		1	0	0	2a	1	0	0	1c
	Biological parameters		2	1	2	2a	2	1	2	1c
Mining										
Seafloor extraction	Population size	Medium	5	2	10	1c	3	2	6	1c
	Geographic range		5	3	15	1c	3	2	6	1c
	Genetic structure		1	1	1	2a	1	0	0	1c
	Biological parameters		3	3	9	2a	3	2	6	1c
Sediment plume	Population size	Medium	5	2-3	10-15	1c	4	2	8	1c
	Geographic range		5	2-3	10-15	1c	4	2	8	1c
	Genetic structure		2	1	2	1c	1	0	0	1c
	Biological parameters		5	2-3	10-15	1c	4	2	8	1c
Toxic chemical release	Population size	Low-Medium	3	2	6	1c	4	2	8	1c
	Geographic range		3	2	6	1c	4	2	8	1c
	Genetic structure		2	1	2	1c	1	0	0	1c
	Biological parameters		3	2	6	1c	4	2	8	1c
	Fishery operation		4	2	8	1c				

3.2.4 Manganese nodule operations

Manganese nodule resources on the abyssal plains present a quite different risk profile for deepwater snapper fisheries and associated species. Exploration and mining operations occur away from the shallower slope and seamount areas where the snapper occur, and the seafloor activities are much deeper. During exploration (Table 3-7), the already low risks posed to snappers and the community trophic linkage pathways remain similar. However, the likelihood and consequence of effects on marine mammals are lower, as these animals are more likely to be moving through an area when crossing the abyssal plains, rather than using seamounts for geo-location or feeding. For the snapper, the likelihood of being affected by the sediment plume is also reduced because such indirect effects will be much deeper than the fish and their prey.

Table 3-7: Expert risk assessment scoring sheet. Deepwater snappers. MN. Exploration phase. Lik = likelihood, Cons = consequence, Conf = confidence

ACTIVITY	Threat	Spatial overlap	Snapper				Community-links			
			Lik	Cons	Risk	Conf	Lik	Cons	Risk	Conf
Ship presence	Population size	Low	1	0	0	2a	1	0	0	2a
	Geographic range		1	0	0	2a	1	0	0	2a
	Genetic structure		1	0	0	2a	1	0	0	2a
	Biological parameters		1	0	0	2a	1	0	0	2a
Surface lights and noise	Population size	Low	1	0	0	2a	1	0	0	2a
	Geographic range		1	0	0	2a	1	0	0	2a
	Genetic structure		1	0	0	2a	1	0	0	2a
	Biological parameters		1	0	0	2a	1	0	0	2a
ROV/other imaging surveys	Population size	Low	1	0	0	2a	1	0	0	2a
	Geographic range		1	0	0	2a	1	0	0	2a
	Genetic structure		1	0	0	2a	1	0	0	2a
	Biological parameters		1	0	0	2a	1	0	0	2a
Acoustic swath mapping	Population size	Low	1	0	0	2a	1	0	0	2a
	Geographic range		1	0	0	2a	1	0	0	2a
	Genetic structure		1	0	0	2a	1	0	0	2a
	Biological parameters		1	0	0	2a	1	0	0	2a
Seismic survey	Population size	Low	1	0	0	2a	1	0	0	2a
	Geographic range		1	0	0	2a	1	0	0	2a
	Genetic structure		1	0	0	2a	1	0	0	2a
	Biological parameters		1	0	0	2a	1	0	0	2a
Spot sampling	Population size	Low	1	0	0	2a	1	0	0	2a
	Geographic range		1	0	0	2a	1	0	0	2a
	Genetic structure		1	0	0	2a	1	0	0	2a

ACTIVITY	Threat	Spatial overlap	Snapper				Community-links			
			Lik	Cons	Risk	Conf	Lik	Cons	Risk	Conf
	Biological parameters		1	0	0	2a	1	0	0	2a
Drilling	Population size	Low	1	0	0	2a	1	0	0	2a
	Geographic range		1	0	0	2a	1	0	0	2a
	Genetic structure		1	0	0	2a	1	0	0	2a
	Biological parameters		1	0	0	2a	1	0	0	2a
Bulk sampling	Population size	Low	1	0	0	2a	1	0	0	2a
	Geographic range		1	0	0	2a	1	0	0	2a
	Genetic structure		1	0	0	2a	1	0	0	2a
	Biological parameters		1	0	0	2a	1	0	0	2a
Sediment plume	Population size	Low	1	0	0	2a	1	0	0	2a
	Geographic range		1	0	0	2a	1	0	0	2a
	Genetic structure		1	0	0	2a	1	0	0	2a
	Biological parameters		1	0	0	2a	1	0	0	2a
Underwater lights and noise	Population size	Low	1	0	0	2a	1	0	0	2a
	Geographic range		1	0	0	2a	1	0	0	2a
	Genetic structure		1	0	0	2a	1	0	0	2a
	Biological parameters		1	0	0	2a	1	0	0	2a

Risks to the species or the fishery are also much lower during a mining phase for manganese nodules (Table 3-8). Seafloor impacts do not alter snapper habitat at all, and therefore have much lower likelihood and typically negligible to minor consequence effects on populations size, distribution, or behaviour of the fish. Underwater lights and noise sources are also much deeper. Wastewater and ecotoxicity scores were appreciably lower than mining risk for SMS and CRC. It is possible plumes released in the water column could affect nearby seamount features, and similarly toxins could be dispersed into sensitive areas depending on the currents in the specific area of disturbance, but nodule mining will not break up the minerals in the same way, and hence be less toxic.

Table 3-8: Expert risk assessment scoring. Deepwater snappers. MN. Mining phase. Lik = likelihood, Cons = consequence, Conf = confidence

ACTIVITY	Threat	Spatial overlap	Snapper				Community-links			
			Lik	Cons	Risk	Conf	Lik	Cons	Risk	Conf

ACTIVITY	Threat	Spatial overlap	Snapper				Community-links			
			Lik	Cons	Risk	Conf	Lik	Cons	Risk	Conf
Ship presence	Population size	Low	1	0	0	2a	1	0	0	2a
	Geographic range		1	0	0	2a	1	0	0	2a
	Genetic structure		1	0	0	2a	1	0	0	2a
	Biological parameters		1	0	0	2a	1	0	0	2a
Surface lights and noise	Population size	Low	1	0	0	2a	1	0	0	2a
	Geographic range		1	0	0	2a	1	0	0	2a
	Genetic structure		1	0	0	2a	1	0	0	2a
	Biological parameters		1	0	0	2a	1	0	0	2a
Seafloor extraction	Population size	Low	1	0	0	2a	1	0	0	2a
	Geographic range		1	0	0	2a	1	0	0	2a
	Genetic structure		1	0	0	2a	1	0	0	2a
	Biological parameters		1	0	0	2a	1	0	0	2a
Sediment plume	Population size	Low	2	1	2	2a	1	0	0	2a
	Geographic range		3	1	3	2a	1	0	0	2a
	Genetic structure		1	0	0	2a	1	0	0	2a
	Biological parameters		3	1	3	2a	1	0	0	2a
Deposition of overburden	Population size	Low	1	0	0	2a	1	0	0	2a
	Geographic range		1	0	0	2a	1	0	0	2a
	Genetic structure		1	0	0	2a	1	0	0	2a
	Biological parameters		1	0	0	2a	1	0	0	2a
Underwater lights and noise	Population size	Low	1	0	0	2a	1	0	0	2a
	Geographic range		1	0	0	2a	1	0	0	2a
	Genetic structure		1	0	0	2a	1	0	0	2a
	Biological parameters		1	0	0	2a	1	0	0	2a
Wastewater return	Population size	Low	2	1	2	2a	1	0	0	2a
	Geographic range		2	1	2	2a	1	0	0	2a
	Genetic structure		1	0	0	2a	1	0	0	2a

ACTIVITY	Threat	Spatial overlap	Snapper				Community-links			
			Lik	Cons	Risk	Conf	Lik	Cons	Risk	Conf
	Biological parameters		2	1	2	2a	1	0	0	2a
Toxic chemical release	Population size	Low	1	0	0	1c	2	2	4	1c
	Geographic range		1	0	0	1c	1	0	0	1c
	Genetic structure		1	0	0	1c	1	0	0	1c
	Biological parameters		2	2	4	1c	2	2	4	1c
	Fishery operation		2	1	2	1c				

3.3 Coastal fisheries

The expert panel considered the range of species covered by the "coastal fisheries" group, and also noted that it included fishing activities inside the reef/lagoon, as well as beyond it in upper slope waters. The fringing reef structure around many islands could be a partial barrier to the impacts of seabed mining, and hence a division was made in the assessment for "reef-fisheries (inside the lagoon) and outside (coastal species).

The location of any mining activity is critical for assessing whether island-based activities (coastal fisheries and aquaculture) would be affected. The proximity estimates in section 2.3.8 suggest that for many mineral resources, there is potential close to the islands, in the order of just several km. Hence a range is given for many of the scores, which reflect a near-field and far-field contrast, that affects both the likelihood of an impact occurring, as well as its severity (because of dilution or dispersal of the effect by the time a far-field activity reaches the island).

There would be no direct physical sampling or mining for any mineral type in very nearshore coastal waters, but indirect effects (such as noise, sediment, etc.) could impact coastal ecosystems, irrespective of the type of mineral. Hence, just a single assessment was made for all three mineral types.

3.3.1 Exploration activities

Most exploration activities were assessed as low risk to both reef and coastal species and fisheries (Table 3-9). It was felt that if bulk sampling occurred close to the coast, there could be damage to localised patches of important benthic habitat (e.g., rocky reef outcrops) and a sediment plume could affect coastal fish species and have community trophic effects through local mortality or changes in behaviour of zooplankton and small fish caused by sediment in the water column. The plume could also affect reef species if it was close to the lagoon entrance.

3.3.2 Mining activities

The physical presence of a ship and barges was regarded as minor (Table 3-10) (and may even be positive for some fish that could aggregate around the operation).

Seafloor extraction was felt unlikely to affect reef species, as it was assumed mining would not occur directly next to the fringing reef of the islands, but it could potentially damage or destroy nearshore habitats used by coastal species (such as offshore rocky outcrops, upwelling areas). The impacts of this will depend on the extent to which fish species can move away from the area without affecting their population dynamics, or are dependent on the area/habitat for some of their life cycle (e.g., spawning, nursery ground, egg-laying habitat) or associated prey. Hence, both coastal species and community linkage impacts were classed as high and moderate respectively. Physical modification of habitat has been extensively studied in estuarine and inshore waters, and although the most serious impacts are generally to benthic invertebrates (Pagliai et al. 1985), general ecosystem-level degradation can occur (Baird & Burton 2001) and there can be flow-on effects to fish assemblages (e.g., de Zwart et al. 2006). Similar damage to habitat could occur from the deposition of .overburden if it was to bury benthic species that are prey for commercial fish species.

The extraction plume if near-shore could also have a moderate impact on coastal fish and fisheries, although this was scored lower than seafloor extraction because there would be less permanent damage to habitat. With a sediment plume, fish may move away temporarily, but return when conditions revert to being more favourable. Community linkages could also be affected by the plume through changes in distribution or abundance of prey which may be more susceptible to high densities of fine particles in the water column or settling on the seafloor. Reef species could be impacted if the sediment plume enters the lagoon and reduces visibility for feeding (e.g., Utne-Palm 2002), or smothers benthic prey. Impacts would be similar from wastewater returns, with a moderate score for operations close to the shore. However, fish responses to suspended sediment are highly variable (Newcombe & Jensen 1996, Wilber & Clarke 2001) and in many cases site-specific (Bolam et al. 2006), and hence such impacts will need to be tested during a test mining phase.

The effects of sub-sea lights and noise from a mining operation are poorly known, but could cause avoidance behaviour by some fish, affecting their population size (and availability to the fishery) if it disrupts aggregation behaviour or causes them to move away from the area.

Toxic chemical release from crushed rocks/nodules from a near-shore mining operation could have a high likelihood of impact, and the consequences could be major for both coastal and reef fishes, as well as the wide marine community and trophic linkages. The likelihood of this happening is slightly lower for the reef fish, but if contaminants did enter the lagoon the consequences could be greater because retention times of the contaminants within the lagoon could be longer if flushing rates are low.

There is also a potential interaction between fisheries, as any impact on abundance or distribution of small baitfish species could flow through to the pole and line fishery.

Table 3-9: Expert panel risk assessment scoring : Coastal fisheries. All mineral resources. Exploration phase. Lik = likelihood, Cons = consequence, Conf = confidence; - indicates a range of scores for far and near mining activities respectively.

ACTIVITY	Threat	Spatial overlap	Reef species				Coastal species				Community-links			
			Lik	Cons	Risk	Conf	Lik	Cons	Risk	Conf	Lik	Cons	Risk	Conf
Ship presence	Population size	Low	1	0	0	2a	1	0	0	2a	1	0	0	2a
	Geographic range		1	0	0	2a	1	0	0	2a	1	0	0	2a
	Genetic structure		1	0	0	2a	1	0	0	2a	1	0	0	2a
	Biological parameters		1	0	0	2a	1	0	0	2a	1	0	0	2a
Surface lights and noise	Population size	Low	1	0	0	2a	1-3	0	0	1c	1	0	0	2a
	Geographic range		1	0	0	2a	1-3	1	1-3	1c	1	0	0	2a
	Genetic structure		1	0	0	2a	1	0	0	1c	1	0	0	2a
	Biological parameters		1	0	0	2a	1-3	1	1-3	1c	1	0	0	2a
ROV/other imaging surveys	Population size	Low-Medium	1	0	0	2a	1-3	0	0	1c	1	0	0	2a
	Geographic range		1	0	0	2a	1-3	1	1-3	1c	1	0	0	2a
	Genetic structure		1	0	0	2a	1	0	0	1c	1	0	0	2a
	Biological parameters		1	0	0	2a	1-3	1	1-3	1c	1	0	0	2a
Acoustic swath mapping	Population size	Low-Medium	1	0	0	2a	1-3	0-1	0-3	1c	1	0	0	2a
	Geographic range		1	0	0	2a	1-3	0-1	0-3	1c	1	0	0	2a
	Genetic structure		1	0	0	2a	1	0	0	1c	1	0	0	2a

	Biological parameters		1	0	0	2a	1-3	0-1	0-3	1c	1	0	0	2a
Seismic survey	Population size	Low-Medium	1	0	0	2a	1-3	0-2	0-6	1c	1	0	0	1c
	Geographic range		1	0	0	2a	1-3	0-2	0-6	1c	1	0	0	1c
	Genetic structure		1	0	0	2a	1-3	0-2	0-6	1c	1	0	0	1c
	Biological parameters		1	0	0	2a	1-3	0-2	0-6	1c	1	0	0	1c
Spot sampling	Population size	Low	1	0	0	2a	1-2	0-1	0-2	1c	1	0	0	2a
	Geographic range		1	0	0	2a	1-2	0-1	0-2	1c	1	0	0	2a
	Genetic structure		1	0	0	2a	1	0-1	0-1	1c	1	0	0	2a
	Biological parameters		1	0	0	2a	1-2	0-1	0-2	1c	1	0	0	2a
Drilling	Population size	Low	1	0	0	2a	1-3	0-2	0-6	1c	1-3	0-2	0-6	1c
	Geographic range		1	0	0	2a	1-3	0-2	0-6	1c	1-3	0-2	0-6	1c
	Genetic structure		1	0	0	2a	1-3	0-2	0-6	1c	1-3	0-2	0-6	1c
	Biological parameters		1	0	0	2a	1-3	0-2	0-6	1c	1-3	0-2	0-6	1c
Bulk sampling	Population size	Low	1	0	0	2a	1-4	1-3	1-12	1c	1-4	1-3	1-12	1c
	Geographic range		1	0	0	2a	1-4	1-3	1-12	1c	1-4	1-3	1-12	1c
	Genetic structure		1	0	0	2a	1-4	1-3	1-12	1c	1-4	1-3	1-12	1c
	Biological parameters		1	0	0	2a	1-4	1-3	1-12	1c	1-4	1-3	1-12	1c
Sediment plume	Population size	Low	1-3	0-2	0-6	1c	1-3	0-2	0-6	1c	1-3	0-2	0-6	1c
	Geographic range		1-3	0-2	0-6	1c	1-3	0-2	0-6	1c	1-3	0-2	0-6	1c
	Genetic structure		1-3	0-2	0-6	1c	1-3	0-2	0-6	1c	1-3	0-2	0-6	1c
	Biological parameters		1-3	0-2	0-6	1c	1-3	0-2	0-6	1c	1-3	0-2	0-6	1c

Underwater lights and noise	Population size	Low-Medium	1-2	0	0-2	1c	1-3	0-1	0-3	1c	1	0	0	2a
	Geographic range		1-2	0	0-2	1c	1-3	0-1	0-3	1c	1	0	0	2a
	Genetic structure		1-2	0	0-2	1c	1-3	0-1	0-3	1c	1	0	0	2a
	Biological parameters		1-2	0	0-2	1c	1-3	0-1	0-3	1c	1	0	0	2a

Table 3-10: Expert panel risk assessment scoring: Coastal fisheries. All mineral resources. Mining phase. Lik = likelihood, Cons = consequence, Conf = confidence; -indicates a range of scores for far and near mining activities respectively.

ACTIVITY	Threat	Spatial overlap	Reef species				Coastal species				Community-links			
			Lik	Cons	Risk	Conf	Lik	Cons	Risk	Conf	Lik	Cons	Risk	Conf
Ship presence	Population size	Low	1	0	0	2a	1	0	0	2a	1	0	0	2a
	Geographic range		1	0	0	2a	1	0	0	2a	1	0	0	2a
	Genetic structure		1	0	0	2a	1	0	0	2a	1	0	0	2a
	Biological parameters		1	0	0	2a	1	0	0	2a	1	0	0	2a
Surface lights and noise	Population size	Low-Medium	1	0	0	2a	1	0	0	2a	1	0	0	2a
	Geographic range		1	0	0	2a	1	0	0	2a	1	0	0	2a
	Genetic structure		1	0	0	2a	1	0	0	2a	1	0	0	2a
	Biological parameters		1	0	0	2a	1	0	0	2a	1	0	0	2a
Seafloor extraction	Population size	Low-Medium	1	0	0	2a	1-4	2-5	2-20	1c	1-4	1-3	1-12	1c
	Geographic range		1	0	0	2a	1-4	2-5	2-20	1c	1-4	1-3	1-12	1c
	Genetic structure		1	0	0	2a	1-4	2-5	2-20	1c	1-4	1-3	1-12	1c
	Biological parameters		1	0	0	2a	1-4	2-5	2-20	1c	1-4	1-3	1-12	1c
Sediment plume	Population size	Low-medium	1-4	1-3	1-12	1c	1-4	1-3	1-12	1c	1-4	1-3	1-12	1c
	Geographic range		1-4	1-3	1-12	1c	1-4	1-3	1-12	1c	1-4	1-3	1-12	1c
	Genetic structure		1-4	1-3	1-12	1c	1-4	1-3	1-12	1c	1-4	1-3	1-12	1c
	Biological parameters		1-4	1-3	1-12	1c	1-4	1-3	1-12	1c	1-4	1-3	1-12	1c

ACTIVITY	Threat	Spatial overlap	Reef species				Coastal species				Community-links			
			Lik	Cons	Risk	Conf	Lik	Cons	Risk	Conf	Lik	Cons	Risk	Conf
Deposition of overburden	Population size	Low	1-4	0	0	2a	1-4	1-3	1-12	1c	1-4	1-2	1-8	1c
	Geographic range		1-4	0	0	2a	1-4	1-3	1-12	1c	1-4	1-2	1-8	1c
	Genetic structure		1-4	0	0	2a	1-4	1-3	1-12	1c	1-4	1-2	1-8	1c
	Biological parameters		1-4	0	0	2a	1-4	1-3	1-12	1c	1-4	1-2	1-8	1c
Underwater lights and noise	Population size	Low-medium	1-3	1	1-3	1c	1-4	1-2	1-8	1c	1-3	1-2	1-6	1c
	Geographic range		1-3	1	1-3	1c	1-4	1-2	1-8	1c	1-3	1-2	1-6	1c
	Genetic structure		1-3	1	1-3	1c	1-4	1-2	1-8	1c	1-3	1-2	1-6	1c
	Biological parameters		1-3	1	1-3	1c	1-4	1-2	1-8	1c	1-3	1-2	1-6	1c
Wastewater return	Population size	Low-Medium	1-4	1-3	1-12	1c	1-4	1-3	1-12	1c	1-4	1-3	1-12	1c
	Geographic range		1-4	1-3	1-12	1c	1-4	1-3	1-12	1c	1-4	1-3	1-12	1c
	Genetic structure		1-4	1-3	1-12	1c	1-4	1-3	1-12	1c	1-4	1-3	1-12	1c
	Biological parameters		1-4	1-3	1-12	1c	1-4	1-3	1-12	1c	1-4	1-3	1-12	1c
Toxic chemical release	Population size	Low-medium	1-4	3-4	3-16	1c	1-5	3	3-15	1c	1-5	3	3-15	1c
	Geographic range		1-4	3-4	3-16	1c	1-5	3	3-15	1c	1-5	3	3-15	1c
	Genetic structure		1-4	3-4	3-16	1c	1-5	3	3-15	1c	1-5	3	3-15	1c
	Biological parameters		1-4	3-4	3-16	1c	1-5	3	3-15	1c	1-5	3	3-15	1c

3.4 Mariculture

The potential risks to aquaculture operations were assessed in a similar way to those for coastal fisheries, with a range adopted to account for whether minerals exploration was taking place near to, or far from, the islands and their infrastructure. The assessment was subdivided by shellfish, shrimps, fish, and seaweed to reflect the diversity of farming, both for the fauna (with differing sensitivities to impacts) and the techniques used. Changes to geographic range were not assessed, as aquaculture species are confined. The assessment also focused on just the farmed stocks, and has not considered associated issues such as spat collection if it occurs locally.

3.4.1 Exploration activities

Ship presence, surface lights and noise, seafloor imaging work, and swath mapping were scored as having remote likelihood and no consequence (Table 3-11). The lower frequency seismic activities if used could have higher likelihood of an impact on shellfish (through vibrations), shrimps and fish (but not seaweed), even though the consequence of this is thought to be low. Similarly, underwater noise from exploration activities on the seafloor would probably have a limited impact, although it should be noted that the uncertainty is high as little is known about the effects of noise. The physical effects of seafloor sampling, test drilling, and bulk sampling would have negligible impacts.

The sediment plume generated during exploration was the only cause of concern. Because mariculture operations are confined and localised, even a small disturbance could have an impact. The likelihood was thought possible, and the consequence could be moderate if a plume (even a small one) happened to move over the area of culture. This could affect all species.

3.4.2 Mining activities

As for exploration, ship presence, surface lights and noise, and seafloor extraction ranked low risk, with low likelihood and negligible consequences of impact (Table 3-12). Underwater noise could also have an impact on animals that might normally move away. This aspect is uncertain, although would not affect genetic structure, but potentially population size or animal condition.

The sediment plume effects, however, from seafloor extraction or the wastewater return, were regarded as definitely possible, and consequences from a near-shore operation could be severe. All species could be affected, although community linkages are less important in an aquaculture situation. A reduction in water quality, visibility, and clogging of feeding mechanisms could impact population size and biological aspects such as growth rates, reproductive output and animal condition.

Potential release of toxic elements from crushed rocks/nodules would also have severe consequences. The scoring for this was the same as the sediment plume. It could take a considerable period of time for the populations to recover, but recovery probably would occur rather than wipe out the stocks. Ecotoxicity would, however, affect the marketability of the product, with significant economic implications.

Table 3-11: Expert risk assessment scoring. Mariculture. All mineral types. Exploration phase. Lik = likelihood, Cons = consequence, Conf = confidence; -indicates a range of scores for far and near mining activities respectively.

ACTIVITY	Threat	Shellfish				Shrimps				Fish				Seaweed				Community-links			
		Lik	Cons	Risk	Conf	Lik	Cons	Risk	Conf	Lik	Cons	Risk	Conf	Lik	Cons	Risk	Conf	Lik	Cons	Risk	Conf
Ship presence	Population size	1	0	0	2a	1	0	0	2a	1	0	0	2a	1	0	0	2a	1	0	0	2a
	Genetic structure	1	0	0	2a	1	0	0	2a	1	0	0	2a	1	0	0	2a	1	0	0	2a
	Biological parameters	1	0	0	2a	1	0	0	2a	1	0	0	2a	1	0	0	2a	1	0	0	2a
Surface lights and noise	Population size	1	0	0	2a	1	0	0	2a	1	0	0	2a	1	0	0	2a	1	0	0	2a
	Genetic structure	1	0	0	2a	1	0	0	2a	1	0	0	2a	1	0	0	2a	1	0	0	2a
	Biological parameters	1	0	0	2a	1	0	0	2a	1	0	0	2a	1	0	0	2a	1	0	0	2a
ROV/other imaging surveys	Population size	1	0	0	2a	1	0	0	2a	1	0	0	2a	1	0	0	2a	1	0	0	2a
	Genetic structure	1	0	0	2a	1	0	0	2a	1	0	0	2a	1	0	0	2a	1	0	0	2a
	Biological parameters	1	0	0	2a	1	0	0	2a	1	0	0	2a	1	0	0	2a	1	0	0	2a
Acoustic swath mapping	Population size	1	0	0	2a	1	0	0	2a	1	0	0	2a	1	0	0	2a	1	0	0	2a
	Genetic structure	1	0	0	2a	1	0	0	2a	1	0	0	2a	1	0	0	2a	1	0	0	2a
	Biological parameters	1	0	0	2a	1	0	0	2a	1	0	0	2a	1	0	0	2a	1	0	0	2a
Seismic survey	Population size	1-4	1	1-4	1c	1-4	1	1-4	1c	1-4	1	1-4	1c	1	0	0	2a	1	0	0	2a
	Genetic structure	1-4	1	1-4	1c	1-4	1	1-4	1c	1-4	1	1-4	1c	1	0	0	2a	1	0	0	2a
	Biological parameters	1-4	1	1-4	1c	1-4	1	1-4	1c	1-4	1	1-4	1c	1	0	0	2a	1	0	0	2a
Spot sampling	Population size	1	0	0	2a	1	0	0	2a	1	0	0	2a	1	0	0	2a	1	0	0	2a

ACTIVITY	Threat	Shellfish				Shrimps				Fish				Seaweed				Community-links			
		Lik	Cons	Risk	Conf	Lik	Cons	Risk	Conf	Lik	Cons	Risk	Conf	Lik	Cons	Risk	Conf	Lik	Cons	Risk	Conf
	Genetic structure	1	0	0	2a	1	0	0	2a	1	0	0	2a	1	0	0	2a	1	0	0	2a
	Biological parameters	1	0	0	2a	1	0	0	2a	1	0	0	2a	1	0	0	2a	1	0	0	2a
Drilling	Population size	1	0	0	2a	1	0	0	2a	1	0	0	2a	1	0	0	2a	1	0	0	2a
	Genetic structure	1	0	0	2a	1	0	0	2a	1	0	0	2a	1	0	0	2a	1	0	0	2a
	Biological parameters	1	0	0	2a	1	0	0	2a	1	0	0	2a	1	0	0	2a	1	0	0	2a
Bulk sampling	Population size	1	0	0	2a	1	0	0	2a	1	0	0	2a	1	0	0	2a	1	0	0	2a
	Genetic structure	1	0	0	2a	1	0	0	2a	1	0	0	2a	1	0	0	2a	1	0	0	2a
	Biological parameters	1	0	0	2a	1	0	0	2a	1	0	0	2a	1	0	0	2a	1	0	0	2a
Sediment plume	Population size	1-4	2	2-8	1c	1-4	2	2-8	1c	1-4	2	2-8	1c	1-4	2	2-8	1c	1-4	2	2-8	1c
	Genetic structure	1-4	2	2-8	1c	1-4	2	2-8	1c	1-4	2	2-8	1c	1-4	2	2-8	1c	1-4	2	2-8	1c
	Biological parameters	1-4	2	2-8	1c	1-4	2	2-8	1c	1-4	2	2-8	1c	1-4	2	2-8	1c	1-4	2	2-8	1c
Underwater lights and noise	Population size	1-4	1	1-4	1c	1-4	1	1-4	1c	1-4	1	1-4	1c	1	0	0	2a	1-4	0	0	1c
	Genetic structure	1-4	1	1-4	1c	1-4	1	1-4	1c	1-4	1	1-4	1c	1	0	0	2a	1-4	0	0	1c
	Biological parameters	1-4	1	1-4	1c	1-4	1	1-4	1c	1-4	1	1-4	1c	1	0	0	2a	1-4	0	0	1c

Table 3-12: Expert risk assessment panel scoring. Mariculture. All mineral types. Mining phase. Lik = likelihood, Cons = consequence, Conf = confidence; -indicates a range of scores for far and near mining activities respectively.

ACTIVITY	Threat	Shellfish				Shrimps				Fish				Seaweed				Community-links			
		Lik	Cons	Risk	Conf	Lik	Cons	Risk	Conf	Lik	Cons	Risk	Conf	Lik	Cons	Risk	Conf	Lik	Cons	Risk	Conf
Ship presence	Population size	1	0	0	2a	1	0	0	2a	1	0	0	2a	1	0	0	2a	1	0	0	2a
	Genetic structure	1	0	0	2a	1	0	0	2a	1	0	0	2a	1	0	0	2a	1	0	0	2a
	Biological parameters	1	0	0	2a	1	0	0	2a	1	0	0	2a	1	0	0	2a	1	0	0	2a
Surface lights and noise	Population size	1	0	0	2a	1	0	0	2a	1	0	0	2a	1	0	0	2a	1	0	0	2a
	Genetic structure	1	0	0	2a	1	0	0	2a	1	0	0	2a	1	0	0	2a	1	0	0	2a
	Biological parameters	1	0	0	2a	1	0	0	2a	1	0	0	2a	1	0	0	2a	1	0	0	2a
Seafloor extraction	Population size	1	0	0	2a	1	0	0	2a	1	0	0	2a	1	0	0	2a	1	0	0	2a
	Genetic structure	1	0	0	2a	1	0	0	2a	1	0	0	2a	1	0	0	2a	1	0	0	2a
	Biological parameters	1	0	0	2a	1	0	0	2a	1	0	0	2a	1	0	0	2a	1	0	0	2a
Sediment plume	Population size	1-4	4	4-16	1c	1-4	4	4-16	1c	1-4	4	4-16	1c	1-4	4	4-16	1c	1-4	3	3-12	1c
	Genetic structure	1-4	4	4-16	1c	1-4	4	4-16	1c	1-4	4	4-16	1c	1-4	4	4-16	1c	1-4	3	3-12	1c
	Biological parameters	1-4	4	4-16	1c	1-4	4	4-16	1c	1-4	4	4-16	1c	1-4	4	4-16	1c	1-4	3	3-12	1c
Deposition of overburden	Population size	1	0	0	2a	1	0	0	2a	1	0	0	2a	1	0	0	2a	1	0	0	2a
	Genetic structure	1	0	0	2a	1	0	0	2a	1	0	0	2a	1	0	0	2a	1	0	0	2a
	Biological parameters	1	0	0	2a	1	0	0	2a	1	0	0	2a	1	0	0	2a	1	0	0	2a
Underwater lights and noise	Population size	1-5	2	2-10	1c	1-5	2	2-10	1c	1-5	2	2-10	1c	1-5	0	0	2a	1-4	2	2-8	1c
	Genetic structure	1-5	0	0	1c	1-5	0	0	1c	1-5	0	0	1c	1-5	0	0	2a	1-4	2	2-8	1c

ACTIVITY	Threat	Shellfish				Shrimps				Fish				Seaweed				Community-links			
		Lik	Cons	Risk	Conf	Lik	Cons	Risk	Conf	Lik	Cons	Risk	Conf	Lik	Cons	Risk	Conf	Lik	Cons	Risk	Conf
	Biological parameters	1-5	2	2-10	1c	1-5	2	2-10	1c	1-5	2	2-10	1c	1-5	0	0	2a	1-4	2	2-8	1c
Wastewater return	Population size	1-5	4	4-20	1c	1-5	4	4-20	1c	1-5	4	4-20	1c	1-5	4	4-20	1c	1-5	4	4-20	1c
	Genetic structure	1-5	4	4-20	1c	1-5	4	4-20	1c	1-5	4	4-20	1c	1-5	4	4-20	1c	1-5	4	4-20	1c
	Biological parameters	1-5	4	4-20	1c	1-5	4	4-20	1c	1-5	4	4-20	1c	1-5	4	4-20	1c	1-5	4	4-20	1c
Toxic chemical release	Population size	1-5	4	4-20	1c	1-5	4	4-20	1c	1-5	4	4-20	1c	1-5	4	4-20	1c	1-5	4	4-20	1c
	Genetic structure	1-5	4	4-20	1c	1-5	4	4-20	1c	1-5	4	4-20	1c	1-5	4	4-20	1c	1-5	4	4-20	1c
	Biological parameters	1-5	4	4-20	1c	1-5	4	4-20	1c	1-5	4	4-20	1c	1-5	4	4-20	1c	1-5	4	4-20	1c

4 Discussion

The risk assessment has deliberately been carried out at a high level. It has been designed to identify and assess general risks to fisheries from deep-sea mining at a regional scale. Individual countries, and particular sites, are not assessed. This detail was beyond the scope of the work, but is clearly a critical future consideration. The EEZs of each country differ in their environmental and oceanographic characteristics, their mineral resources, and their fisheries. More detailed site-specific assessments will be needed in future. The assessment tables are also based on there being an interaction between a resource and a fishery. Hence, they do not try and integrate over areas where there is low likelihood of any fishery or mining interaction (by definition a very low risk) or the converse where there is a proven resource, and established fisheries.

The distribution of minerals is very wide. The polygons provided by SPC and used to guide the overlap of minerals and fisheries do not have mineral density information, nor do they take into account bathymetry constraints (e.g., where a MN polygon is drawn covering shallow waters as well). This is not a problem at the high and initial level that this risk assessment is intended for, but if individual countries undertake similar assessments more tailored for their situation, then the likely sites of mining need to be identified as clearly as possible to provide an idea of the likely spatial separation of fisheries and a mining operation.

This is particularly apparent in the assessments we present for coastal fisheries and mariculture. While it may not appear very useful to present a wide range of risks, it represents the actual situation that needs to be evaluated for a mining application. Indirect effects, such as dispersal of a sediment plume, can extend appreciable distances. A plume created from a single ploughing disturbance on the abyssal plains off Peru was visible for up to 6 hours on camera footage (Thiel et al. 2001), and modelling of sediment plume drift in abyssal plain depths indicated dispersal of up to 100 km, given the current flows in the area (Rolinski et al. 2001). Modelling studies were conducted for an SMS site off Papua New Guinea indicating that deposition of overburden would result in a layer of sediment up to 500 mm thick at the deposition site with a gradually declining extent of influence up to 1 km away (Coffey 2008). Sedimentation from the wastewater plume will likely be evident up to 10 km away, however deposition is expected to be less than background natural sedimentation rates (Coffey 2008). Current flows at depth are highly variable in the region (see Figure 2-7), and each country will experience a different flow regime driven by the larger-scale oceanographic currents, as well as local topography. Hence it has not been possible to make an assessment based on “average” dispersal, or distance offshore of a particular mineral resource.

We have assessed mining effects under the assumption of a single operation. If there were more mining events, the size and nature of the mining venture changed, or there were other cumulative effects occurring (e.g., changing ocean currents, climate change, new deep-sea fisheries) then scores would change. The definitions used from the MIDAS-GOBI study were in the context of SMS mining in the North Atlantic, CRC in the northern Pacific, and MN in the central-eastern Pacific. These are plausible scenarios for mining in other regions as well, but we note these conditions may alter if more western South Pacific operations are proposed, and as mining technology develops specific to the conditions in the region.

Many of the moderate to high risks are driven by the likelihood of an effect occurring, rather than high levels of consequence. This is an important consideration for how the risks are managed. The same risk score can be derived from a low likelihood-high consequence, high likelihood-low consequence, or equal combinations (see Table 2-6). However, mitigation measures, and management options to cope with certain situations will vary depending on the source of the risk. Arguably, the activities that have high consequence are likely to be of greater concern to stakeholders and managers, and are the effects that may prioritise mitigation measures.

Existing management measures, or regulations, have not been considered, given the wide regional approach. Distance offshore has been included as a near-far range in our consideration of risks to coastal fisheries and aquaculture, but more detailed assessments are possible where there is a regulation or management recommendation that any minerals exploration has to be a certain distance from any island (e.g., 50 n.mi in the Cook Islands EEZ was imposed by the Seabed Minerals Authority in its DSM tender round, and is a regulation in the draft Marae Moana Bill).

There are also interactions between some fisheries. Pole and line fishing, for example, utilises live bait. A source of this for many of the fishers, is around the islands, where the vessels will catch small baitfish and keep them in tanks on board. Hence a reduction in coastal baitfish species abundance will flow through to the pole and line tuna fishery a long distance away from the actual islands.

The original Request for Proposals included Social, Cultural and Economic elements as well as the ecological and environmental ones we have focussed on here. The inclusion of marine mammals as a component in the Appendix was the only non-fishery aspect we addressed, because of the social and cultural significance of these megafauna. They were also a component of the ecosystem that would not be partially or completely covered by other parts of the risk assessment for the fish or fisheries. For example, the sensitivity of whales to sound appears far greater than for fish, and this would not appear as a risk factor otherwise. In contrast, other social and cultural elements, such as taonga species or aspects of food security for local populations, are included in the risk to coastal fisheries. The other forms of assessment are equally important to the ecological one presented here, and need to be included in a more detailed impact assessment required if any exploitation licence was considered.

Risk assessment is a dynamic and sequential process. There is not just a single ERA done for a commercial project. This is a "Level 1" qualitative assessment, and one of its major roles is to screen potential risks and identify those that are unlikely to pose any significant risk (meaning those activities/threats need not necessarily be considered further) and those which should be the focus of more detailed risk assessment subsequently (as part of a new "Level 2" assessment). Typically a level 1 ERA should be done at the beginning of any exploration phase, and that will guide data collection to inform a level 2 assessment (as more specific information becomes available on the site and potential mining operation characteristics) prior to any exploitation application (Swaddling et al. 2016).

The preceding discussion highlights that this is a very preliminary assessment. There are many qualifications and caveats, but nevertheless we are confident that the main sources of risk have been identified, and the likely impacts on fisheries have been ranked in a reasonable manner that can help guide more detailed assessments to focus on the main risks, and develop mitigation measures to minimise levels of residual risk. Such measures can involve a range of operational modifications to gear, as well as temporal or spatial management (see Clark & Smith 2013 and other chapters in SPC 2013a, b, c). With respect to the risks assessed in this report, many could be reduced by spatial separation of areas of fishing and mining (especially SMS and CRC), ensuring mining is excluded from nearshore areas (for coastal fisheries and mariculture), and perhaps temporal closures in areas where fish may be spawning or marine mammals migrate at certain times of year.

4.1 Key fisheries-related issues to be addressed in EIAs

A robust EIA will incorporate the findings of an earlier ERA which can enable scientific studies during exploration to target aspects of high risk or scientific uncertainty (e.g., Swaddling 2016, Ellis et al. in press) and develop strong baseline studies for subsequent monitoring programmes Swaddling et al. 2016). However, below are outlined some of the key aspects of an EIA that should be considered in proposals to conduct exploration for DSM.

The distribution of commercial fish and fisheries, and their association with seamounts, was an important consideration in the ERA when addressing the likelihood of a seabed activity having an impact on the fishery. A number of tuna and deepwater snapper species can have an association with seamount-type features. The nature and extent of any "seamount affinity" needs to be considered. Aspects include the residence time of fish on a seamount, as well as the functional role it plays such as whether a feeding ground, or spawning site. If the fish can move away to another site, then it is unlikely that an impact from mining will affect larger-scale stock dynamics, but if there is a strong affinity for an important biological function, then impacts could be serious. This applies not just to the commercial species, but also the associated bycatch species, for which there is limited information.

In many cases, it is likely that deep-sea mining will occur at greater depths than the fishery. However, the indirect effects through dispersal of sediment plumes and wastewater returns can occur over a larger, and potentially shallower, area than the direct physical footprint of mining. Oceanographic factors (such as current flow rates and direction) need to be considered to evaluate the likely extent of any effect from mining sites that may at first glance seem far away or too deep to affect fisheries.

Cumulative impacts need to be assessed. Many of the commercial and artisanal fish species may be at or near their sustainable levels. Additional impacts from mining will add to existing stressors, and even small effects may be important. Although climate change effects are longer-term than fishing or mining impacts, these also need to be considered, as they could influence future habitat suitability and fisheries success.

Mitigation measures need to be clearly evaluated in the context of a risk assessment. These should include consideration of distance of operations from any island, the discharge depth of wastewater return, the possibility of hooded extraction machines to reduce seafloor sediment, and techniques to reduce light or noise impacts.

4.2 Key knowledge and data gaps identified

The assessment has highlighted sediment plumes and ecotoxicity as consistently important sources of uncertainty and threat to fish and fisheries. There could be a long list of gaps and future research priorities, but below are highlighted several that are critical to improving future risk assessment and environmental impact assessments.

Sediment plumes are well recognised as being a critical element of DSM EIAs (Clark et al 2014b, Swaddling et al. 2016). Plume modelling is often carried out, but this requires detailed oceanographic data on an appropriate scale, as well as an understanding of the biological resilience. The latter aspect is particularly important, because faunal responses can be variable. Deep-sea sedimentation studies often focus on benthic invertebrates (e.g., Larsson & Purser 2011, Tjensvoll et al. 2013), but fisheries data are sparse. Newcombe & Jensen (1996) undertook a meta-analysis of 80 reports on fish responses to suspended sediment in streams and estuaries, and related impacts to the concentration of suspended sediment, and its duration. Some species were highly sensitive, but there are no known studies on Pacific commercial species.

Many of the elements contained in mineral deposits may be ecotoxic (As, Pb, Cd) and so an important issue for mining of such deposits is whether as they are crushed/ground, they could release quantities of heavy metals or toxic elements. Recent research in New Zealand shows enrichment of a number of trace elements composition of CRC and MN compared to standard deep-sea rocks or sediments (e.g., U, Mo, Sb, As, Sr, Cd). Elutriate testing of sediments from phosphorite nodule areas showed relatively high concentrations for dissolved copper and total ammoniacal-N, which would require dilutions of 22x and 1.5x to meet the Australasian contaminant guidelines. However, most contaminant standards use shallow water species to assess sensitivity. There is an urgent need to consider both deep-sea species, and fish more in evaluating toxic element and contaminant effects. Hence, this is another priority area for developing a greater understanding of potential impacts.

There is also limited understanding of the life history of many of the fish species targeted in fisheries. There are often good data on the distribution and abundance of adults of the species, but the depth range and distribution of juveniles is less well known. The sensitivity of juveniles may differ from that of adults, and so efforts are needed to improve understanding of how DSM activities may affect early life history stages, and ultimately recruitment into the adult fishery. This involves an understanding of predator-prey and habitat requirements at different times through the life history of the main commercial species, as well as major bycatch species.

The effects of noise/vibrations are poorly understood for most fish species. In this risk assessment, they were important factors for marine mammals, where avoidance behaviour is documented. There are also guidelines for assessing effects of sound on marine mammals (NMFS 2016). However, clear data on thresholds of noise that cause physiological impacts (such as hearing damage, barotrauma, stress) on fishes are less developed (Popper & Hastings 2009, Hawkins et al. 2014). Natural sources of noise in the marine environment are important for sensing the environment, and for communication. Behavioural responses include fish avoiding large approaching vessels, with potentially reduced catch rates of commercial species in areas of seismic surveys; disruption of spawning sites in shallow coastal waters; and altered predator-prey detection responses (see review by Stanley & Jeffs 2016).

Community linkages are also a major gap in the knowledge of deep-sea mining impacts. Even where the fisheries might be shallower than mining, many fish species rely upon zooplankton which vertically migrate to greater depths during the day. Impacts from mining seamounts could be important for affecting community structure, and wider ecosystem dynamics. Hence, more information is needed for mining impacts on non-commercial species that ultimately will affect ecosystem services that support the commercial fisheries.

4.3 Recommendations for further studies and research

Given the limited understanding of deep-sea ecosystem structure and function in the western-central Pacific Ocean, there is a challenging amount of research required to underpin the development of a DSM industry. Much can be learnt from studies being undertaken in the Clarion-Clipperton Zone, off New Zealand, and in the north Atlantic Ocean. It can also be coupled with a cautious precautionary approach to mining development, and robust monitoring and adaptive management programmes. Nevertheless, extensive site-specific studies will be needed, tailored to the particular resource, location, and mining technology. On a more general level, this ERA has highlighted that amongst the key studies that will be required is a better understanding of the fisheries habitat, and the indirect impacts of sedimentation and ecotoxicity on the ecosystem.

Improved knowledge of seamount affinities of commercial species is needed. Especially notable here is that the risk profile for deepwater snappers was affected by our assumption that there could be resident populations on seamounts (as well as migratory fish). This makes the species potentially vulnerable to localised mining disturbance, and would be a priority for any EIA for SMS or CRC within the distributional range of the snapper species complex. Evaluation of the importance of seamount habitat for other life history stages of the main commercial species, and associated bycatch species, is also a high priority for further research.

Sedimentation research is needed to improve understanding of the thresholds at which fish might be affected by plumes. Wilber & Clarke (2001) summarise three key aspects that underpin required knowledge of sedimentation effects: the suspended sediment characteristics typical of both ambient and mining-induced conditions, the biological responses of aquatic organisms to these suspended sediment dosages, and the likelihood that organisms of interest will encounter suspended sediment plumes. If mining is likely to occur close to any island, then coastal species should be studied and assessed using, as a starting point, the empirical equations developed by Newcombe & Jensen (1996).

Research on the effects of environmental contaminants on deep-sea fish is difficult, as laboratory tests cannot generally be done. It is often assumed that fish will move away from lethal doses of heavy metals or toxic elements, but often toxicant exposure is sub-lethal, affecting fish behaviour such as predator avoidance, reproductive and social interactions (Scott & Sloman 2004) and condition (de Zwart et al. 2006). Monitoring contaminant levels, such as suggested by Swaddling et al (2016) can be combined with fish observations over time (such as through moored cameras/acoustics) that may give insight into effects of mining activities on more localised fish distributions (such as deepwater snappers, coastal species).

More specific recommendations for future studies will be required as information becomes available on likely habitats and mineral types to be explored. As there is currently no deep-sea mining, there is time to develop the necessary scientific and management approaches to support a robust evaluation of the risks from seabed mining on Pacific fisheries.

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Appendix 1

Risk assessment information for marine mammals

Marine mammal distribution

Marine mammals are an important component of western South Pacific marine ecosystems, and of high cultural value. Various species have a widespread distribution throughout the region, and hence data were compiled on known locations to evaluate the overlap with mineral resources and commercial fisheries. An extract was made from OBIS-SEAMAP (Halpin et al. 2009) and species distributions plotted relative to the mineral types (Figure 2-6).

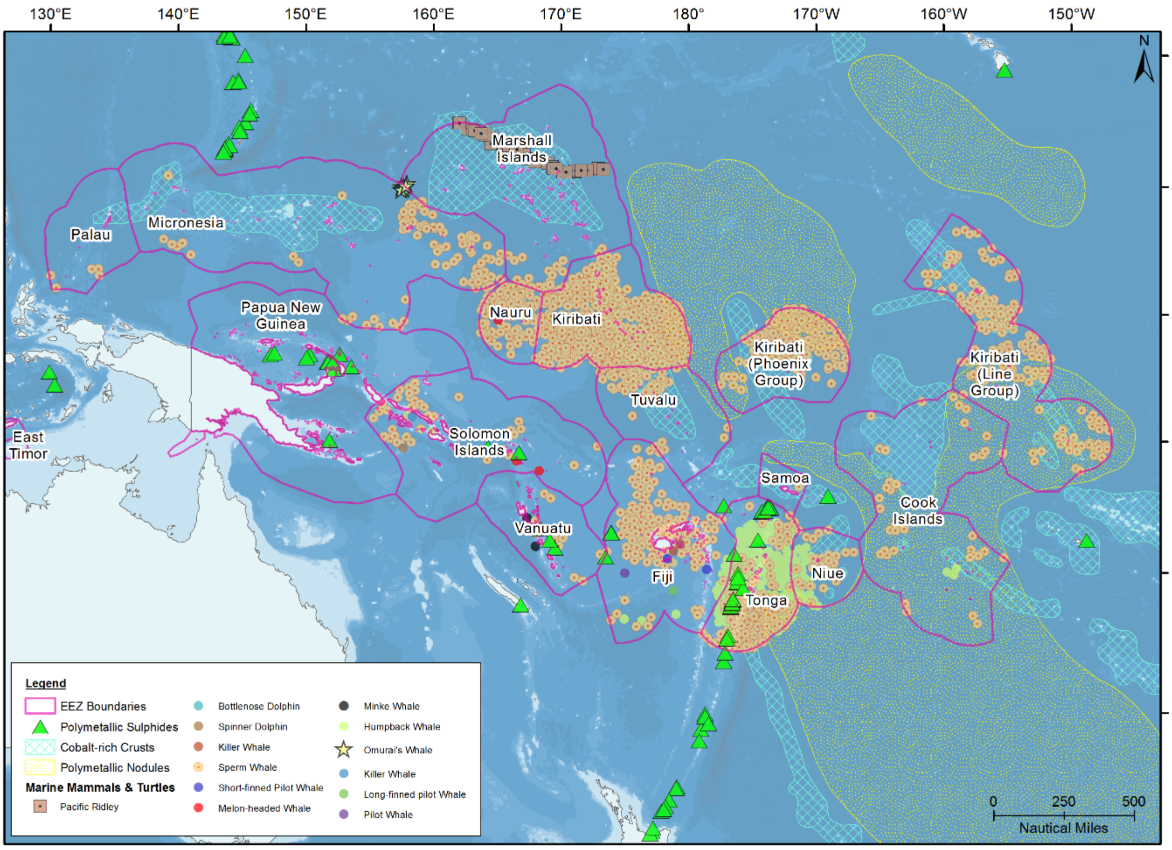

Figure A-1: Distribution of reports of marine mammals relative to deep-sea minerals within the western South Pacific Ocean (source OBIS-SEAMAP).

The number of species records was summarised further by EEZ and mineral type distribution. Table A-1 shows the number of records within the EEZ, and if they are in the CRC only, MN only, or the area of overlap. There were no sightings close to the known vent sites but this may be a problem of biased distribution of sampling effort rather than a reflection of actual cetacean distribution.

Table A-1: The number of marine mammal and turtle records by EEZ and by mineral type (CRC and MN).

Common Name	Scientific Name	Cook Islands	Fiji	Kiribati	Line Group	Marshall Islands	Micronesia	Nauru	Niue	Palau	Phoenix Group	Samoa	Solomon Islands	Tonga	Tuvalu	Vanuatu	Grand Total
Crust Total		3		128	44	34	1		12		28	1		3	28		**282**
Humpback Whale	*Megaptera novaeangliae*								1								**1**
Pacific ridley	*Lepidochelys olivacea*					31											**31**
Sperm Whale	*Physeter macrocephalus*	3		128	44	3	1		11		28	1		3	28		**250**
Nodule Total		36		44	54				5		81			63			**283**
Humpback Whale	*Megaptera novaeangliae*	3							4					37			**44**
pilot whales	*Globicephala*			1													**1**
Sperm Whale	*Physeter macrocephalus*	33		43	54				1		81			26			**238**
Nodule_Crust Total					10												**10**
Sperm Whale	*Physeter macrocephalus*				10												**10**
No Impact Total		2	185	304	59	30	80	95	36	5	43		47	311	28	14	**1239**
Bottlenose Dolphin	*Tursiops truncatus*															1	**1**

Common Name	Scientific Name	Cook Islands	Fiji	Kiribati	Line Group	Marshall Islands	Micronesia	Nauru	Niue	Palau	Phoenix Group	Samoa	Solomon Islands	Tonga	Tuvalu	Vanuatu	Grand Total
Humpback Whale	*Megaptera novaeangliae*		18						22				2	200			**242**
killer whale	*Orcinus orca*		2										2				**4**
long-finned pilot whale	*Globicephala melas*		1														**1**
Melon-headed Whale	*Peponocephala electra*							1					2				**3**
Minke Whale	*Balaenoptera acutorostrata*															2	**2**
Omurai's Whale	*Balaenoptera omurai*					0	0										**0**
Pacific ridley	*Lepidochelys olivacea*					7											**7**
pilot whales	*Globicephala*		1														**1**
Short-finned Pilot Whale	*Globicephala macrorhynchus*		21														**21**
Sperm Whale	*Physeter macrocephalus*	2	142	304	59	23	80	94	14	5	43		40	111	28	11	**956**
Spinner Dolphin	*Stenella longirostris*												1				**1**
Grand Total		**41**	**185**	**476**	**167**	**64**	**81**	**95**	**53**	**5**	**152**	**1**	**47**	**377**	**56**	**14**	**1814**

Risk assessment for marine mammals

For each of the fisheries, and resource environments, the risk to marine mammals was also assessed as the panel considered each fishery. These results are given in Tables A-2 to A-7 for tuna fisheries (exploration and mining), deepwater snapper fisheries (exploration and mining, and coastal fisheries (exploration and mining). It is difficult to generalise the risk to marine mammals, as-specific location and characteristics of a mining site need to be considered. Nevertheless, their sensitivity to noise, and use of seamounts as potential navigation and feeding areas means their behaviour can be affected by exploration and mining operations.
The assessment focuses on whales and dolphins. Although some consideration was also given to turtles, these should be evaluated separately given their different ecological characteristics, and their inshore/beach habitat use.

Tuna longline fishery risk assessment

For both SMS and CRC mining operations, marine mammals could be affected by elements of seismic survey work (e.g., if sub-bottom profiling was carried out, or there was the use of airguns or boomers), as well as test drilling, bulk sampling, and the noise created by seafloor activities. However, although confident an impact was likely (5 being may occur), the consequences were generally minor. This would involve potential avoidance of the seamount area rather than any direct effect on the survival of the mammals or their population status.

The greater depth of MN operations, and their more offshore location over abyssal plains, means that this resource would have less effect than SMS or CRC.

Deepwater snapper fishery risk assessment

For SMS and CRC sites that are relevant to deepwater snapper, marine mammals in these habitats could be affected. As for the tuna assessment, it is the role of seamounts in marine mammal ecology that makes the likelihood of noise, vibrations and general disturbance by drilling, bulk sampling, or seafloor vehicles possible to occasional, even though the consequences are minor to moderate.

Coastal fisheries risk assessment

Whereas exploration activities generally imposed a minor risk to fisheries, there is again potential disturbance to marine mammals, with seismic, drilling, bulk sampling and underwater noise affecting their behaviour, with possible avoidance of the area.

Mining could have more significant impacts, especially surface lights and noise that could have an effect on the behaviour, and potential population size, of turtles that use local beaches, through a reduction in reproductive success or survival if nearby lights and noise disturb them or their predators. Marine mammal sensitivity to noise means their distribution could be affected, but it would have no effect on population size.

Table A-2: Expert Panel Assessment scores Marine Mammal risk assessment for tuna fisheries (longline, purse seine, pole fisheries). CRC and SMS. Exploration activities. Lik = likelihood, Cons = consequence, Conf = confidence.

ACTIVITY	Threat	SMS				CRC			
		Lik	Cons	Risk	Conf	Lik	Cons	Risk	Conf
Ship presence	Population size	1	0	0	1c	1	0	0	1c
	Geographic range	2	0	0	1c	2	0	0	1c
	Genetic structure	1	0	0	1c	1	0	0	1c
	Biological parameters	1	0	0	1c	1	0	0	1c
Surface lights and noise	Population size	1	0	0	2a	1	0	0	2a
	Geographic range	1	0	0	2a	1	0	0	2a
	Genetic structure	1	0	0	2a	1	0	0	2a
	Biological parameters	1	0	0	2a	1	0	0	2a
ROV/other imaging surveys	Population size	1	0	0	2a	1	0	0	2a
	Geographic range	1	0	0	2a	1	0	0	2a
	Genetic structure	1	0	0	2a	1	0	0	2a
	Biological parameters	1	0	0	2a	1	0	0	2a
Acoustic swath mapping	Population size	1	0	0	2a	1	0	0	2a
	Geographic range	1	0	0	2a	1	0	0	2a
	Genetic structure	1	0	0	2a	1	0	0	2a
	Biological parameters	1	0	0	2a	1	0	0	2a

ACTIVITY	Threat	SMS				CRC			
		Lik	Cons	Risk	Conf	Lik	Cons	Risk	Conf
Seismic survey	Population size	1	0	0	1c	1	0	0	1c
	Geographic range	5	1	5	2c	5	1	5	2c
	Genetic structure	1	0	0	1c	1	0	0	1c
	Biological parameters	5	1	5	2c	5	1	5	2c
Spot sampling	Population size	1	0	0	2a	1	0	0	2a
	Geographic range	1	0	0	2a	1	0	0	2a
	Genetic structure	1	0	0	2a	1	0	0	2a
	Biological parameters	1	0	0	2a	1	0	0	2a
Test drilling	Population size	1	0	0	1c	1	0	0	1c
	Geographic range	5	1	5	2c	5	1	5	2c
	Genetic structure	1	0	0	1c	1	0	0	1c
	Biological parameters	5	1	5	2c	5	1	5	2c
Bulk sampling	Population size	1	0	0	1c	1	0	0	1c
	Geographic range	5	1	5	2c	5	1	5	2c
	Genetic structure	1	0	0	1c	1	0	0	1c
	Biological parameters	5	1	5	2c	5	1	5	2c
Sediment plume	Population size	1	1	1	1c	1	1	1	1c
	Geographic range	2	1	2	1c	2	1	2	1c

ACTIVITY	Threat	SMS				CRC			
		Lik	Cons	Risk	Conf	Lik	Cons	Risk	Conf
	Genetic structure	1	0	0	1c	1	0	0	1c
	Biological parameters	2	1	2	1c	2	1	2	1c
Underwater lights & noise	Population size	1	1	1	1c	1	1	1	1c
	Geographic range	4	2	8	2c	4	2	8	2c
	Genetic structure	1	0	0	1c	1	0	0	1c
	Biological parameters	2	2	4	2a	2	2	4	2a

Table A-3: Expert panel assessment. Marine mammal risk assessment for tuna (longline fishery, purse seine, pole) fisheries habitat. SMS, CRC and MN. Mining phase. Lik = likelihood, Cons = consequence, Conf = confidence.

ACTIVITY	Threat	SMS				CRC				MN			
		Lik	Cons	Risk	Conf	Lik	Cons	Risk	Conf	Lik	Cons	Risk	Conf
Ship presence	Population size	1	0	0	1c	1	0	0	1c	1	0	0	1c
	Geographic range	2	0	0	1c	2	0	0	1c	2	0	0	1c
	Genetic structure	1	0	0	1c	1	0	0	1c	1	0	0	1c
	Biological parameters	1	0	0	1c	1	0	0	1c	1	0	0	1c
Surface lights and noise	Population size	1	0	0	1c	1	0	0	1c	1	0	0	1c
	Geographic range	2	0	0	1c	2	0	0	1c	2	0	0	1c
	Genetic structure	1	0	0	1c	1	0	0	1c	1	0	0	1c
	Biological parameters	1	0	0	1c	1	0	0	1c	1	0	0	1c
Seafloor extraction	Population size	1	0	0	1c	1	0	0	1c	1	0	0	1c

ACTIVITY	Threat	SMS				CRC				MN			
		Lik	Cons	Risk	Conf	Lik	Cons	Risk	Conf	Lik	Cons	Risk	Conf
	Geographic range	2	0	0	1c	2	0	0	1c	2	0	0	1c
	Genetic structure	1	0	0	1c	1	0	0	1c	1	0	0	1c
	Biological parameters	1	0	0	1c	1	0	0	1c	1	0	0	1c
Sediment plume	Population size	1	1	1	1c	1	1	1	1c	1	1	1	1c
	Geographic range	4	2	8	1c	4	2	8	1c	4	2	8	1c
	Genetic structure	1	0	0	1c	1	0	0	1c	1	0	0	1c
	Biological parameters	2	1	2	1c	2	1	2	1c	2	1	2	1c
Deposition of overburden	Population size	1	0	0	1c	1	0	0	1c	1	1	1	1c
	Geographic range	2	0	0	1c	2	0	0	1c	4	2	8	1c
	Genetic structure	1	0	0	1c	1	0	0	1c	1	0	0	1c
	Biological parameters	1	0	0	1c	1	0	0	1c	2	1	2	1c
Underwater lights and noise	Population size	1	1	1	1c	1	1	1	1c	1	1	1	1c
	Geographic range	6	3	18	2c	6	3	18	2c	1	1	1	1c
	Genetic structure	1	0	0	1c	1	0	0	1c	1	1	1	1c
	Biological parameters	3	2	6	2a	3	2	6	2a	1	1	1	1c
Wastewater return	Population size	1	1	1	1c	1	1	1	1c	1	1	1	1c
	Geographic range	4	2	8	1c	4	2	8	1c	1	1	1	1c
	Genetic structure	1	0	0	1c	1	0	0	1c	1	1	1	1c

ACTIVITY	Threat	SMS				CRC				MN			
		Lik	Cons	Risk	Conf	Lik	Cons	Risk	Conf	Lik	Cons	Risk	Conf
	Biological parameters	2	1	2	1c	2	1	2	1c	1	1	1	1c
Toxic chemical release	Population size	1	0	0	1c	1	0	0	1c	1	0	0	1c
	Geographic range	1	0	0	1c	1	0	0	1c	1	0	0	1c
	Genetic structure	1	0	0	1c	1	0	0	1c	1	0	0	1c
	Biological parameters	1	1	1	1c	1	1	1	1c	1	1	1	1c

Table A-4: Expert panel risk assessment scoring for marine mammals. Deepwater snapper habitat and fishery. Exploration phase. Lik = likelihood, Cons = consequence, Conf = confidence.

ACTIVITY	Threat	SMS				CRC				MN			
		Lik	Cons	Risk	Conf	Lik	Cons	Risk	Conf	Lik	Cons	Risk	Conf
Ship presence	Population size	1	0	0	1c	1	0	0	1c	1	0	0	1c
	Geographic range	1	0	0	1c	1	0	0	1c	1	0	0	1c
	Genetic structure	1	0	0	1c	1	0	0	1c	1	0	0	1c
	Biological parameters	1	0	0	1c	1	0	0	1c	1	0	0	1c
Surface lights and noise	Population size	1	0	0	1c	1	0	0	1c	1	0	0	2a
	Geographic range	1	0	0	1c	1	0	0	1c	1	0	0	2a
	Genetic structure	1	0	0	1c	1	0	0	1c	1	0	0	2a
	Biological parameters	1	0	0	1c	1	0	0	1c	1	0	0	2a
ROV/other imaging surveys	Population size	1	0	0	1c	1	0	0	1c	1	0	0	2a
	Geographic range	2	0	0	1c	2	0	0	1c	1	0	0	2a
	Genetic structure	1	0	0	1c	1	0	0	1c	1	0	0	2a
	Biological parameters	1	0	0	1c	1	0	0	1c	1	0	0	2a
Acoustic swath mapping	Population size	1	0	0	2a	1	0	0	2a	1	0	0	2a
	Geographic range	1	0	0	2a	1	0	0	2a	1	0	0	2a
	Genetic structure	1	0	0	2a	1	0	0	2a	1	0	0	2a
	Biological parameters	1	0	0	2a	1	0	0	2a	1	0	0	2a

Seismic survey	Population size	1	0	0	1c	1	0	0	1c	1	0	0	2a
	Geographic range	4	1	4	2c	4	1	4	2c	2	1	2	2a
	Genetic structure	1	0	0	1c	1	0	0	1c	1	0	0	2a
	Biological parameters	4	1	4	2c	4	1	4	2c	2	1	2	2a
Spot sampling	Population size	1	0	0	2a	1	0	0	2a	1	0	0	2a
	Geographic range	1	0	0	2a	1	0	0	2a	1	0	0	2a
	Genetic structure	1	0	0	2a	1	0	0	2a	1	0	0	2a
	Biological parameters	1	0	0	2a	1	0	0	2a	1	0	0	2a
Drilling	Population size	1	0	0	1c	1	0	0	1c	1	0	0	2a
	Geographic range	5	1	5	2c	5	1	5	2c	1	0	0	2a
	Genetic structure	1	0	0	1c	1	0	0	1c	1	0	0	2a
	Biological parameters	5	1	5	2c	5	1	5	2c	1	0	0	2a
Bulk sampling	Population size	1	0	0	1c	1	0	0	1c	1	0	0	2a
	Geographic range	5	1	5	2c	5	1	5	2c	2	1	2	2a
	Genetic structure	1	0	0	1c	1	0	0	1c	1	0	0	2a
	Biological parameters	5	1	5	2c	5	1	5	2c	2	1	2	2a
Sediment plume	Population size	1	1	1	1c	1	1	1	1c	1	0		2a
	Geographic range	2	2	4	1c	2	2	4	1c	1	0		2a
	Genetic structure	1	0	0	1c	1	0	0	1c	1	0		2a
	Biological parameters	2	1	2	1c	2	1	2	1c	1	0		2a
Underwater lights and noise	Population size	1	1	1	1c	1	1	1	1c	1	0	0	2a
	Geographic range	4	2	8	2c	4	2	8	2c	2	1	2	2a
	Genetic structure	1	0	0	1c	1	0	0	1c	1	0	0	2a
	Biological parameters	2	2	4	2a	2	2	4	2a	2	1	2	2a

Table A-5: Expert panel risk assessment scoring for marine mammals. Deepwater snapper habitat and fishery. Mining phase. Lik = likelihood, Cons = consequence, Conf = confidence.

ACTIVITY	Threat	SMS				CRC				MN			
		Lik	Cons	Risk	Conf	Lik	Cons	Risk	Conf	Lik	Cons	Risk	Conf
Ship presence	Population size	1	0	0	1c	1	0	0	1c	1	0	0	2a
	Geographic range	2	0	0	1c	2	0	0	1c	1	0	0	2a
	Genetic structure	1	0	0	1c	1	0	0	1c	1	0	0	2a
	Biological parameters	1	0	0	1c	1	0	0	1c	1	0	0	2a
Surface lights and noise	Population size	1	0	0	1c	1	0	0	1c	1	0	0	1c
	Geographic range	2	0	0	1c	2	0	0	1c	2	1	2	1c
	Genetic structure	1	0	0	1c	1	0	0	1c	1	0	0	1c
	Biological parameters	1	0	0	1c	1	0	0	1c	1	0	0	1c
Seafloor extraction	Population size	1	0	0	1c	1	0	0	1c	1	0	0	1c
	Geographic range	2	0	0	1c	2	0	0	1c	1	0	0	1c
	Genetic structure	1	0	0	1c	1	0	0	1c	1	0	0	1c
	Biological parameters	1	0	0	1c	1	0	0	1c	1	0	0	1c
Sediment plume	Population size	1	1	1	1c	1	1	1	1c	1	1	1	1c
	Geographic range	4	1	4	1c	3	1	3	1c	3	1	3	1c
	Genetic structure	1	0	0	1c	1	0	0	1c	1	0	0	1c
	Biological parameters	1	1	1	1c	1	1	1	1c	3	1	3	1c
Deposition of overburden	Population size	1	0	0	1c	1	0	0	1c	1	0	0	2a
	Geographic range	2	0	0	1c	2	0	0	1c	1	0	0	2a
	Genetic structure	1	0	0	1c	1	0	0	1c	1	0	0	2a
	Biological parameters	1	0	0	1c	1	0	0	1c	1	0	0	2a
Underwater lights and noise	Population size	1	1	1	1c	1	1	1	1c	1	0	0	1c
	Geographic range	6	3	18	2c	6	3	18	2c	3	1	3	1c
	Genetic structure	1	0	0	1c	1	0	0	1c	1	0	0	1c
	Biological parameters	3	2	6	2a	3	2	6	2a	3	1	3	1c
Wastewater return	Population size	1	1	1	1c	1	1	1	1c	1	1	1	1c

ACTIVITY	Threat	SMS				CRC				MN			
		Lik	Cons	Risk	Conf	Lik	Cons	Risk	Conf	Lik	Cons	Risk	Conf
	Geographic range	4	2	8	1c	4	2	8	1c	2	1	2	1c
	Genetic structure	1	0	0	1c	1	0	0	1c	1	0	0	1c
	Biological parameters	2	1	2	1c	2	1	2	1c	2	1	2	1c
Toxic chemical release	Population size	1	1	1	1c	1	1	1	1c	1	0	0	1c
	Geographic range	4	2	8	1c	3	2	6	1c	1	0	0	1c
	Genetic structure	1	0	0	1c	1	0	0	1c	1	0	0	1c
	Biological parameters	2	1	2	1c	2	1	2	1c	1	1	1	1c

Table A-6: Expert panel risk assessment scoring for marine mammals and Coastal fisheries habitats. All mineral resources. Exploration phase. Lik = likelihood, Cons = consequence, Conf = confidence.

ACTIVITY	Threat	SMS, CRC, MN			
		Lik	Cons	Risk	Conf
Ship presence	Population size	1	0	0	2a
	Geographic range	1	0	0	2a
	Genetic structure	1	0	0	2a
	Biological parameters	1	0	0	2a
Surface lights and noise	Population size	1	0	0	2a
	Geographic range	1	0	0	2a
	Genetic structure	1	0	0	2a
	Biological parameters	1	0	0	2a
ROV/other imaging surveys	Population size	1	0	0	2a
	Geographic range	1	0	0	2a
	Genetic structure	1	0	0	2a
	Biological parameters	1	0	0	2a
Acoustic swath mapping	Population size	1	0	0	2a
	Geographic range	1	0	0	2a
	Genetic structure	1	0	0	2a
	Biological parameters	1	0	0	2a

ACTIVITY	Threat	SMS, CRC, MN			
		Lik	Cons	Risk	Conf
Seismic survey	Population size	1	0	0	1c
	Geographic range	4	1	4	2c
	Genetic structure	1	0	0	1c
	Biological parameters	4	1	4	2c
Spot sampling	Population size	1	0	0	2a
	Geographic range	1	0	0	2a
	Genetic structure	1	0	0	2a
	Biological parameters	1	0	0	2a
Test drilling	Population size	1	0	0	1c
	Geographic range	4	1	4	2c
	Genetic structure	1	0	0	1c
	Biological parameters	4	1	4	2c
Bulk sampling	Population size	1	0	0	1c
	Geographic range	4	1	4	2c
	Genetic structure	1	0	0	1c
	Biological parameters	4	1	4	2c
Sediment plume	Population size	1	1	1	1c
	Geographic range	2	2	4	1c
	Genetic structure	1	0	0	1c
	Biological parameters	2	1	2	1c
Underwater lights & noise	Population size	1	1	1	1c
	Geographic range	4	2	8	2c
	Genetic structure	1	0	0	1c
	Biological parameters	2	2	4	2a

Table A-7: Expert panel risk assessment scoring for marine mammals in Coastal fisheries habitat. All mineral resources. Mining phase. Lik = likelihood, Cons = consequence, Conf = confidence; -,indicates a range of scores for far and near mining activities respectively.

ACTIVITY	Threat	SMS, CRC, MN			
		Lik	Cons	Risk	Conf
Ship presence	Population size	1	0	0	1c
	Geographic range	2	0	0	1c
	Genetic structure	1	0	0	1c
	Biological parameters	1	0	0	1c
Surface lights and noise	Population size	1-3	0-3	0-9	1c
	Geographic range	2	0	0	1c
	Genetic structure	1	0	0	1c
	Biological parameters	1-4	0-3	0-12	1c
Seafloor extraction	Population size	1	0	0	1c
	Geographic range	2	0	0	1c
	Genetic structure	1	0	0	1c
	Biological parameters	1	0	0	1c
Sediment plume	Population size	1	1	1	1c
	Geographic range	4	2	8	1c
	Genetic structure	1	0	0	1c
	Biological parameters	2	1-3	2-6	1c
Deposition of overburden	Population size	1	0	0	1c

ACTIVITY	Threat	SMS, CRC, MN			
		Lik	Cons	Risk	Conf
	Geographic range	2	0		1c
	Genetic structure	1	0		1c
	Biological parameters	1	0		1c
Underwater lights and noise	Population size	1	1	1	1c
	Geographic range	5	3	15	2c
	Genetic structure	1	0	0	1c
	Biological parameters	3	2-4	6-12	2a
Wastewater return	Population size	1	1	1	1c
	Geographic range	4	2	8	1c
	Genetic structure	1	0	0	1c
	Biological parameters	2	1	2	1c
Toxic chemical release	Population size	1	0	0	1c
	Geographic range	1	0	0	1c
	Genetic structure	1	0	0	1c
	Biological parameters	1	1	1	1c