

Environmental management frameworks for offshore mining: the New Zealand approach



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ABSTRACT

The New Zealand region contains untapped natural mineral, oil, and gas resources while also supporting globally unique and diverse faunal communities that need to be managed sustainably. In this paper key information from the international literature is reviewed that can underpin an Environmental Mining Management System which includes elements of Environmental Risk Assessment, Environmental Impact Assessment and Environmental Management Planning. This paper focuses on four developing areas of seafloor mining activities presently being undertaken or planned in the New Zealand region: hydrocarbons (oil and gas), minerals, ironsands and phosphorite nodules. A number of issues with the implementation of environmental management systems are identified including the difficulty of assessing new marine activities or technologies and the need for standardised reporting metrics. Finally, the development of ecosystem-based management and marine spatial planning is discussed which will be required to enhance environmental mining management frameworks in New Zealand.

1. Introduction

The renewed strong global interest in extraction of offshore marine mineral resources has affected New Zealand as a country which has sovereign rights to the world's fourth largest Exclusive Economic Zone (EEZ) [1]. Internationally, most commercial marine mining ventures to date have focused on aggregates, diamonds, tin, magnesium, salt, sulphur, gold, and heavy minerals generally confined to shallow depths near shore [2]. However, the industry is evolving and mining in deeper waters is now feasible with phosphate, massive sulphide deposits, polymetallic nodules and cobalt-rich crusts regarded as potential future prospects. New Zealand's EEZ contains large untapped mineral, oil, and gas resources that have considerable economic potential (Fig. 1). Seafloor mineral deposits have been estimated to be worth up to \$500 billion NZD [3] while the value of oil exports in the year to June 2014 was \$1.61 billion NZD with estimated exports from methanol of \$1 billion NZD [4]. New Zealand waters also support a globally unique and diverse biota [5], that contributes important ecosystem goods and services including significant fisheries resources [6–8] that need to be protected.

New Zealand is recognised internationally for its environmental

management and innovative regulatory frameworks [9], as demonstrated for instance by the implementation of the first no-take marine reserve in 1975 [10] and the introduction of a quota management system for fisheries in the 1980's [11,12]. A major element of management in New Zealand includes the recognition in policies and regulations of the Māori (indigenous) connection with the oceans, and Māori have specific rights as parties of the Treaty of Waitangi [13], the foundation document of modern New Zealand. Overall, there is a strong commitment to wise stewardship of natural resources including close cultural connections to the ocean [9].

The Exclusive Economic Zone and Continental Shelf (Environmental Effects) Act 2012 (EEZ Act) and the Crown Minerals Act 1991 provide the legislative and regulatory framework for environmentally sustainable exploration and exploitation of offshore mineral resources. The EEZ Act is the principal legislation concerned with how to manage the effects of offshore petroleum and minerals activities, which the public perceive as high risk [14]. Because the EEZ Act is relatively recent, there is limited experience with impact assessment in this environment, and little case law to help interpretation of the Act. Internationally however there is a much longer history of offshore petroleum and mining activities and therefore a larger body of literature and guidance

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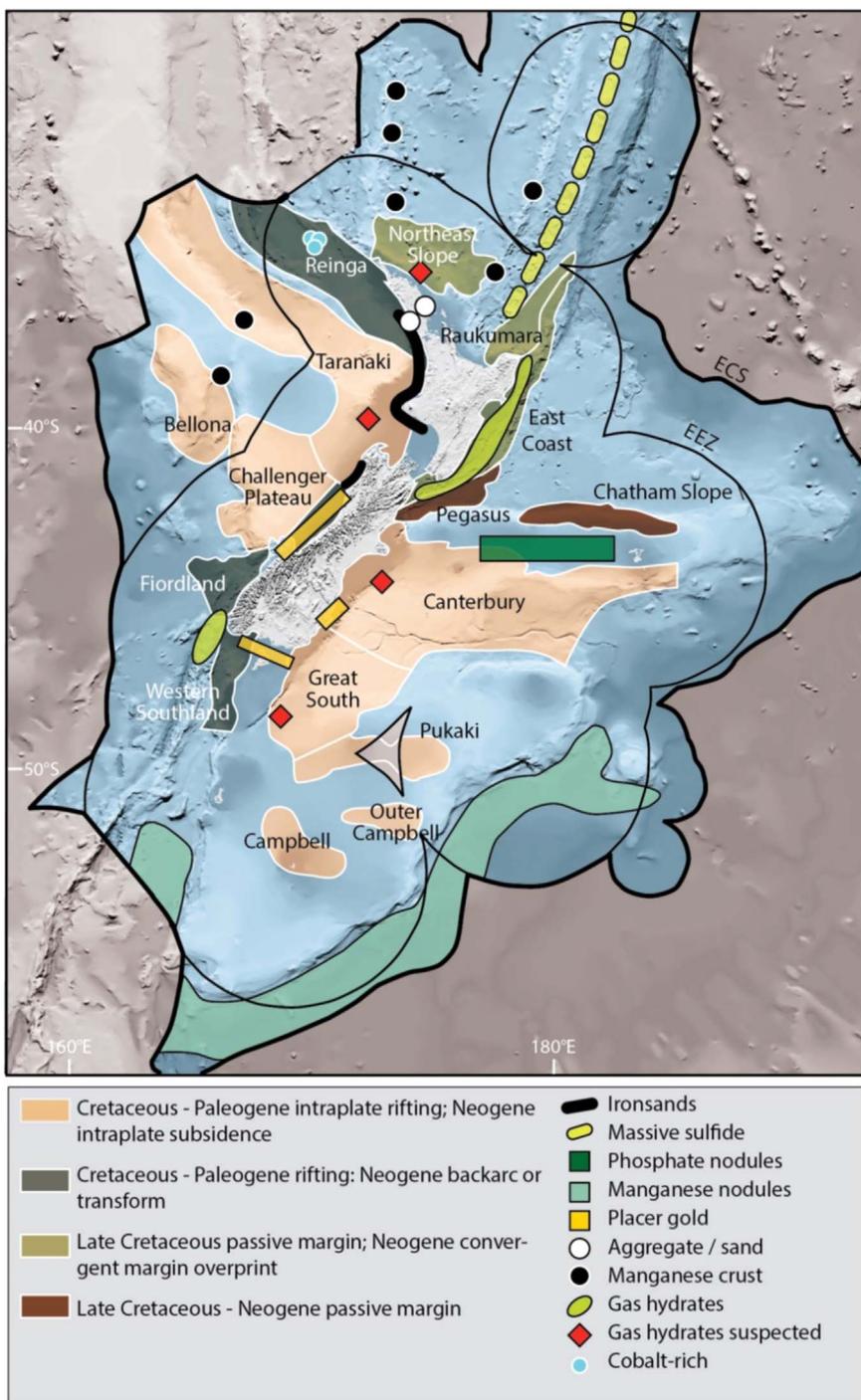


Fig. 1. Offshore hydrocarbon basins and mineral resources within New Zealand Exclusive Economic Zone (EEZ) and Extended Continental Shelf (ECS). Modified from [132].

for best practice approaches and methods for effects management.

The motivation for this review paper resulted from the lack of standardised environmental management principles for new emerging sectors. Further, a lack of best practice scientific guidelines increases the risk that environmental management practices may be insufficient to protect the marine environment and can also increase the likelihood of applications being rejected. The need for such guidance was expressed to our research team by regulators, industry and stakeholders alike. This review therefore focuses on the development of generic components of an environmental assessment framework that could be used for offshore mining applications in the future. Our review also considers lessons learned from the first marine consent applications that were made under the new EEZ Act in terms of science and policy gaps. The development of such a framework is also relevant for emerging

sectors globally where, similar to New Zealand, some of the first applications are occurring in other jurisdictions.

There are many approaches, methods and tools available to help understand potential impacts of activities (see [Supplementary material](#)). The three main tools that are generally used to determine the impacts of an activity focus on risk, impact assessment and management plans. Fig. 2 illustrates an “Environmental Mining Management System” (EMMS) framework that makes explicit the links between these three key tools: Environmental Risk Assessment (ERA) and Environmental Impact Assessment (EIA) are evaluated first which then guide the subsequent development of Environmental Management Plans (EMP). This EMMS framework helps structure our review of best practice undertaken or developed in New Zealand and other countries with reference also to guidance produced by the International Seabed

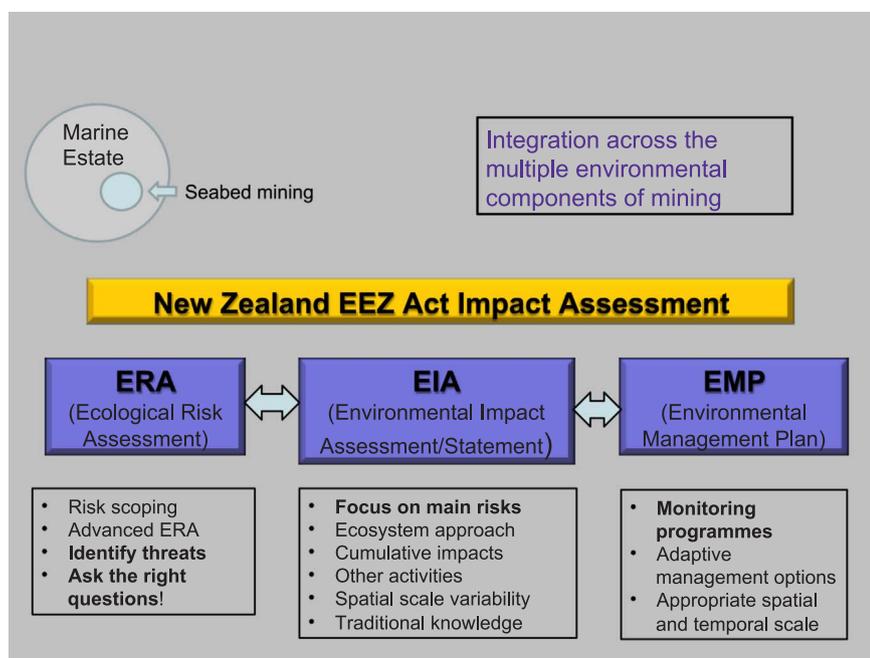


Fig. 2. A schematic drawing of elements of an environmental mining management system under the EEZ Act, showing the relationship between Environmental Risk Assessment, Environmental Impact Assessment and Environmental Management Plans (from [47]).

Authority (ISA) and the Pacific Community (previously Secretariat of the Pacific Community; SPC). In reviewing the international literature key components that should be considered in an ERA, EIA and EMP by industry sector are identified.

In this review paper the legislative frameworks that underpin New Zealand environmental management are briefly outlined first, and then the structure and processes of ERA, EIA and EMPs are considered. The impact assessment and management plan sections provide guidance on the four fastest developing areas of seafloor mining activities presently being undertaken or planned in the New Zealand region: hydrocarbons (oil and gas), offshore minerals mining (seafloor massive sulphides (SMS)), ironsand mining and phosphorite nodules. Existing research gaps and the need for the development of both strategic assessments and ecosystem based management to enhance environmental management frameworks are discussed before summarising our findings.

1.1. The New Zealand legislative context

The legislative framework for offshore mining in New Zealand is established through three main pieces of legislation. The Crown Minerals Act 1991 (CM Act) controls exploration and extraction so that any person wishing to explore for or mine minerals and petroleum must apply for a permit to do so (see CM Act Section 1A, [15]). A government agency, New Zealand Petroleum and Minerals (see <http://www.nzpam.govt.nz/cms>), is responsible for the preparation of Minerals Programmes. These programmes help establish policies, procedures, and provisions to be applied for in the management of any Crown owned mineral that is likely to be the subject of an application for a permit (CM Act Section 14). New Zealand Petroleum and Minerals manage the prospecting, exploration and mining permit regime including petroleum block offers, minerals tenders and regulatory compliance (CM Act Part 1B).

The environmental effects of petroleum and minerals activities are managed by two pieces of legislation depending on the location of the activity. In coastal waters, from the mean high water springs line out to 12 nautical miles is the ‘coastal marine area’ or territorial sea, in which environmental effects are managed under the Resource Management Act 1991 (the RMA) [16,17]. This makes regional councils responsible for managing environmental effects in the coastal marine area (as well as on land). Beyond 12 nautical miles out to the extended continental shelf boundary, including the EEZ, environmental effects are managed

under the EEZ Act. This act designates the Environmental Protection Authority (EPA) to be responsible for managing the environmental effects of certain activities.

The purpose of the EEZ Act is to promote sustainable management of the natural resources of the EEZ and extended continental shelf, and (through a 2013 amendment) to protect the environment from pollution by regulating or prohibiting the discharge of harmful substances and the dumping or incineration of waste or other matter (see Table 1 for references to pertinent sections of the Act). The EEZ Act defines sustainable management in a very similar way to the RMA, and aims to balance managing natural resources for economic benefit while ensuring the needs of future generations are met, the life supporting capacity of the environment is maintained, and adverse effects of activities on the environment are avoided, remedied or mitigated.

The EEZ Act allows the Minister for the Environment to classify activities as ‘permitted’, ‘discretionary’ and ‘prohibited’. The classification depends on a number of considerations outlined in the EEZ Act, including the environmental effects of the activity, the importance of protecting rare and vulnerable ecosystems, and the economic benefit to New Zealand. The default situation under the EEZ Act is that all activities are discretionary, unless permitted or prohibited through regulations [18]. Permitted activities include seismic surveying, cable laying, marine scientific research and the prospecting and exploration phases of oil and gas and minerals operations (except exploratory drilling). Operators need to obtain a marine consent from the EPA before they can undertake any activities even for those classified as discretionary. This involves preparing an application, which must include an impact assessment and a nationally notified public process, with the ability for the public to make submissions, present at a hearing and appeal decisions. Prohibited activities include dumping of wastes other than those allowed for in the London Protocol, discharges of oily waste from machinery beyond thresholds set out in MARPOL (Annex 1) and discharges of garbage other than set out in the MARPOL convention (Annex V) (See [19]).

The RMA and EEZ Act have similar purposes. Both restrict certain activities to control environmental effects, and require assessments of these effects to be prepared for any proposed activity (Table 1). Anyone applying to undertake an activity that crosses over the 12 nautical miles boundary would need to prepare an impact assessment that meets the requirements of both Acts. A key difference between the Acts (Table 1) is in the national and regional instruments available. Under the RMA,

Table 1
Comparison of RMA and EEZ Act approaches to managing environmental impacts.

Attribute	EEZ Act	RMA
Purpose of the Act - promote the sustainable management of natural resources	Yes – s10	Yes – s5
Meaning of environmental effect – including cumulative effects; regardless of scale, intensity, duration, or frequency; consider potential effect of high probability, and low probability with high impact	Yes – s6	Yes – s3
Requirement for assessment of effects of an activity	Yes – s39 (Impact assessment)	Yes – s88(2)(b) Assessment of Environmental Effects (AEE) plus Schedule 4
General duty to avoid, remedy or mitigate effects	Yes – s25(1)(a)	Yes – s17
National instruments	Yes – Regulations e.g., to define permitted and non-notified activities	Yes – national policy statements e.g., coastal and freshwater management; national environmental standards; air quality
Regional instruments	No	Policy statements and plans
Different classes of activities and consenting regime	Yes – s35, 36, 37 permitted, discretionary, prohibited	Yes – s77A(2) permitted, controlled, restricted discretionary, discretionary, non-complying or prohibited
Risk based approach to effects management	Yes – evidenced by categories of activities, definition of effect, level of detail required for impact assessment based on scale and significance of activity, use of adaptive management and bonds	Yes – evidenced by categories of activities, definition of effect, level of detail required in AEE based on scale and significance of activity, use of bonds (Rouse & Norton 2010)
Precautionary approach	Explicit – s61	Implicit
Adaptive management	Explicit – s64	Implicit

policy statements and plans provide a strategic and spatial framework for management. Both Acts can be said to be risk based determined by the likely scale and significance of effect of the activity (see Table 1 and [20]), but the EEZ Act contains explicit statements requiring decision makers to favour caution and environmental protection when faced with uncertain or inadequate information.

1.2. Environmental risk assessment (ERA)

ERA is a fundamental process in protecting habitats from human activities. It includes three key steps: effects evaluation, risk assessment, and risk management [21]. There are a number of methods that can be applied in ERA, and summaries are given by Lackey [22], Burgman [23] and Suter [24]. General risk assessment frameworks are used to inform decision making and may use ‘expert’ qualitative and/or quantitative data [24]. Within New Zealand, the Australia Standard/ New Zealand Standard for Risk Management (AS/NZS ISO 31000 [21]) involves identifying, analysing, evaluating, and treating risks (Fig. 3) as an approach to guide risk management. Within New Zealand, ERA methods have been applied to a range of situations including fisheries management (e.g. [25–28]), coastal hazards [29] and various marine activities [14].

There are many definitions of risk and methods to assess risk, and there can also be a difference in the underlying concept of risk [30,31]. A “likelihood-consequence” approach expresses risk as the product of

the expected likelihood and consequence of an event, and is often regarded as suitable for rare and unpredictable events (such as a major oil spill). The risks arising from activities that are predictable (where the likelihood is known), ongoing, and cumulative (such as fishing and some seabed mining activities) may be better suited to an “exposure-effects” approach [30], where the size, duration and scale of the impact is used to assess the ecological consequence of the impact [32].

Most current ERA methods conform to a multi-stage process whereby assessments are carried out at certain levels of detail: Level 1 is largely qualitative; Level 2 is semi-quantitative; and Level 3 is quantitative (e.g. [30]). This means that various levels of assessment, involving a variety of methods, can be carried out depending on the nature and extent of data, changes in scope and complexity, and specific issues facing the mining or drilling situation. In the context of offshore mining, several ERAs might be required. At the project scoping stage, an initial level 1 ERA would identify the likely main sources of impact, which can then help guide data collection during exploration. Such data can then inform a more detailed ERA (perhaps a level 2 assessment) at the time of any EIA for an exploitation permit. ERAs should be subject to regular feedback (as more information becomes available) and review [33].

ERA requires clear management goals to be most effective. Goal setting is improved through a collaborative problem formulation process which is then translated into information needs; and developed in collaboration with decision makers, assessors, scientists and stakeholders as part of an ongoing dialogue [34]. Problem formulation is linked with screening of risks, monitoring requirements and ongoing feedback (see Fig. 3).

A likelihood-consequence assessment of risks associated with many activities (including oil and gas, and a range of offshore minerals) that occur within New Zealand’s EEZ was conducted as part of the development of the EEZ Act [14]. The risk assessment outlined a scoring-type approach as to how activities might be classified, using permitted, discretionary, and prohibited classes. The analysis/evaluation component involved an assessment of the likelihood of the activity or event occurring, and then the consequences of that event following the AS/ NZS ISO 31000 standard. Appropriate ecological measures and indicators of risk were combined into a qualitative risk analysis matrix, which ranked levels of risk from low to extreme. The report included an examination of risks in terms of: i) source, magnitude, frequency and intensity; ii) potential consequence; and iii) likelihood of a level of consequence occurring. Phosphorite nodule and SMS mining had

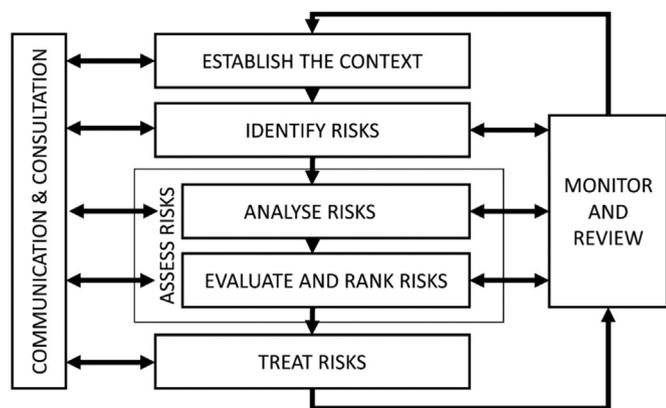


Fig. 3. The basic steps of risk management process (adapted from [21]).

Table 2
Main components required in an EIA by receiving environment (From [43] and [47]).

Receiving environment	Main components assessed in EIA
Surface	Increased vessel activities and potential pollution (includes risks associated with extreme weather events). Reduction in primary production through shading by discharges (if near-surface discharges occur in photic zone).
Water column	Effects on behaviour of surface mammals, fish and birds through changes in water composition and clarity, noise and lights from vessel activity. Effects on behaviour of mammals, mesopelagic or migratory fish and plankton through changes in water composition (e.g., chemical contamination) and clarity. Bioaccumulation of toxic metals through food chain. Sediment plume through water column from seafloor operations or midwater discharges. Local changes in pH. Nutrient and trace mineral enrichment (if near-surface discharges in photic zone). Potential oxygen depletion.
Seafloor	Direct physical impact of mining/sampling gear. Smothering/burying of animals by sediment. Change in seafloor sediment characteristics post mining (e.g., removal of large particulate material suitable for attached species colonisation). Clogging of suspension feeders. Toxic effects with metal release (and other contaminants). Loss of essential habitat (spawning/nursery grounds). Likely time periods for recolonization and recovery of key species groups.

between three and four activities classified as posing an extreme risk to the environment. Oil and gas production had three activities classified as posing a high risk to the environment while ironsand mining had four high risk activities [14].

A recent review has identified significant advancements in the development of risk assessment over the past few decades, but some problems still exist in the methodology [35]. The main problem is that there is no systematic research or application internationally on the methods of ERA in strategic decision-making processes. Without integration into strategic processes the ability to adequately predict cumulative impacts is limited, which will be particularly important for offshore minerals development, where spatial overlaps may occur with established commercial fisheries.

1.3. Environmental impact assessment (EIA)

The first formal EIA system was established by the US National Environmental Policy Act in 1970 [36,37]. This legislation was implemented in response to growing public concern about the environmental consequences of development, the changing scale of industrial developments post-World War II and recognised failures of existing decision tools (particularly cost benefit analysis) to address concerns [38]. The use of EIAs has subsequently developed rapidly and is now adopted by more than 100 nations [38]. However while EIA practice has a long history in the USA, in other countries the application of impact assessment is more recent [39].

The International Association for Impact Assessment [40] defines an EIA as "*the process of identifying, predicting, evaluating and mitigating the biophysical, social, and other relevant effects of development proposals prior to major decisions being taken and commitments made*". An EIA can predict the environmental effects of proposed initiatives before they are carried out, with the aim of minimising or avoiding adverse environmental effects and to incorporate environmental factors into decision making [41]. The focus (or scope) of an EIA should be identified early in the environmental assessment process, and this may involve an emphasis on components of the environment that are most valued by society [42]. Within New Zealand a standard guide to preparing a basic assessment of environmental effects was prepared for activities occurring under the RMA [42], but can provide guidance for offshore EIAs due to similarities in the legislation. In New Zealand, separate cultural impact assessments (CIA) documenting Māori cultural values, interests and associations with an area or a resource, including the potential impacts of a proposed activity on these values, are often commissioned as a separate report. CIAs are a tool to facilitate meaningful and effective participation of Māori, and the assessment of impacts on cultural values, interests and associations is generally an important part of the

resource consenting process under the RMA and EEZ Acts. This is particularly relevant where activities are likely to have an effect on Māori historic heritage or the relationship of Māori and their culture and traditions with their ancestral lands, water, sites and sacred places.

While there is still considerable debate in the academic literature over the relative merits and limitations of the EIA process, there is a general consensus that EIAs have led to enhanced consideration of environmental factors in decision-making [37].

1.3.1. Offshore mining EIAs

Impact assessments are required for a wide range of activities worldwide which means a wealth of experience and literature is available internationally with regards to offshore petroleum and for some mineral related activities. While an EIA essentially focuses on the biophysical environment, increasingly EIAs are considering economic, social and cultural factors as well. The latter factors can be considered within an EIA or as a separate report, depending on the detail required by the relevant legislation and regulations. Internationally, exploration for mineral resources in marine areas beyond national jurisdictions led to the development of a provisional EIA template for deep-sea mining activities [43], partly based on the structure of an Environmental Impact Statement prepared for SMS mining off Papua New Guinea [44]. The ISA template is intended to guide contractors or industry to achieve consistency in EIA information internationally. The ISA template has since been revised [45,46] and also used in developing guidelines for EIAs that could bridge the international template and the requirements of the EEZ Act in New Zealand [47].

The effectiveness of EIAs has been found to be limited when they have too much focus on baseline work and not enough emphasis on key impacts of the activity [39]. In the development of the New Zealand impact assessment guidelines Clark [47] recommended that key impacts from offshore mining activities should be assessed and structured by receptor or depth range (outlined in Table 2, see also [43]). Specifically, structuring the EIA by receptor or depth enables an understanding of the source and nature of impacts caused by the operation and helps to focus the EIA. Typically petroleum and mining cause physical disturbance of the seabed, and an associated sediment plume that will disperse beyond the actual footprint of the direct mining operation (e.g. [47–52]). There is also potential impact from leakage of material through riser pipes, or semi-enclosed collection methods (e.g. grab), as well as discharges of processing waters and fines after sorting on the surface platform [53]. The list of impacts to be assessed by depth range identified in Table 2 was developed by considering the source and nature of impacts and linking this with effects on the environment. One of the key tasks in describing the major impacts of an activity on the environment includes providing information on their nature and

extent as the basis for developing plans to mitigate such impacts. In the case of uncertain or inadequate information (under the EEZ Act) adaptive management can be considered to allow the activity to go ahead.

An adaptive management approach is defined as: i) allowing an activity to commence on a small scale or for a short period so that its effects on the environment and existing interests can be monitored; ii) any other approach that allows an activity to be undertaken so that its effects can be assessed and the activity discontinued, or continued with or without amendment, on the basis of the measurement of those effects [54].

In a New Zealand context adaptive management approaches can be implemented by the EPA by imposing conditions on granted marine consents. For example, marine consents can be granted that stipulate that an activity is to be undertaken in stages, with a requirement for regular monitoring and reporting before the next stage of the activity may be undertaken. Adaptive management is an established tool for managing environmental effects where there are uncertainties about the potential impacts of a proposed activity [20,54]. Therefore where there is a high level of uncertainty in an EIA, the applicant should consider offering suggestions for monitoring to guide ‘adaptive management’ for the proposed activities. There is an extensive literature on methods for adaptive management, with a key technical report being that of the US Department of the Interior [55], but an emphasis must be on its use as a decision-learning tool, not a trial and error approach [47].

1.3.2. EIA guidance for the offshore hydrocarbon sector

EIAs for most offshore hydrocarbon oilfields internationally and in New Zealand involve consideration of valued ecosystem components which include seabirds, marine mammals and sea turtles, benthic habitats, fish and commercial fisheries and protected natural areas (for example see [56–58]) (Table 3). Valued ecosystem components are usually selected based upon public interest from early consultation and workshops as well as social, cultural, economic or aesthetic values and scientific community concerns. Hydrocarbon EIAs typically contain two main sections [56–58]: i) information about the existing physical and biological environments focusing on the specific valued ecosystem components; and ii) an assessment of the potential effects of each project phase and its associated components / activities, including mitigation measures, residual environmental effects and proposed follow-up initiatives.

For this sector, EIA frameworks for physico-chemical and benthic components are well developed. There is a good understanding of potential impacts on the marine environment from experience with offshore hydrocarbon platforms. Project phases typically include routine development operations, normal production and maintenance operations, decommissioning and accidental events. In assessing the environmental effects of a project, an overall evaluation of the potential for an ‘adverse’ or ‘positive’ environmental effect is determined [56,57]. The evaluation criteria for assessing environmental effects include the magnitude, geographic extent, frequency, duration, and reversibility of the impacts, as well as ecological, socio-cultural and economic implications. Recent New Zealand impact assessments for hydrocarbon activities have followed international standards in evaluating the potential for adverse environmental effects on valued ecosystem components, including measures to avoid, remedy, or mitigate effects [58] with cultural assessments included in the assessment.

New Zealand oil and gas condensate operations have been particularly active in the Taranaki Basin since 1959, with nine producing wells (21 licenses) from 16 companies. To date, all marine consent applications for offshore hydrocarbon activities that have been lodged under the EEZ Act have been granted by the EPA. Two of these applications were publicly notified and proceeded to a hearing, whilst an additional two non-notified marine consent applications were approved. Approval was likely based on the relatively long history of

operations and associated knowledge of impacts with offshore platforms, where the adverse effects of the majority of activities for which marine consents were sought were evaluated as low risk. These included impacts on marine mammals, seabirds, fish, marine reserves and conservation areas, marine biota from the cumulative build-up on the seafloor of drill cuttings, chemical bioaccumulation in fish species amongst others. Effects on benthic and planktonic species and major oil spill events were, however, evaluated as medium risk.

In New Zealand and internationally, there are a few remaining uncertainties regarding environmental effects of the offshore oil industry that can limit the efficacy of EIA predictions. These include scientific gaps related to long-term chronic ecosystem effects and impacts of drilling programmes on deep-sea and hard bottom habitats, and the cumulative effects of multiple oil and gas activities as well as fisheries operations. Research to address cumulative impacts will be necessary to provide information on factors such as the potential of benthic communities to recover in areas where multiple wells are in operation, specifically to assess connectivity and recovery dynamics under differing scales of disturbance. This is a field of research that is rapidly developing, but is often data-limited in deep-sea environments [59,60].

1.3.3. EIA guidance for offshore minerals mining

Offshore mining is a recent endeavour, and hence there is less literature to provide guidance for this sector. In general the major effects of minerals mining will include habitat removal, crushing of animals, creation of sediment plumes, noise, light, accidental events etc. The description of the event, and its impacts, are organised by depth zone in the ISA template (surface, midwater, benthic), and a similar approach was suggested for SMS mining [61], by the Pacific Community [33,49–51] for mineral resources in the Southwest Pacific Ocean, and in New Zealand [46] (Table 3).

There are substantial scientific gaps which will require ongoing research [62], as the current scientific understanding of the types of effects from these activities on the marine environment are less well understood compared with oil and gas. In particular, knowledge on the scale of physical and biological effects created by the sediment plumes including dispersion distances, ecotoxicity and cumulative effects need more focused study.

1.3.4. EIA guidance for offshore iron sand mining

Extraction of sands for recovery of iron deposits is usually conducted with hydraulic dredges by vacuuming or, in some cases, by mechanical dredging [63]. Mechanical dredges can have more severe impacts than hydraulic dredges, but they are usually more localised on the seabed [64]. The impacts of offshore sand mining on marine fauna and their habitats therefore include: i) the removal of substrates that serve as habitat for fish and invertebrates; ii) creation of (or conversion to) less productive or uninhabitable sites such as anoxic depressions or highly hydrated clay/silt substrates; iii) release of harmful or toxic materials either in association with mining the seafloor, or from incidental or accidental releases from machinery and materials used for mining; iv) creation of harmful suspended sediment levels; and v) modification of hydrologic conditions causing adverse impacts to habitats [64,65]. In addition, mineral extraction can potentially have secondary adverse effects on fishery habitats at the mining site and surrounding areas.

In New Zealand the first marine consent application under the EEZ Act to mine iron sands from the seabed off the southern Taranaki coast was made by Trans-Tasman Resources (TTR) [66]. The key elements considered by their EIA application are summarised in Table 3, including key elements covered by the US Minerals Management Service. Key components of the TTR application included a significant focus on the direct removal of habitat and the creation of sediment plumes resulting from mining operations. The application was declined, with the major reasons stated by the EPA decision making committee being uncertainties in the

Table 3

Recommended key components in EIAs by industry sector. Offshore hydrocarbon EIAs representing good practice (from [47,56,57]). International Seabed Authority [43] template provides guidance for polymetallic nodules, seafloor massive sulphides (SMS) and cobalt-rich ferromanganese crusts. Ironsands mining based on MMS [63] and Trans-Tasman Resources application [66]. Phosphorite EIA example is taken from Sandpiper project and Chatham Rock Phosphate application [67,68].

Offshore hydrocarbon EIAs	ISA template for general offshore mining programmes	Ironsands mining	Phosphorite mining
<p>General components:</p> <ul style="list-style-type: none"> ● Policy, legal and administrative context ● Project description ● Description of the existing physical environment <ul style="list-style-type: none"> Meteorology and air quality Geological setting Water quality Seabed sediment Natural hazards Noise Greenhouse gas emissions ● Description of the existing biological environment by depth range (surface, midwater, seafloor) or receptor <ul style="list-style-type: none"> Plankton Fish Mammals and turtles Seabirds Benthic invertebrates Sensitive habitats ● Description of the existing onshore environment ● Description of the existing socio-economic environment ● Consultation ● Assessment of impacts on the physical environment and proposed mitigation ● Assessment of impacts on the biological environment and proposed mitigation ● Assessment of impacts on the onshore environment and proposed mitigation ● Assessment of impacts on the socio-economic environment and proposed mitigation 	<p>General components:</p> <ul style="list-style-type: none"> ● A description of the existing environment ● The proposed development activity and its objectives ● Anticipated bio-physical and socio-economic impacts (direct/indirect, reversible/ irreversible) of the activity ● Details of remedial actions that are proposed ● The benefits to be derived from the project ● Details of the consultation programme undertaken by the applicant, including degree of public interest ● End-use plans for the development activity. <p>Detailed description:</p> <ul style="list-style-type: none"> ● Geological setting ● Physical oceanography ● Water quality ● Sediment characteristics ● Biological community: <ul style="list-style-type: none"> Midwater (zooplankton, mesopelagic and bathypelagic fish, deep diving mammals) Benthic (epifauna & infauna, demersal fish) ● Natural hazards ● Noise ● Description of on-shore environment ● Socio-economic environment 	<p>General components:</p> <ul style="list-style-type: none"> ● Key elements of the project (excavation, processing, de-ored sediment deposition, transfer and export, fuel, ports, navigational safety, ballast water, risk management and operating procedures) ● Potential effects of activities (e.g., anchoring, extraction, sand re-deposition, noise and vibrations, presence of floating production storage and offloading vessel, lighting, discharges to air etc.) ● Assessment of environmental effects <ul style="list-style-type: none"> ● Waves ● Surf breaks ● Natural landforms / geomorphic character ● Deposition of substances on shore ● Currents and cross shelf sand transport ● Longshore and cross shore transport ● Coastal erosion / accretion ● Ecological effects ● Marine Mammals ● Human health ● Effects on optical properties ● Sediment plume and sediment re-suspension ● Effects on existing interests ● Effect on iwi ● Recreation ● Commercial fishing ● Archaeology ● Public access ● Economic benefits ● Mitigation Measures ● Conditions ● Environmental Monitoring Management Plan (EMMP) framework ● Overall evaluation 	<p>General components:</p> <ul style="list-style-type: none"> ● Legislation and policy framework ● Project description including proposed mining operation ● Description of the existing environment ● Environmental impact assessment ● Social, cultural and economic impact assessment ● Public consultation ● Environmental management plan ● Alternatives assessment <p>Detailed description:</p> <ul style="list-style-type: none"> ● Geology ● Meteorology ● Physical oceanography <ul style="list-style-type: none"> Waves Tides and currents Water masses Water circulation Upwelling Nutrient and oxygen distributions Water clarity, salinity, temperature ● Biological environment <ul style="list-style-type: none"> Plankton Benthic habitat and fauna Benthic habitat and fauna Mesopelagic biota Fish Seabirds Marine mammals ● Commercial fisheries ● Shipping and navigation

scope and significance of the potential adverse environmental effects, and impacts on existing interests such as the fishing industry and iwi (Māori kinship group or tribe). Key uncertainties identified by the committee were the effects of plumes and mining disturbance on primary productivity (as the operation would occur at depths of 50–100 m) and benthic communities. The potential effects of the sediment plume on primary production and benthic communities have been further assessed based on revised plume and optical property models, literature information and additional local and international expert input in a revised TTR application that is being considered in 2017 [66].

1.3.5. EIA guidance for offshore phosphorite nodule mining

Marine sources have not to date played a major role in phosphate markets with few marine projects currently in operation [67]. However, the Sandpiper phosphate project off the coast of Namibia represents one of the most advanced marine assessments to date [67]. The key issues addressed in the Sandpiper EIA were determined through a scoping process and the categories of issues identified during this process are

given in Table 3. The EIA provided a significance rating of project effects for: i) fisheries, mammals and seabirds; ii) marine water quality; iii) benthos; and iv) jellyfish. The significance rating was based on the extent, duration, probability, intensity and magnitude of the likely impact. More recently there has been interest in marine phosphate mining projects off Mexico and New Zealand.

In New Zealand, the first marine consent application to mine phosphorite nodules on the Chatham Rise was proposed by Chatham Rock Phosphate Ltd [68]. The key elements considered in their EIA are also summarised in Table 3. The application was rejected by a decision-making committee; and like the TTR decision, the major reasons given included uncertainty about the baseline environment, the nature and extent of adverse effects on biological communities, and impacts on existing interests (e.g. fisheries). Benthic communities include potentially unique protected stony coral communities which represent rare and vulnerable ecosystems. Further gaps in knowledge include potential impacts of deposition of sediment on areas adjacent to the mining blocks and on the wider marine ecosystem.

1.3.6. Considerations for future EIAs

There is a huge literature on the relative merits and limitations of impact assessments. Despite issues with how effective they sometimes are [69], there is a general consensus that the EIA process represents a globally significant decision tool resulting in enhanced consideration of environmental and social factors in decision making processes [39]. A review of worldwide trends in the implementation of EIAs noted improvements that included more comprehensive assessments (not just biophysical), inclusion of assessments earlier in the development process, mandatory requirements for EIAs, an increase in closely monitored assessments, more ambitious assessments with regards to sustainability objectives and finally a growing recognition of scientific uncertainties and the need to apply precaution in the decision making process [70]. However in order for the EIA process to reach its full potential a number of issues have also been identified that will require further consideration. In reviewing their current effectiveness, Glasson identified four issues, two of which are readily resolved, while two will require ongoing research and novel approaches [39]. These identified issues are; i) the nature of the assessment can be problematic, especially the description of adequate environmental baselines or establishing the effects of development stages when it is a new technology or activity, ii) the quality and efficiency of the EIA process can vary widely, often with overly descriptive baseline work and not enough focus on key impacts, iii) the relative roles of participants in the EIA process can vary significantly and this has been identified as limiting the effectiveness of the process, and iv) frameworks that integrate EIAs within wider strategic environmental assessments, at an EEZ scale, will need to be developed.

In New Zealand, the first issue is particularly relevant where there are marine mining applications involving new technologies and mining activities. A review of the first four applications lodged under the EEZ Act indicates that applications for mining activities were not straightforward. Specifically, two marine consents were granted for existing offshore activities (hydrocarbon drilling) where effects on the marine environment are known and considered to be low risk. Conversely, the two minerals marine consent applications for ironsand and phosphorite nodule mining which would be new activities, were both rejected (TTRs revised assessment is under review). This was in part due to less scientific certainty about the effects of these activities on the receiving environment and in part due to the higher risks associated with the larger geographical scale of these new activities. Approaches to resolve this issue include establishing the likely scale of effects from these activities by carefully designed environmental monitoring programmes for operations initially over restricted spatial scales and the potential use of adaptive management as a means to assess the scale and nature of effects. The third issue, differential access to the EIA process of various stakeholders (developers, affected parties, the general public, regulators), can be affected by access to information and can also be compounded by limited timeframes for submissions which can restrict stakeholder engagement in various jurisdictions. For example, in 2016 a ‘direction’ pursuant to s158(3) of the EEZ Act restricted the publication or communication of certain information to only the EEZ Committee, EPA staff dealing with the application, EPA experts and persons whom entered into a confidentiality agreement with the applicant. This ‘direction’ resulted in an appeal through New Zealand’s Environment Court [71]. The Environment Court decision ruled in favour of access to sensitive information, citing the importance of access in the public’s right to participate effectively in the consent process. It is critical that the decision making process is as comprehensive and transparent as possible. A sound process in New Zealand has been found to be vital because the application stage is the only point where applicants and submitters can establish the substantive facts of the application [72]. Based on the first four applications, the timeframe for hearings and decisions has also been identified as a key barrier to an effective process [72]. Currently, hearings on notified applications are limited to 40 days and decisions on notified applications must then be

issued within 20 days of the hearing. Adherence to strict timeframes runs the risk that crucial information will be omitted or that certain evidence will not be adequately tested. Similarly, such strict timeframes may inadvertently increase the likelihood that the EPA will decline applications. Hence the current EEZ Act’s timeframes may represent a barrier to an effective process and this may need to be evaluated. In New Zealand, solutions to this problem will also likely require more collaborative processes. A recent “horizon scanning” exercise identified the importance of management solutions that balance long-term and short-term benefits and which specifically encompass societal engagement in decision-making [13]. Difficulties with existing management frameworks in New Zealand have been reviewed [9] and participatory approaches to managing multi-use marine environments were recommended. In general there are increasing calls for new marine policy and management actions to deal fairly with multiple uses, to engage multiple sectors of society in the decision-making process, and to transform practice to better cope with change [9,73,74]. Such an expansion in the process can be very time consuming [9], however efforts that increase participatory approaches within EIA processes and marine management frameworks are required. These could include combined workshops and collaborative mapping, participatory geographic information systems, scenario planning, mental models (cognitive representations of external reality, see [75]) and multi-criteria decision analysis as examples [73]. Finally while the need for integration of strategic environmental assessment frameworks at an EEZ scale still requires development, in New Zealand councils are increasingly adopting a regional approach to marine assessment planning and monitoring programmes that fall under the RMA.

1.4. Environmental management plans (EMP)

1.4.1. Regulatory framework

EMPs specify approaches and methods to test predictions of impacts made in the EIA, detect changes in the marine environment, and determine whether any changes were caused by the project [76]. In general, offshore plans typically monitor the following environmental components dependent on industry sector: physical and chemical oceanography, sediment quality, benthic community composition, water quality, water column communities including zooplankton, commercial fisheries, heavy metal bioaccumulation, marine mammals, seabirds and bathymetry (with wave monitoring if changes in coastal morphology could occur due to extraction) [76,77].

All major global marine industries are present in New Zealand, with significant potential to expand and diversify the economy [13]. Fisheries (both commercial and recreational) have a long history and are believed to be near capacity [78], while exploration of other natural (petroleum, minerals, renewable energy) or farmed resources suggests that there is the potential for significant expansion [79,80]. To date, EMPs have been conducted for a range of activities including sand extraction, aquaculture (finfish and shellfish) and offshore petroleum and gas operations. Adequate monitoring programmes for existing and emerging sectors are required to ensure management of the use of New Zealand’s natural resources within environmental limits.

1.4.2. EMPs for the offshore hydrocarbon sector

Oil and gas EMP programmes typically monitor two broad components: i) sediment and water quality; and ii) commercial fisheries (Table 4; also [53,81–85]). Internationally, the former is common to most EMPs, while the latter is dependent on regional policies and site-specific information [53]. The first component focuses on assessing the effects on benthic sediment quality (primarily from discharged drilling fluids) and monitoring the discharge water quality (primarily from discharged produced waters). Most sampling designs employ a radial gradient sampling pattern recommended for point-source pollution, including one or more far-field reference stations (Fig. 4; also [76,86,87]) with pre- and post-drilling surveys. Internationally, it is

Table 4
Recommended components of EMP monitoring programmes representing good practice by industry sector.

Offshore Hydrocarbon (from [53,76,82–85,91])	Sand extraction (from [63])	Phosphorite nodule mining (from [43])
<p>Sediment and water quality component</p> <ul style="list-style-type: none"> • The zone of influence of drilling muds and cuttings and associated biological effects by monitoring the physical and chemical characteristics of sediments and effects on benthic infauna and laboratory test animals • The zone of influence of project activities and associated biological effects by determining physical and chemical characteristics of water samples and examining phytoplankton pigment concentrations at various distances from point of discharge. <p>Commercial fish component</p> <ul style="list-style-type: none"> • Contamination in fish tissue by monitoring chemical body burden • The biological effects of contamination on fish by monitoring fish taint • The biological effects of contamination on fish health by measuring various health indices. 	<p>Benthic communities & their trophic relationships to fish</p> <ul style="list-style-type: none"> • This component measures community structure and secondary production for benthic assemblages and additionally fish assemblage biomass <p>Marine mammals and wildlife</p> <ul style="list-style-type: none"> • Monitoring includes collection of data on marine wildlife distribution, associated behaviours, and stranding during the dredging operations <p>Sediment sampling and analysis</p> <p>Wave monitoring and modeling</p> <ul style="list-style-type: none"> • To assess if changes in bathymetry from dredging influences wave patterns at the impact site, inshore of the impact site, and in adjacent nearshore areas <p>Bathymetric and substrate surveys</p> <ul style="list-style-type: none"> • To determine the change in bathymetry associated with sand removal <p>Shoreline monitoring and modeling</p> <ul style="list-style-type: none"> • To assess the effects of changes in wave patterns on changes to the shoreline and nearshore morphodynamics. 	<p>Physical oceanography</p> <ul style="list-style-type: none"> • Description of currents, sedimentation rates etc. <p>Chemical oceanography</p> <ul style="list-style-type: none"> • Description of nutrients, particle loads, temperature and dissolved gas profiles etc. <p>Sediment properties</p> <ul style="list-style-type: none"> • Sediment composition, pore water profiles, and grain size <p>Seafloor communities</p> <ul style="list-style-type: none"> • Benthic invertebrate communities including infauna and demersal fish. This should include considerations of species richness, biodiversity, faunal densities and community structures. <p>Trace metal bioaccumulation in benthic organisms</p> <p>Monitoring zooplankton and fish around the depth of the plume in the pelagic zone</p> <p>Monitoring plankton community in upper surface waters</p> <p>Marine mammals and other pelagic megafauna</p>

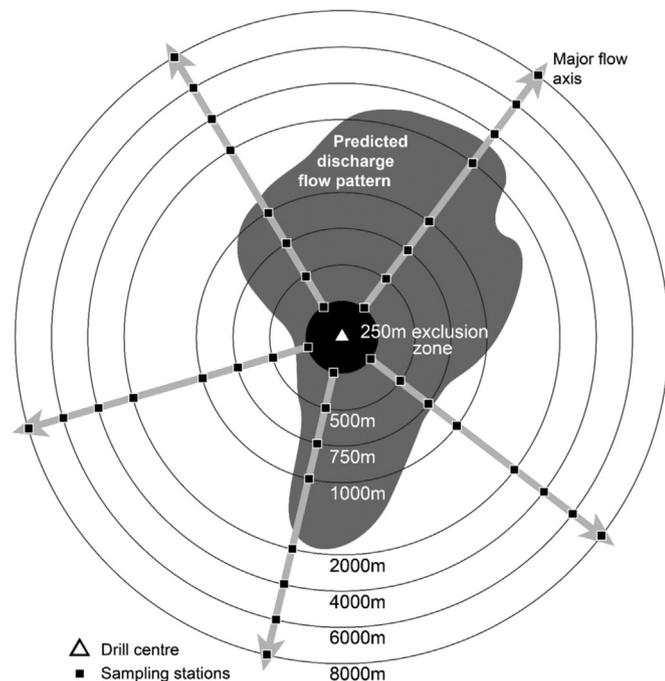


Fig. 4. Sampling design layout commonly used in environmental effects monitoring programmes for offshore hydrocarbon platforms. Sediment and biological samples are taken with distance from drill centre and additional axes are often aligned with the predominant currents. The black circle around the drill centre indicates the 250 m Maritime Safety exclusion zone (as enacted by Maritime NZ under the Continental Shelf Act 1964 and the Maritime Transport Act 1994). Note sampling distances are not to scale.

recommended that sediment core samples be taken [76,88] with benthic macrofauna determined from grab samples [76]. In some cases, benthic meiofauna and epifauna are also collected from core samples and video imagery respectively dependent on the habitat type [53]. Regional monitoring programmes can also include other environmental

components such as seabirds and marine mammals [89]. However, these components are more difficult to monitor and it has been recognised that estimates of seabird mortality associated with offshore hydrocarbon activities are weak [89,90]. The level of regional monitoring is often highly variable and many EMPs do not adequately assess cumulative effects representing a gap across many jurisdictions.

Within New Zealand, a protocol for EMPs around offshore hydrocarbon platforms within the main hydrocarbon producing basin in Taranaki has been developed [91]. A major goal of this is to provide a robust, standardised approach to monitoring discharges from offshore installations. It is consistent with earlier environmental monitoring assessments of installation discharges in the region and following international standards is divided into two primary components: i) assessment of effects on soft-bottom seabed habitats; and ii) monitoring of discharge water quality. Recommendations for monitoring, which have been adopted by most operators in New Zealand include a minimum 20 station design that is sampled for all operations including pre and post-drilling and production [91]. Sampling is based on traditional benthic macrofaunal and sediment analysis at these 20 stations. New monitoring developments include the application of sequencing of environmental DNA (eDNA) which is increasingly being used as an alternative to traditional morphological-based identification to characterize biological assemblages and monitor anthropogenic impacts in marine environments. In New Zealand, metabarcoding techniques were found to represent an effective tool for assessing benthic community changes near offshore oil and gas platforms [92,93] and can be used to complement current monitoring techniques based on traditional taxonomic identification of the macrofauna. The application of these new monitoring techniques will likely increase in the future as the costs of sequencing decrease and they reduce processing times associated with identification of benthic biota at offshore mining sites [92]. To date, wider regional monitoring programmes that assess seabirds and mammals or cumulative effects of multiple wells or platforms are not routinely conducted in New Zealand.

1.4.3. EMPs for offshore minerals mining

No offshore mineral mining operations for SMS, polymetallic nodules or cobalt-rich crusts that would require monitoring have occurred in New Zealand to date. However general considerations for environmental management of mineral mining have been summarised in a series of reports by the SPC [49–51] for SMS, polymetallic nodules, and cobalt-rich crusts. These reports stress the importance of a clear definition of environmental objectives at the outset of any proposed activity, as these determine the nature of required research and data collection to support EIAs and EMPs. Objectives typically involve maintaining biodiversity and ecosystem health and function, as well as reducing any impacts of mining and pollution, and include management principles such as the ecosystem approach to management and the precautionary principle (e.g. [94–96]). There are a number of guidelines that describe details of EMP surveys for polymetallic nodules [97], SMS and cobalt-rich crusts [98] as well as a recent update and revision of scientific guidelines for all mineral types [33]. Targeted monitoring is often recommended for the following ecosystem components: large marine megafauna (such as seabirds, marine mammals, whale and basking sharks); benthic communities including endemic vent megafauna; physical and chemical characteristics of water; and heavy metal accumulation in commercial fish stocks.

The potential impact caused by minerals mining are generally quantified by comparing the status of un-impacted (the baseline state and control site) conditions with impacted conditions (mined sites) [61]. For SMS deposits, because benthic organisms often have localised distributions or slow recovery rates [52,61,96,99,100], monitoring programmes include covering long periods of time to account for natural variability, high levels of endemism and slow recovery rates of species in these habitats [77]. Marine spatial planning in general represents an important tool to effectively manage the impacts of minerals mining operations where ecosystem reserves are seen as key tools to manage the different spatial scales of benthic community structure and mining impacts [45,59,101]. For example, guidelines for spatial management of SMS sites have been developed [99], and criteria put forward to identify areas that should be considered ecosystem reserves. Key selection aspects included identifying sites that meet the Convention on Biological Diversity criteria for ecologically or biologically significant areas. Networks of such ecosystem reserves within bioregions should be established with their size and spacing sufficient to ensure connectivity and take into account the pattern of distribution of benthic habitats [99].

1.4.4. EMPs for offshore ironsand mining

Internationally, programmes to reduce environmental damage associated with long-term and large-scale use of sand and gravel extraction from the continental shelf have been developed and encompass a comprehensive physical and biological monitoring programme for sand-mining activities [63]. These EMP monitoring programmes consider effects of direct removal and sediment plumes, and include benthic communities and their trophic relationship to fish, marine mammals and wildlife, sediment sampling, wave and shoreline monitoring and bathymetry surveys (Table 4). Essentially the key elements for monitoring include sand transport and deposition, and the composition and abundance of benthic communities, as required for coastal sand extraction. Protocols have been defined for the monitoring elements to ensure consistency of methods among studies (detailed in [63,102]) which would be applicable in a New Zealand context. The recommended monitoring is based on a stratified design comparing dredged and control areas whereby impacts and recovery are inferred by differences in temporal trends or changes in biological similarity. Strata would be defined by factors known to affect the distribution and abundance of organisms and communities in the region, and informed by plume dispersion models to assist the spatial layout of sediment and benthic sampling. Further information on environmental impacts and associated recovery rates associated with sand extraction can be found in Boyd [103] and Cooper [104].

1.4.5. EMPs for offshore phosphorite nodule mining

No applications to mine phosphorite nodules under the EEZ Act have been approved, although like ironsands mining, the uncertainty around environmental impacts would require careful monitoring design and consideration within an EMP. Internationally the ISA has developed baseline and monitoring requirements for polymetallic nodule exploration [97,105] as well as for SMS and cobalt-rich ferromanganese crusts [98]. The recommendations for baseline monitoring are generally similar in each instance, and are summarised in Table 4.

In general, Before-After-Control-Impact (BACI) designs within mining and comparable reference areas have been recommended [98]. In areas where mining is proposed over large geographical regions spatial management plans based on applied principles for the design of marine protected area networks are recommended [106]. Larger spatial management plans are required because the scale of mining could occur over large areas compared with point source impacts (e.g. a well head). For example, a recent EMP for the Clarion-Clipperton Zone in the eastern Pacific Ocean recommended dividing the zone into three east-west and three north-south strata for conservation management [107], with a design that should protect 30–50% of the total region from polymetallic nodule mining [106,108]. Marine spatial planning options, including marine protected area networks, will be particularly important when considering new mining applications where the effects are likely to occur over large spatial areas [109]. There are a number of analytical approaches and tools to aid protected area design (e.g. [110]). Spatial management tools such as Marxan [111] and Zonation [112] allow selection of sites that balance biodiversity values while minimising the cost of protection to existing or potential resource users. In a New Zealand context, the CRP application utilised Zonation to evaluate spatial options to propose a small network of closed no-mining areas in their mining application for nodules on the Chatham Rise [113].

1.4.6. Considerations for EMPs in the future

On a global scale, legislation is increasingly implemented to assess the ecological integrity of fresh and marine waters [114–116]. Initiatives include the Oceans Act 2000 of the USA and the European Water Framework Directive [117] and the European Marine Strategy [118]. The main goal of these directives is to achieve Good Environmental Status (GES) of marine waters. The European Union defines GES as “the environmental status of marine waters where these provide ecologically diverse and dynamic oceans and seas which are clean, healthy and productive” with the aim of achieving GES of EU waters by 2020. Integrating environmental protection legislation into environmental management requires firstly assessing ecological integrity to determine GES, evaluating whether significant ecological degradation could occur, or has occurred, identifying the spatial extent and location of ecological degradation, and determining causes of unacceptable degradation in order to guide management actions [114]. An integral part of determining ecological integrity is the measurement of biological communities, typically emphasising analyses of plankton, benthos, macroalgae and fish. For offshore operations, marine mammals and seabirds will also be important ecological components. In the development of protocols for evaluating GES, benthic macroinvertebrate communities are the most consistently emphasised biotic component of aquatic ecosystems. However a plethora of methodologies with many indices, metrics and evaluation tools are presently available (see summary in [119]). While the hydrocarbon oil and gas sector has a system for consistent monitoring and reporting of environmental parameters, for the offshore minerals sector standardisation of measures of health or indices is essential, but still in development [33,45,120]. This is often further complicated by the fact that the ecology of deep-sea regions is less well known. The development of monitoring components for offshore mining will therefore require ongoing evaluation but can be linked with other New Zealand monitoring initiatives [121] and international efforts to standardise GES reporting.

Even with the best monitoring and reporting programmes in place, a key challenge is the need to enhance knowledge about the conditions under which sudden, disruptive and substantive undesirable changes are likely to occur and the potential implications of such changes for New Zealand [13,122]. Surprises, thresholds and tipping points are increasingly documented in the ecological literature, as human activities push systems beyond the ecosystem's adaptive capacity [123,124]. These tipping points often demonstrate that there is an environmental limit to certain kinds of economic growth. Cumulative effects, through additional new marine industries, climate change and other stressors, can also reduce environmental resilience and increase the risk of environmental or economic collapse [123]. The potential for unexpected and irreversible environmental shifts to occur emphasises the need to adopt a precautionary approach and manage exploitation of marine resources well within known environmental limits. In general, managing for cumulative effects also requires good Strategic Environmental Assessments or Ecosystem Based Management approaches.

1.5. Strategic environmental assessment and ecosystem based management

Strategic Environmental Assessments (SEA) are systematic decision support processes that go beyond the evaluation of site-specific project impacts to consider the broader policy and regional planning context in which development projects operate [125]. SEA approaches consider the cumulative effects of a sector expanding in a given area or region. Their development is the responsibility of the regulator, such as the regional council in a New Zealand context. While SEA approaches are applied to individual sectors (e.g. oil and gas), broader ecosystem based management approaches are meant to be cross-sectoral with all industry activities, potential future uses, and existing recreational and cultural values of the marine environment considered simultaneously.

An ecosystem approach to management is the comprehensive integrated management of all human activities based on the best available scientific knowledge about the ecosystem and its dynamics [126]. Integrated management frameworks developed from the need to balance multiple objectives related to achieving economic as well as environmental sustainability [127] where sustainable development is established for all activities in the whole area. This is a marked departure from existing approaches that usually focus on a single sector or activity. Similar to SEA processes, the responsibility of ecosystem-based management (EBM) does not lie with industry, but falls at a higher national policy level. Wider EBM initiatives will be required which integrate all potential uses of offshore environments (such as mining, energy, fisheries, shipping, cultural and biodiversity values) into decision-making processes. In New Zealand, regional SEA frameworks are currently being adopted by regional councils for specific industry sectors. At a national level, EBM is being developed for New Zealand's major commercial fisheries, and more broadly as part of a ten-year Sustainable Seas National Science Challenge (see <http://sustainableseaschallenge.co.nz/>). As well as developing EBM decision support tools the challenge is incorporating cultural, spiritual, economic and environmental values that New Zealanders have for the marine environment.

2. Discussion and recommendations

In New Zealand a relatively new legislative framework, the EEZ Act, has been introduced that provides clear boundaries within which offshore mining operations must manage the environmental effects of their activities. The Act requires the development of environmental, social and cultural impact assessments that include consultation with iwi and other existing users. Decision makers must balance economic, social and environmental concerns in evaluating proposals for major economic activities via a publicly notified marine consent process. Whilst the EEZ Act has been described as a credible first step in addressing concerns surrounding the management of offshore resources

the first decisions under the Act have also exposed some weaknesses in the new legislative regime [72]. Given the expanding number of offshore mining applications, both within New Zealand and internationally, this review paper provides guidance for the offshore mining sector based on best practice and lessons learnt from the first applications lodged under the newly implemented EEZ Act.

For offshore mining operations there should be a well-structured framework constituting an Environmental Mining Management System (EMMS) (Fig. 2). The three stage process of risk assessment, impact assessment and management planning forms a comprehensive foundation for managing offshore activities. Ecological risk assessment acts firstly as a scoping stage to highlight the main elements at risk from the activity, and helps structure data collection during exploration that identifies and informs the key aspects that the EIA should focus on (Fig. 2). A key task of the EIA is to then describe the major impacts of an activity on the environment and provide information on their nature and extent as the basis for developing plans to mitigate such impacts. The EIA should enable a management plan to be formulated that covers the progression from exploration to exploitation, and includes detailed descriptions of how the operation is to be managed to ensure environmental objectives are met. The EMP then monitors the scale of effects to ensure management objectives are met. The baseline data collected during exploration is crucial to ensure the EMP is well structured, and flexible. This review provides clear recommendations on components that should be assessed in an EIA (Table 3) and monitored within an EMP (Table 4) by industry sector based on best practice from both the New Zealand and international experience. In summarising key components that should be considered, particularly for new sectors, it is hoped that practitioners can improve on these methods and ensure resource use is balanced with environmental sustainability outcomes.

Based on the New Zealand experience, it has been found that decision making processes are enhanced when an EMMS is developed using collaborative processes with local communities and resource users. This must include genuine collaborative processes with iwi. Collaborative or participatory forms of planning and decision-making are widely used in efforts to resolve conflicts over scarce resources and have been found to provide the opportunity for building social capital and trust [128]. Whilst participatory approaches can be successful, ensuring there is support for collaboration from the outset and having a well-designed process have been found to result in improved outcomes [128]. A set of design principles and recommendations for participatory approaches have been developed from experiences gained by assessing resource management case studies in New Zealand [129]. These principles are based on having a strong sense of place, prioritising long-term solutions over short-term benefits, collective engagement of all key stakeholders including a willingness to compromise, negotiated consensus on sustainability goals, flexibility to renegotiate goals and guidance by a skilled facilitator [129]. These participatory examples from New Zealand suggest that local social-ecological systems can shift toward more sustainable trajectories if well-designed processes are in place to support collaborative planning [129].

2.1. Major gaps

This review has also identified a number of issues that have limited the efficacy of good environmental management. This includes gaps in science knowledge and limited guidance on best practice for how to conduct an ERA, EIA and EMP. Firstly, science gaps that will need to be better addressed by the science community include the difficulty in EIAs of assessment and monitoring for new marine activities or technologies in the marine estate. Under the EEZ Act, two of the first four notified marine consent applications submitted have been declined due in large part to scientific uncertainty. This has created concern from industry who have asked for an effective and pragmatic approach to assessing environmental effects which include explicit consideration of

managing uncertainty and risk, and approaches that provide opportunities for adaptive management [130]. As mining activities expand there will be an increasing need for science to be able to clearly identify uncertainty and recognize the cumulative effects of multiple activities. It is hoped that the development of integrated management frameworks will better enable uncertainties to be identified and quantified. Scientific uncertainties can occur due to limited *a priori* knowledge of the impacts of a new activity on the marine environment, or because a known activity is occurring in a new area for which there is limited information about the ecology of the region. Uncertainty can also arise due to cumulative effects from industry expansion or additional multiple stressors from other anthropogenic disturbances (such as fisheries). In these cases there is the potential for ecological “surprises” to occur, with substantial and unanticipated changes in the abundance of one or more species from previously unsuspected processes [131]. This can best be addressed by building a collaborative framework across science, governance, and society that can help stakeholders navigate uncertainties and ecological surprises [9].

A second gap relates to good practice or governance structures that will need to be considered by management and policy experts. This includes inherent difficulties when participants have differential access to the environmental assessment process and in New Zealand this is often a concern expressed by local communities and resource users. Based on the first four applications, the timeframe for hearings and decisions has been identified as a key barrier to an effective process with the suggestion that a revision of the current EEZ Act's timeframes would be in the interests of all concerned and lead to a higher quality process [72]. Another complementary but longer-term approach is to develop more ecosystem based and participatory approaches to managing multi-use environments. These approaches are already being developed both in the marine environment [9,13] and for freshwater ecosystems with the recent New Zealand freshwater management reform process, and can provide the overarching vision that New Zealanders have for marine spaces. Internationally, many countries are adopting visionary frameworks for marine ecosystems to ensure healthy, resilient and productive oceans for present and future generations such as the US Oceans Policy and the European Marine Strategy Framework.

A further policy difficulty for New Zealand relates to the absence of a national planning framework for managing the oceans. Currently major marine consent applications for offshore mining activities in New Zealand are reviewed by an EPA appointed decision-making committee. Committee members must review the marine consents on a case-by-case basis taking into account a list of qualitative decision-making criteria that refer to effects on the environment, existing interests, economic benefits and other matters. Currently the EEZ Act is not supported by guiding documents such as national environmental standards, and policy statements or plans. This differs from applications lodged within the territorial coastal area, where RMA decision makers must give regard to the New Zealand Coastal Policy Statement that provides objectives and policies on environmental issues that must be considered in the decision-making process. The development of EEZ policy statements has been recommended as part of a Resource Legislation Amendment Bill, and this would provide the required national environmental standards and policy statements to facilitate better decision-making processes in the future.

3. Conclusions

This review concludes that the New Zealand EEZ Act represents a positive first step towards an effective management regime for New Zealand's offshore resources. Within this legal framework it is recommended that a structured EMMS framework be adopted for sustainable environmental management. The review also provides clear recommendations on the components of the environment that should be assessed in the impact and monitoring phases for the four largest

potential offshore mining sectors based on best practice. As well as providing guidance on key principles that should be used for existing and new emerging sectors, this review evaluates lessons learnt from the first four publicly notified offshore mining applications lodged under the EEZ Act. This evaluation identified gaps related to scientific uncertainty and policy gaps related to the timeframes of the hearing process and a lack of clear policy statements under the Act. These gaps represent areas for future work in terms of both scientific research and policy implementation that are relevant both in a New Zealand and international context. Finally, environmental management plans for the offshore mining sector should sit within a wider ecosystem-based management framework where management plans are developed collaboratively with iwi and resource users to ensure all values of the marine estate are considered. New Zealand recognizes that meaningful and ongoing participation of iwi and stakeholders will be essential to sustained implementation of ecosystem-based management ideally resulting in better conflict resolution and sustainable resource use.

Competing financial interests

The authors of this paper have no financial conflicts to declare.

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Appendix A. Supporting information

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