Potential Impacts of Petroleum and Mineral Exploration and Production on Hector's and Māui Dolphins

A Literature Review

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Disclaimer:

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Contents

Figures

Tables

Executive Summary

The North Island population of Hector's dolphins (*Cephalorhynchus hectori*) is formally described as a subspecies, the Māui dolphin (*Cephalorhynchus hectori maui*). Both Hector's and Māui dolphins, are endemic to New Zealand waters, where animals are exposed to a range of human (anthropogenic) and non-human-induced threats. To better protect these species, the Department of Conservation (DOC) and Fisheries New Zealand (FNZ) are currently in the process of updating the Threat Management Plan (TMP) for Hector's and Māui dolphins. To assist in determining potential measures that could be taken to protect these dolphins from non-fishing related threats, DOC commissioned JASCO Applied Sciences (JASCO) to undertake a literature review on potential impacts of petroleum and minerals exploration and production on Hector's and Māui dolphins. This document presents a collaborative effort by JASCO, Cawthron Institute (New Zealand) and Ocean Science Consulting NZ (Asia-Pacific) Limited (OSC-NZ).

This literature review focusses on knowns and unknowns of potential impacts from New Zealand oil and gas (O&G) and mineral exploration and production on Hector's and Māui dolphins in New Zealand waters. Overall, assessment of potential impacts is hampered by lack of information, specifically regarding effects of acoustic emissions on these animals. To fill these knowledge gaps, this review draws primarily on information from relevant studies conducted overseas, and uses knowledge on the better-studied, similarly-sized, anatomically, physiologically, and ecologically-comparable harbour porpoise (*Phocoena phocoena*) as a proxy for Hector's and Māui dolphins.

The Taranaki Basin is currently the only O&G producing basin in New Zealand, with no production wells being drilled beyond the Taranaki shelf edge. Exploration drilling in deeper parts of the EEZ, however, revealed petroleum systems in other parts of New Zealand's EEZ with considerable potential for further discoveries. The New Zealand government decided to not issue any new permits for offshore exploration of O&G resources. Current exploration permits will be honoured for coastal and offshore areas off the North and South Islands. To date, several ongoing and future exploration permits exist and will be honoured for coastal and offshore areas off the North and South Islands. Restriction for mineral extraction exist through the Resource Management Act and the Exclusive Economic Zone and Continental Shelf (Environmental Effects) Act 2012.

Several other industrial activities such as pile driving, drilling, and vessel traffic are linked intrinsically with O&G exploration and production and mineral operations. All these activities emit (or have potential to emit) chemical and/or physical pollutants that can affect Hector's and Māui dolphins directly or indirectly; negative effects are likely to be caused by noise, collision and entrainment, habitat degradation, remobilisation of contaminants, sedimentation, and increases in suspended sediment concentrations.

There are no direct audiometric data available for Hector's and Māui dolphins and indirect information such as their acoustic vocalisations provide insufficient baseline information for assessing risk of noise-induced effects. The acoustic characteristics of the harbour porpoise's vocalisations are similar to those of Hector's/Māui dolphins; this, along with other biological, anatomical, physiological, and ecological similarities between the species makes the harbour porpoise a good proxy for elucidating noise-induced effects on the dolphins. Based on the similarities found between the species, it is justifiable classifying Hector's/Māui dolphins as high-frequency (HF) cetaceans and to infer information on their susceptibility to noise-induced effects on the auditory system from harbour porpoises. The most appropriate noise exposure threshold levels to protect them from auditory effects would be the HF-criteria proposed by the U.S. National Marine Fisheries Service (2018); criteria for onset of behavioural disturbance suggested by Wood et al. (2012) for sensitive species seem to provide the most appropriate approach to regulating the behavioural effects of noise on Hector's/Māui dolphins.

Harbour porpoises also face many similar potential threats in the northern hemisphere that Hector's and Māui dolphins are exposed to in New Zealand waters. Sounds emitted during seismic surveys and offshore pile driving have the loudest source levels and pose the highest risk for causing auditory impairment such as temporary threshold shift (TTS); however, auditory information on susceptibility for TTS from harbour porpoises and noise propagation modelling results from previous seismic surveys indicate this risk is relatively low if the frequency-specific sensitivity of these species is considered and audiometric weighting functions are applied. Other major activities, such as drilling, dredging, and vessel traffic pose only a minor risk for auditory impairment for Hector's and Māui

dolphins but may pose other risks such as exclusion from areas where activities are occurring, and habitat destruction.

The most likely noise-induced effect caused by all activities considered in this report is behavioural reactions. Severity and extent depend on received levels but are also variable between individuals and highly context specific. No scientifically-robust data are available on behavioural responses of Hector’s and Māui dolphins to sound exposure. Information obtained from studies on harbour porpoises are not applicable in this context due to inter-specific differences and context-specificity of animal behaviour, and no concrete risk assessment can be made to date.

The optimal techniques to mitigate physical or behavioural effects of anthropogenic activities on Hector’s and Māui dolphins is avoidance of areas and implementation of additional buffer zones when dolphins are using them for biologically important activities, coupled with strict adherence to existing, or activity-specific monitoring and mitigation schemes when activities are permitted to occur.

Cumulative effects are another major knowledge gap in this assessment, and modelling frameworks such as Interim Population Consequences of Disturbance Model can be useful in conceptualising future scientific and regulatory approaches.

Effects caused through bioaccumulation of toxins and other non-acoustic emissions from industrial activities either individually or interactively, lead to systemic suppression of immune function in marine fauna. These stressors are equally difficult to quantify or link to any single, or combination of activities, but existing information from other areas indicate that, as long as highly contaminated discharges are avoided, the risk for food web transmission of contaminants via phytoplankton and zooplankton is slight, and catastrophic effects on Hector’s and Māui dolphins are unlikely.

Overall, this assessment lacks relevant species-specific Hector’s and Māui dolphin data. Attempts to populate knowledge gaps with information from harbour porpoises as a proxy provides some insights into the severity and likelihood of effects; Nevertheless, the paucity of information available on Hector’s and Māui dolphins substantially reduces the validity of conclusions on quantifying long-term effects of O&G and mineral exploration and production.

1. Introduction

Hector's dolphin (*Cephalorhynchus hectori*) (Figure 1) is the only endemic dolphin found within New Zealand waters. This species is mainly found around South Island coastal regions while the North island population is distinguished as a sub-species known as Māui dolphin (*Cephalorhynchus hectori maui*) (Baker et al. 2002). The latest population estimate for the total Hector's population around the South Island (excluding sounds and harbours) amounts to 14,849 animals (95% CI = 11 923–18 492), while the most recent published estimate for Māui dolphins (>1 year old) is 55 (95% CL = 48–69) (Hamner et al. 2012a). To better protect these dolphins and especially the critically endangered (as per International Union for Conservation of Nature) or nationally critical Māui dolphin (as per New Zealand Threat Classification System), the Department of Conservation (DOC) and Fisheries New Zealand (FNZ) use the non-statutory Threat Management Plan (TMP) to reduce risk to the dolphins, and it's being reviewed to ensure it's appropriate.

Figure 1. Māui dolphin. Photo: Bernd Würsig et al. (2017).

DOC commissioned JASCO to undertake a literature review of the potential impacts to Hector's/Māui dolphins from petroleum and mineral exploration and production to inform an assessment of potential non-fishing-related threats. This document presents a collaborative effort by JASCO Applied Sciences (JASCO)(Australia), Cawthron Institute (New Zealand), and Ocean Science Consulting (New Zealand).

This literature review characterises the emissions (which can be of physical and/or chemical) of these two industrial activities but also takes related activities and their emissions into account. Maps are provided to give an overview of the past and current status of oil and gas (O&G) and mineral mining activities. Emphasis is then given to acoustic emissions, and detailed information is provided to inform the assessment of their effects. A key aspect for assessing risk exposure and potential impact is determining Hector's/Māui dolphin distributional overlap with zones where these activities occur. Two approaches for describing current Hector's/Māui dolphin distribution are considered in this report, 1) a precautionary proxy based on the 100 m depth contour around New Zealand (Slooten 2013b; referred to as the HMD proxy area) and 2) the spatial area being currently considered for the Hector's/Māui dolphin Threat Management Plan by Ministry of Primary Industries (MPI), FNZ and DOC (Figure 2).

Relevant aspects of the biology of the Hector's/Māui dolphins are reviewed and discussed: the available scientific information on foraging and diet of Hector's/Māui dolphins is presented, as well as the current knowledge about their vocalisations and hearing. To put this into context, background information on acoustic metrics, noise exposure criteria, and impact categories is provided.

To complement the existing information on Hector's/ Māui dolphins, the review draws on information from relevant case studies conducted overseas and uses knowledge on harbour porpoises (*Phocoena phocoena*) as a proxy given this species' comparable anatomical features and auditory characteristics. A discussion of cumulative effects, as well as monitoring and mitigating effects, are provided as these are two important aspects for developing efficient conservation strategies. Before discussing the effects of O&G and mineral mining activities on Hector's/Māui dolphins, results from studies on harbour porpoises are given. This review concludes with a list of gaps in knowledge and research recommendations.

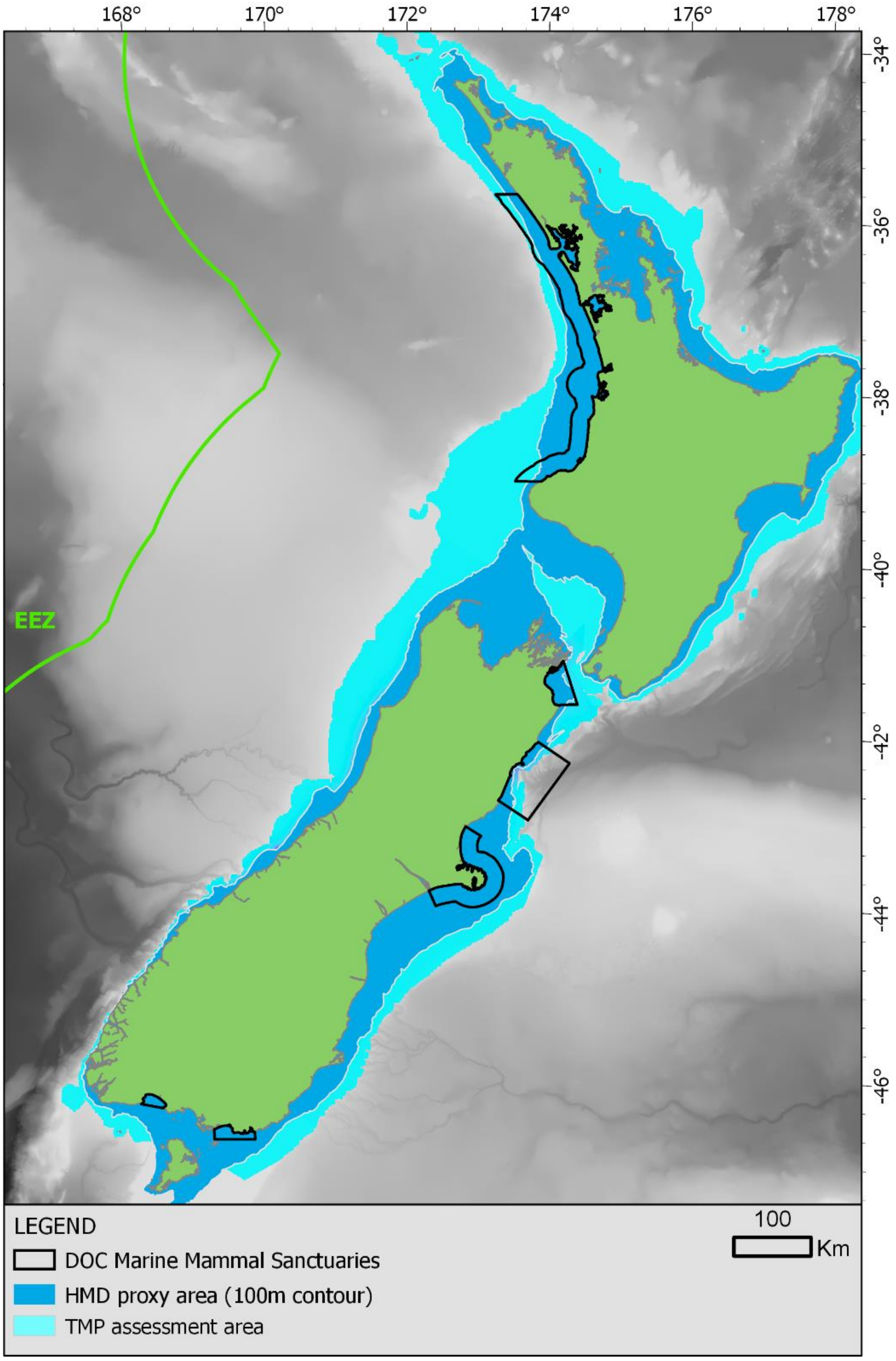

Figure 2. Map of the areas used for quantifying potential overlap between Hector's/Māui dolphins and oil and gas, as well as mineral activities within New Zealand waters in Table 1. The spatial assessment area being considered by the Hector's/Māui dolphin Threat Management Plan (TMP) is shown in light blue and the 100 m depth contour–a proxy for the species' potential distribution (proposed by Slooten 2013b) is shown in dark blue on top. The relevant marine mammal sanctuaries are represented with a black outline.

2. Status of the Oil & Gas and the Mineral Mining Activities in New Zealand

There is increasing interest in oil and gas prospecting and mineral extraction in offshore continental shelf areas of New Zealand. New Zealand has sovereign rights to the world's fourth largest Exclusive Economic Zone (EEZ; Ellis et al. 2017), with at least 14 sedimentary basins with hydrocarbon potential (Figure 3).

Marine resources are generally split into two groups (Lamarche and Clark 2013):

1. Petroleum, which includes oil, gas and gas hydrates[1] (collectively known as O&G)
2. Minerals, which includes:
    a. Coastal resources (e.g., sand, aggregates, and placer deposits (heavy minerals and gems)), and,
    b. Deep-sea minerals (e.g., massive sulphides and precipitates (phosphorites and manganese nodules).

[1] Gas hydrate is an ice-like form of water that contains gas in its cavities. Although there is estimated to be a vast resource of gas hydrates along the east coast of the North Island, at present the technological cost of extracting the hydrates renders production uneconomical (Lamarche and Clark 2013).

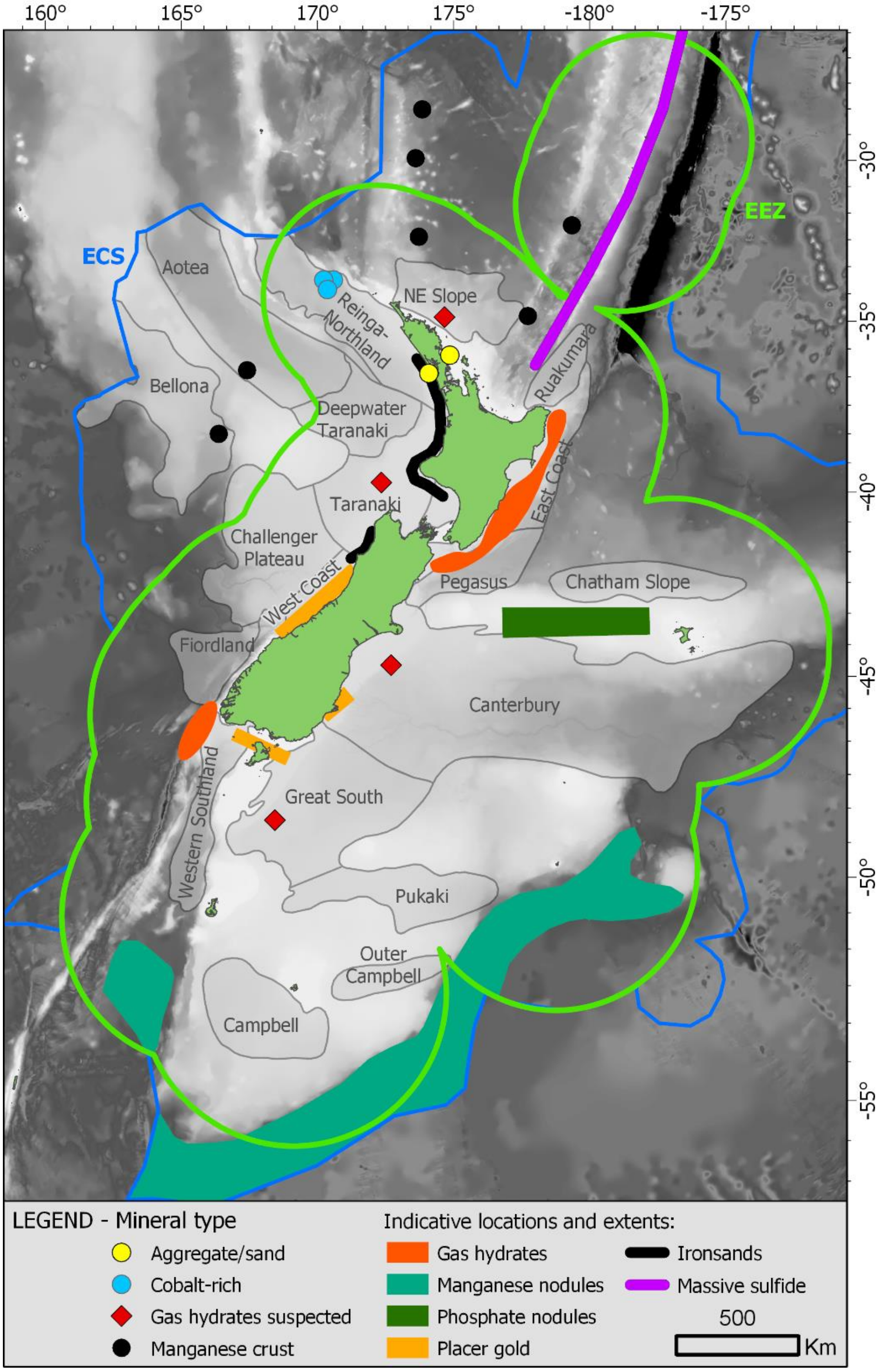

Figure 3. Indicative location and extent of offshore hydrocarbon basins and mineral resources within New Zealand Exclusive Economic Zone (EEZ) and Extended Continental Shelf (ECS). Names indicate individual offshore basins. Modified from MacDiarmid et al. (2011).

2.1. Petroleum

The Taranaki Basin is currently the only O&G producing basin in New Zealand, with over 400 onshore and offshore exploration and production wells drilled to date (MacDiarmid et al. 2011) (Figure 4). No production wells have been drilled beyond the Taranaki shelf edge. Exploration drilling in deeper parts of the EEZ, for instance within the Great South Basin southeast of the South Island, revealed petroleum systems in other parts of New Zealand's EEZ. This indicates considerable potential for further discoveries. Some of these areas could be larger than the Maui field, which is currently New Zealand's largest field.

Based on active permits only, there are approximately 22 coastal and offshore[2] exploration permits managed by New Zealand Petroleum and Mineral (NZPAM[3]) within Taranaki and the west coast of the North Island, east coast of the North Island, and southeast coast of the South Island. There are a further seven active mining permits/licenses all within the Taranaki Basin (Figure 5). Together, these permits cover an area of approximately 100,000 km^2.

In April 2018, the New Zealand government announced that it would cease issuing further offshore exploration permits for O&G resources. This decision will be given legal effect by (the Crown Minerals [Petroleum] Amendment Bill, CMPAB 2018), should it become law. Should this happen, existing permits will be honoured, and exploration and extraction will continue within them (depending upon the permit).

[2] 'Offshore' refers to the area outside of New Zealand's territorial seas. 'Coastal' refers to the area within the territorial sea boundary, and below the mean high-water mark.

[3] The government agency that manages the government's petroleum and mineral portfolio as part of the Ministry of Business, Innovation and Employment (MBIE).

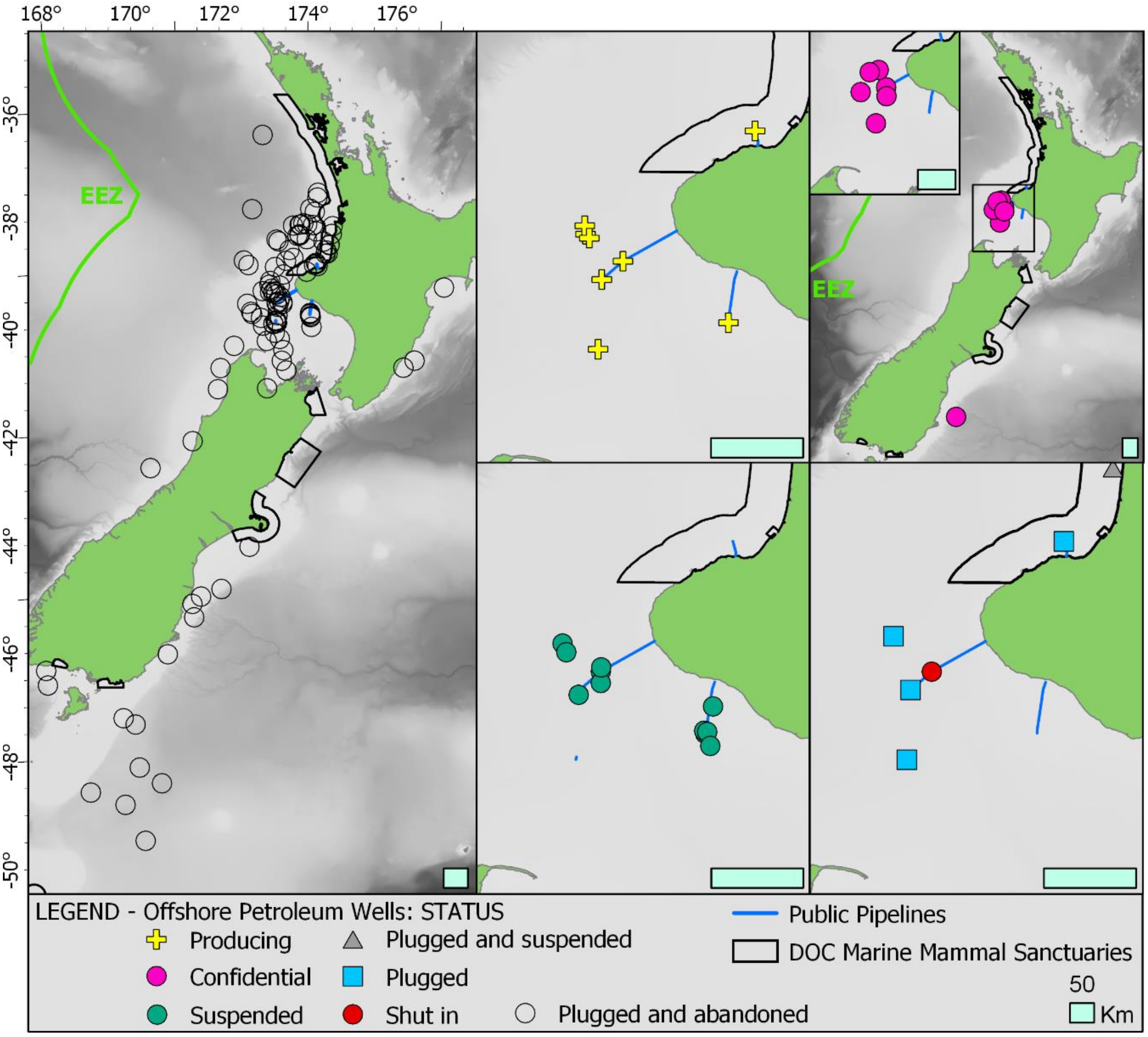

Figure 4. The locations of onshore and offshore well sites for Oil & Gas (O&G) production and exploration within New Zealand's Exclusive Economic Zone (EEZ) based on currently active permits and/or licenses. Information supplied by the Ministry of Business, Innovation, and Employment (MBIE) December 2018.

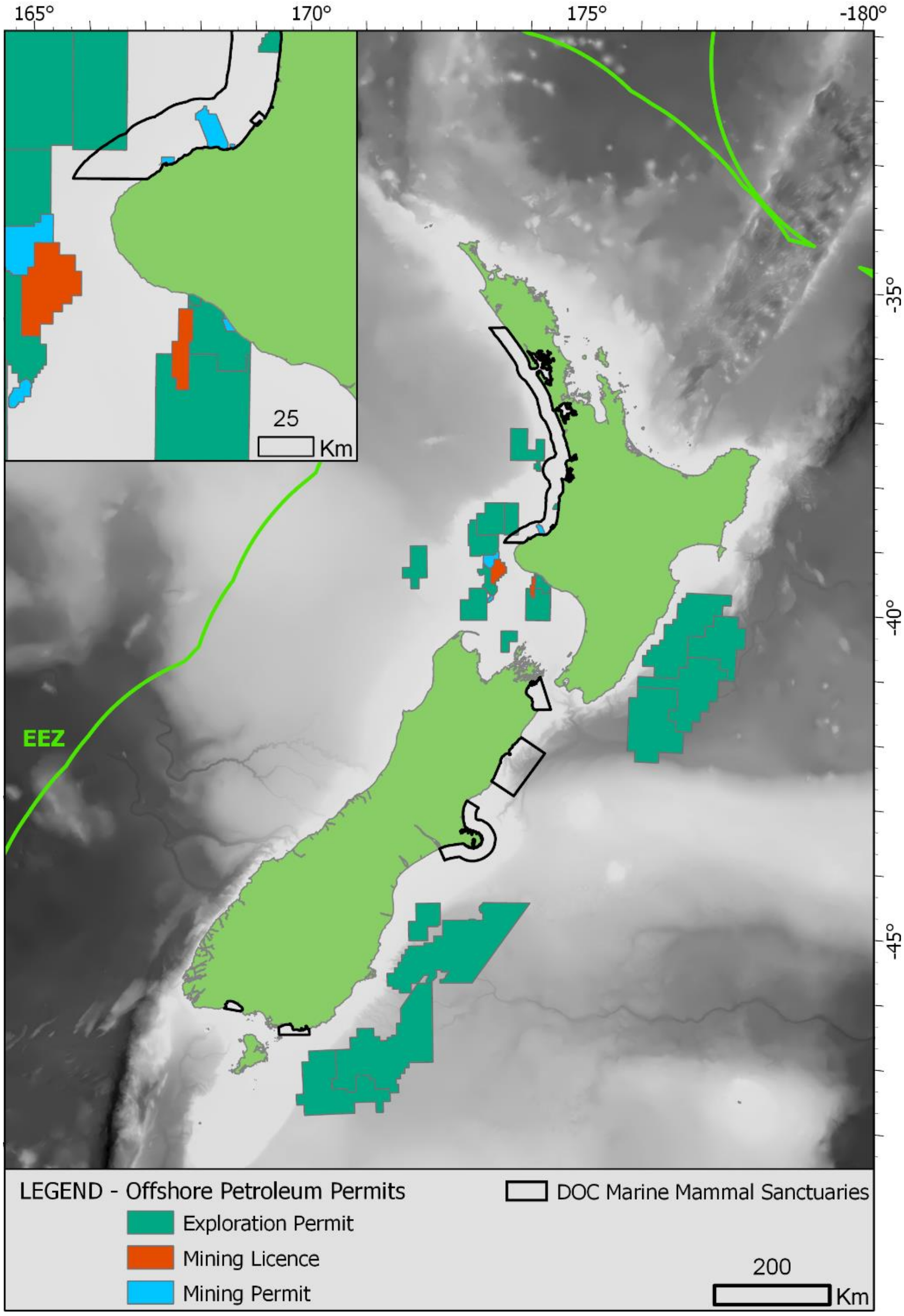

Figure 5. The locations of New Zealand Petroleum and Minerals (NZPAM) Oil & Gas (O&G) exploration and mining permit blocks shaded in blue within New Zealand's Exclusive Economic Zone (EEZ) based on currently active permits and/or licenses. Information downloaded from NZPAM webmaps, November 2018 and MBIE December 2018. DOC: New Zealand Department of Conservation.

2.2. Minerals

There is presently no restriction on permits for coastal and offshore mineral extraction exploration or production (iron sands, massive sulphide deposits, phosphate nodules, etc.). The seven active mineral permit areas in New Zealand's coastal space cover just over 5,500 km^2 located within the Taranaki Basin, Canterbury Basin, and the upper Bay of Plenty (Figure 6). In August 2017, the Environmental Protection Authority (EPA) in New Zealand granted Trans-Tasman Resources Limited (TTRL) consent to mine 50 million tonnes of iron sand annually for 35 years in the South Taranaki Bight. This decision was contested in court, with a High Court decision released on 28 Aug 2018 quashing the decision and referring the application back to the Decision-Making Committee for reconsideration. This decision was subsequently appealed by TTRL, and a final decision is expected in 2019.

In New Zealand, placer deposits[4] are predominantly found in shallow coastal areas. They include iron sand (west coasts of the North and South Islands) and aggregate gold deposits (Figure 3). Deep-sea mineral resources in New Zealand include: seafloor massive sulphides[5] (containing iron, manganese, gold, silver, copper, and zinc) in the region of the Kermadec Arc; polymetallic nodules (e.g., ferro/manganese) on the Campbell Plateau; phosphorite nodules on the Chatham Rise; and cobalt-rich crusts on North Island seamounts.

[4] Placer deposits are those that have accumulated by physical process (i.e., waves, currents, and wind).

[5] Associated with thermal vents.

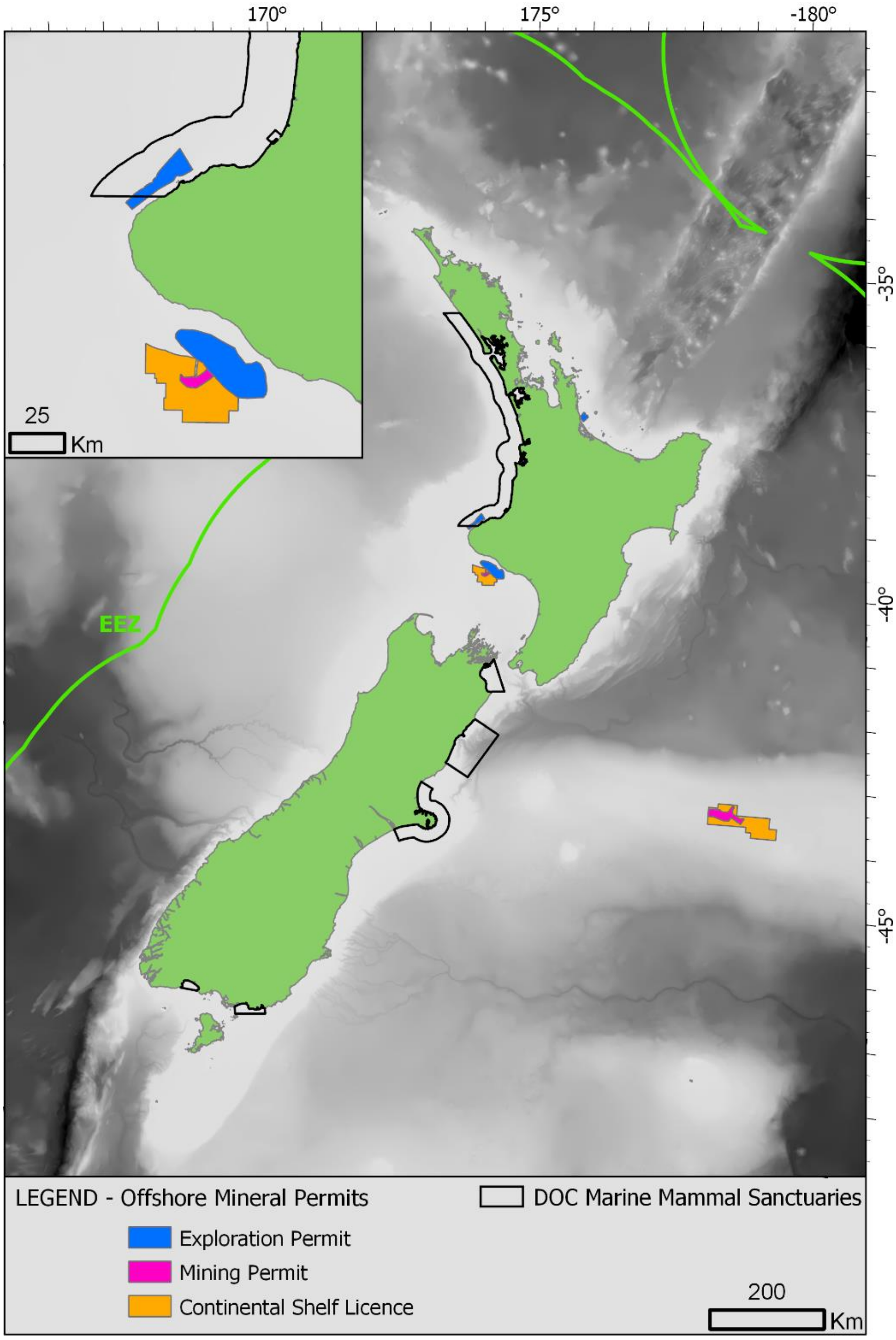

Figure 6. The locations of mineral exploration and mining permit blocks within New Zealand's Exclusive Economic Zone based on currently active permits and/or licenses. Information downloaded from New Zealand Petroleum and Minerals (NZPAM) webmaps, November 2018 and supplied by the Ministry of Business, Innovation and Employment (MBIE), December 2018.

2.3. Activities Associated with O&G and Mineral Extraction

The general developmental phases in O&G and mineral activities are: 1) prospecting (broadscale surveying for deposits), 2) exploration (fine scale sampling for deposits), 3) production, and 4) abandoning/decommissioning (MacDiarmid et al. 2011). Seismic surveys associated with prospecting, exploring and production phases may have adverse effects on marine mammals. Seismic surveying for these purposes[6] is not a new occurrence within the New Zealand marine environment. Vast swaths of seismic surveys having been carried out throughout the marine area since the late 1950s. As illustrated in Figures 7 and 8, past surveys focused on the west coast of the North Island (Taranaki Basin) and the east coast of the lower South Island (Great South Basin and Canterbury Basin).

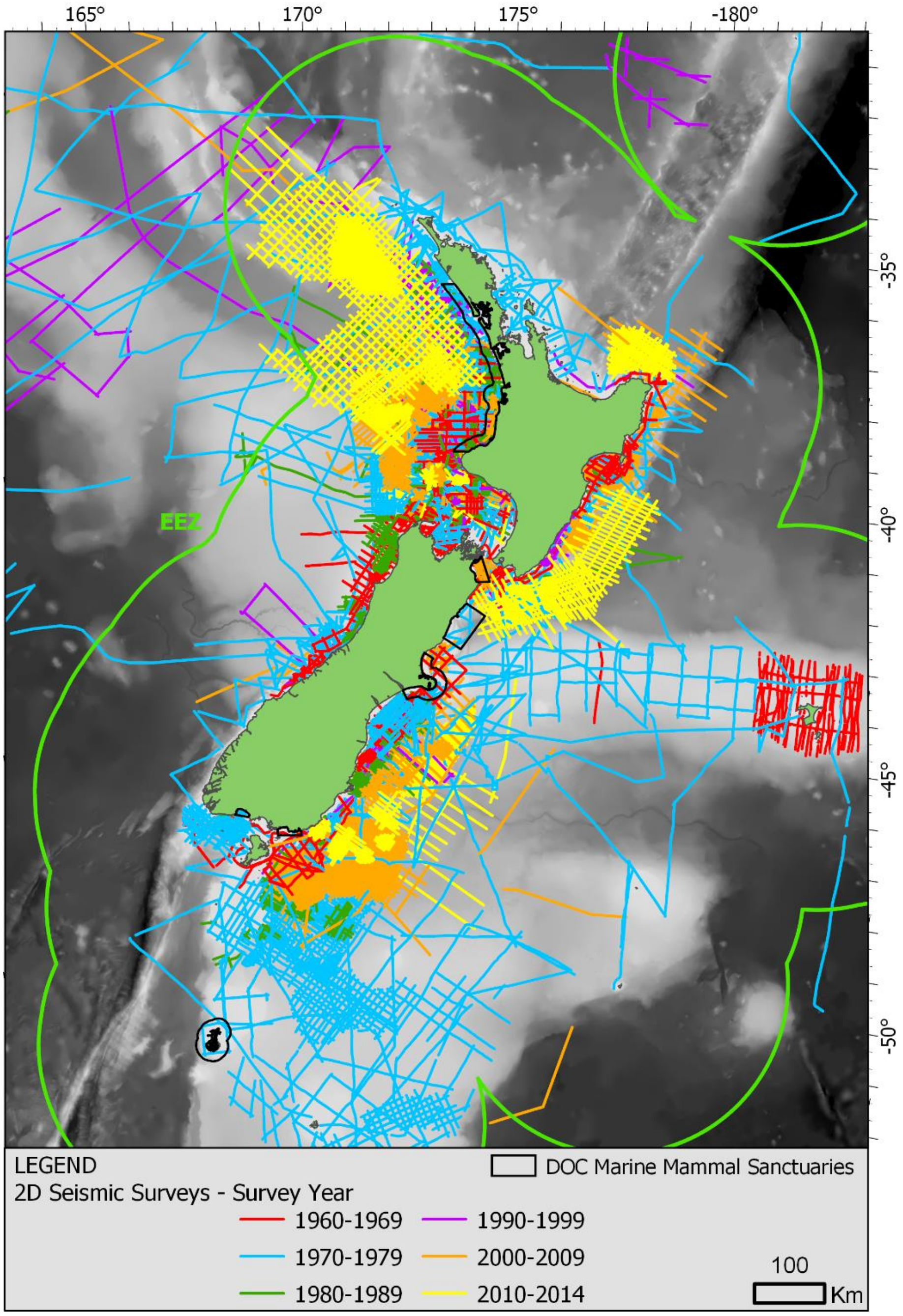

Figure 7. Seismic survey locations for Oil & Gas (O&G) and mineral prospecting and/ or exploration phases for two-dimensional (2-D) seismic surveys between 1958 and 2014 within New Zealand's Exclusive Economic Zone (EEZ). Surveys have been colour coded by decade. Information downloaded from New Zealand Petroleum and Minerals (NZPAM) webmaps, November 2018. The boundaries of the various Department of Conservation (DOC) marine mammal sanctuaries are outlined in black, noting that these sanctuaries have been gazetted at different time periods beginning in 1984.

[6] For petroleum and mineral prospecting and exploration but does not including any seismic work for research (i.e., seabed mapping).

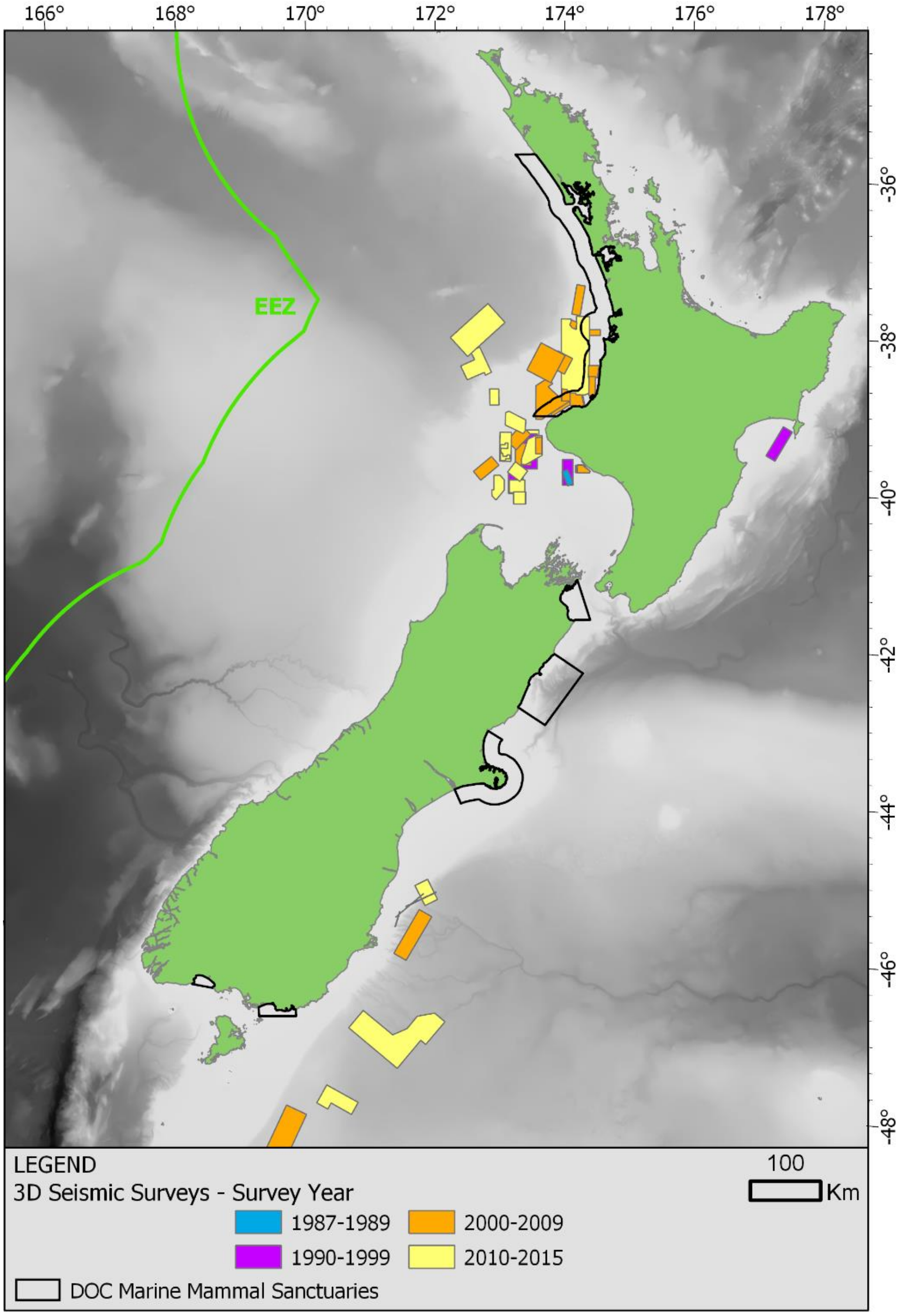

Figure 8. Seismic survey area locations for Oil & Gas (O&G) and mineral prospecting and/ or exploration phases for three-dimensional (3-D) seismic surveys between 1987 and 2015 within New Zealand's Exclusive Economic Zone. Surveys have been colour coded by decade. Information downloaded from New Zealand Petroleum and Minerals (NZPAM) webmaps, November 2018. Boundaries of the various Department of Conservation (DOC) marine mammal sanctuaries are outlined in black, noting that these sanctuaries have been gazetted at different time periods beginning in 1984.

2.4. Legislation

Figure 9 shows the marine areas where marine legislation for O&G and mineral activities applies in New Zealand. The Exclusive Economic Zone and Continental Shelf (Environmental Effects) Act (EEZ Act 2012) and the Crown Minerals Act (1991) provide the principal legislative and regulatory framework for exploration and exploitation of offshore mineral resources (i.e. beyond twelve (12) nautical miles). Within the territorial seas and foreshore, the Resource Management Act (1991) substitutes the EEZ Act within this framework. Several different government agencies are responsible for permitting and licencing of different phases explained above. Appendix A and the Ministry for the Environment website[7] contain a brief summary diagram explaining this process.

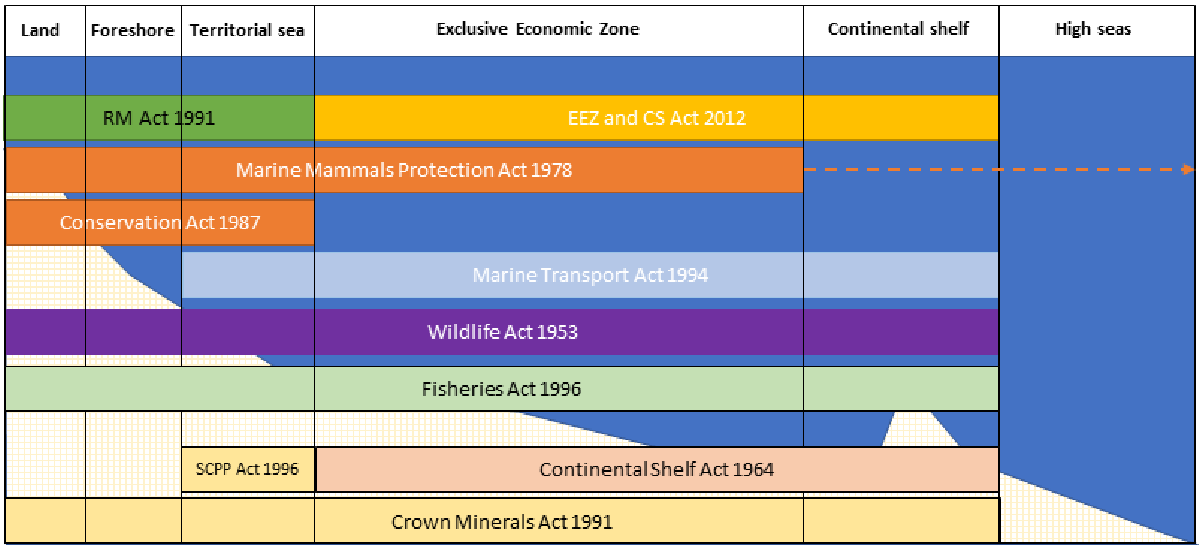

Figure 9. Spatial extent of legislation and regulations relevant to Oil & Gas (O&G) activities within New Zealand's Exclusive Economic Zone (EEZ). (modified from MacDiarmid et al. 2011). RM: Resource Management, EEZ: Exclusive economic zone, CS: Continental shelf, SCPP: Submarine Cables and Pipelines Protection Act. See MacDiarmid et al. (2011) for more details.

2.4.1. Production and drilling site exclusion zones

Although not strictly marine conservation areas, the following legislative protection areas and access restrictions associated with existing offshore facilities provide some conservation protection:

- Taranaki Offshore Precautionary Area (MNZ 2007): As of mid-2007, this extended area was identified by Maritime New Zealand as a precautionary measure. All ships must navigate in this area with particular caution to reduce the risk of a maritime incident and resulting marine pollution in consequence of the high level of offshore O&G activity.
- New Zealand Nautical Almanac (Land Information New Zealand 2018): All vessels are required/recommended to keep a safe margin of distance (at least 5 nm clear) from all offshore installations.
- Submarine Cables and Pipelines Protection Act (SCPP 1996): for the protection of submarine cables and pipelines in coastal New Zealand. There are also orders surrounding specific O&G fields in the Taranaki offshore/nearshore region.
- Continental Shelf Act (1964). Safety zones, made under the Continental Shelf Act, are specified in the following regulations:
  - Continental Shelf (Maui A Safety Zone) Regulations 1975
  - Continental Shelf (Maui B Safety Zone) Regulations 1991
  - Continental Shelf (Pohokura B Safety Zone) Regulations 2006
  - Continental Shelf (Kupe Safety Zone) Regulations 2006

[7] http://www.mfe.govt.nz/sites/default/files/media/who-does-what-in-offshore-waters.pdf

- Continental Shelf (Umuroa Installation Safety Zone) Regulations 2008
- Continental Shelf (Maari Development Safety Zones) Regulations 2008

2.5. Trends

While two-dimensional (2-D) or three-dimensional (3-D) seismic surveying have been underway in New Zealand waters since the later 1950s and 1980s, respectively, DOC required proponents to notify them of seismic surveys requiring marine mammal observers (MMOs) from 2012.[8] While Figure 10 highlights the total number of annual seismic surveys (with MMOs on-board), individual surveys can vary substantially in terms of length and duration. Hence, while 2013/2014 had a large number of MMO-observed seismic surveys, these were relatively short surveys compared to the scale of longer-lasting, multi-client surveys being conducted after 2014 (D. Lundquist, DOC, pers. comm). Hence, for any relative comparisons, these data should be reviewed with reference to Table 1.

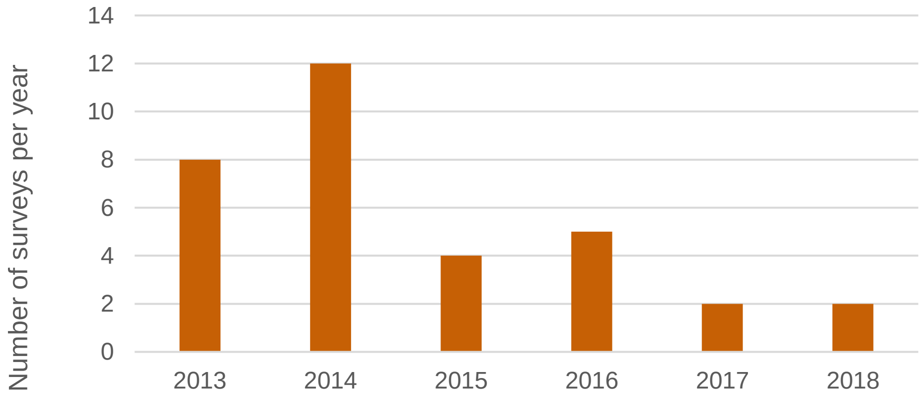

Figure 10. The annual number of 3-D seismic surveys undertaken since the Department of Conservation, New Zealand implemented mandatory marine mammal observers onboard (summer 2012–2013) (Data supplied by D. Lunquist, DOC).

The number of O&G prospecting, exploratory and production permits granted each year with NZ is highly variable and contingent on market interest as a function of commodity prices, available acreage, new discoveries and government policies. In addition, permit allocation methods and commencement patterns often depend on what the government decides to offer. Thus, permits also vary between exploration vs production, between different basins and resource types. Figure 11 highlights this variability in the number of currently active permits issued between 1970 and 2000.

[8] In 2012, the *Code of Conduct for Minimising Acoustic Disturbance to Marine Mammals from Seismic Survey Operation*s (the Code) in New Zealand waters was substantially expanded by the Department of Conservation and adopted by the New Zealand seismic surveying community.

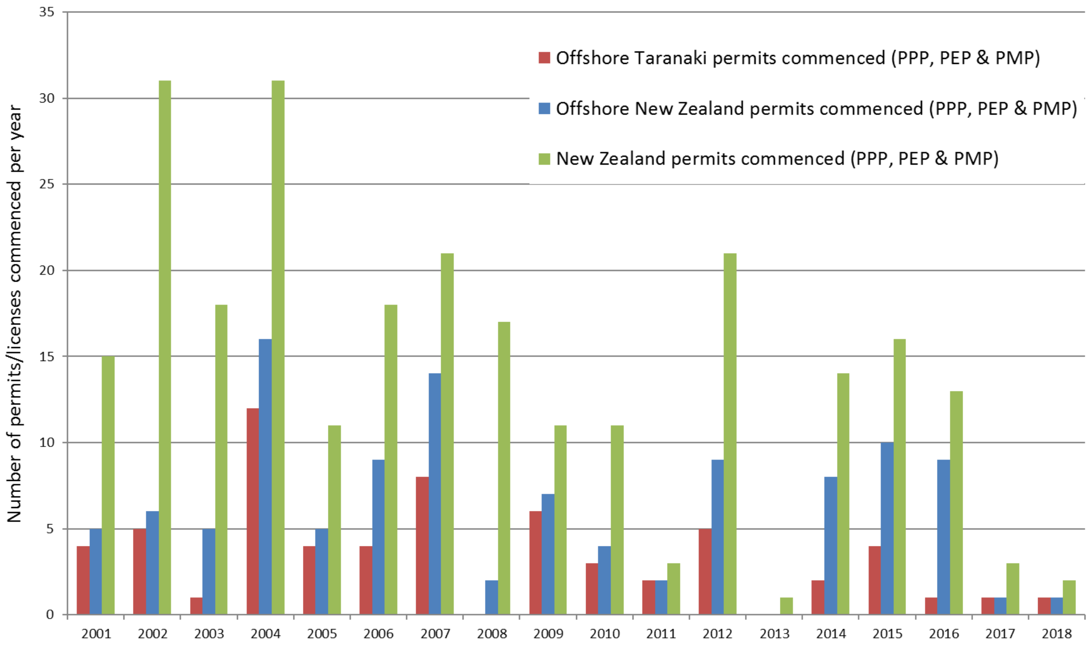

Figure 11. The number of offshore Oil & Gas (O&G) prospecting, exploratory and/or production permits and licenses issued annually within New Zealand since the late 1970s. The data set only recognises currently active permits issued between 1970 to 2000. (Data provided by J. Decker, MBIE).

2.6. Overlap with Hector's and Māui Dolphin Distribution

The spatial information on currently active O&G permits and licenses as well as all previous seismic surveys undertaken within New Zealand's EEZ were supplied by the Ministry of Business, Innovation and Employment (MBIE). Table 1 quantifies the total overlap of these activities with Hector's/Mui's dolphins in the following three ways:

1. Overlap within the EEZ,
2. Overlap with the spatial area being currently considered for the Hector's/Māui dolphin TMP by Ministry of Primary Industries (MPI), FNZ and DOC ('TMP assessment area'), and
3. Overlap with a precautionary proxy for the species' current distribution. The species' distribution proxy is based on the 100 m depth contour around New Zealand (Slooten 2013b) and any marine mammal sanctuaries (approximation of Hector's/Māui dolphins' habitat, 'HMD proxy area').

Out of the total O&G exploration and production activities currently occurring around New Zealand, approximately 5.4% are located within the 100 m depth contour. Only a small proportion of these permits or well sites are active and currently under production (9% of permits and 20% of well sites; Table 1, Figure 12). Most permits are located within the South Taranaki Bight, with a few small area located near New Plymouth and within the West Coast North Island Marine Mammal sanctuary (WCNIMMS, 'North Island Sanctuary', established for Māui dolphins) as Figure 13 demonstrates.

Approximately 33% of active mineral permits and 31% of licences overlap with the TMP and 100 m contour areas (Table 1, Figure 13). As with petroleum permits, mineral activity is also concentrated within the South Taranaki Bight with only a small proportion of exploratory permits found outside this region near New Plymouth and overlapping with the North Island Sanctuary.

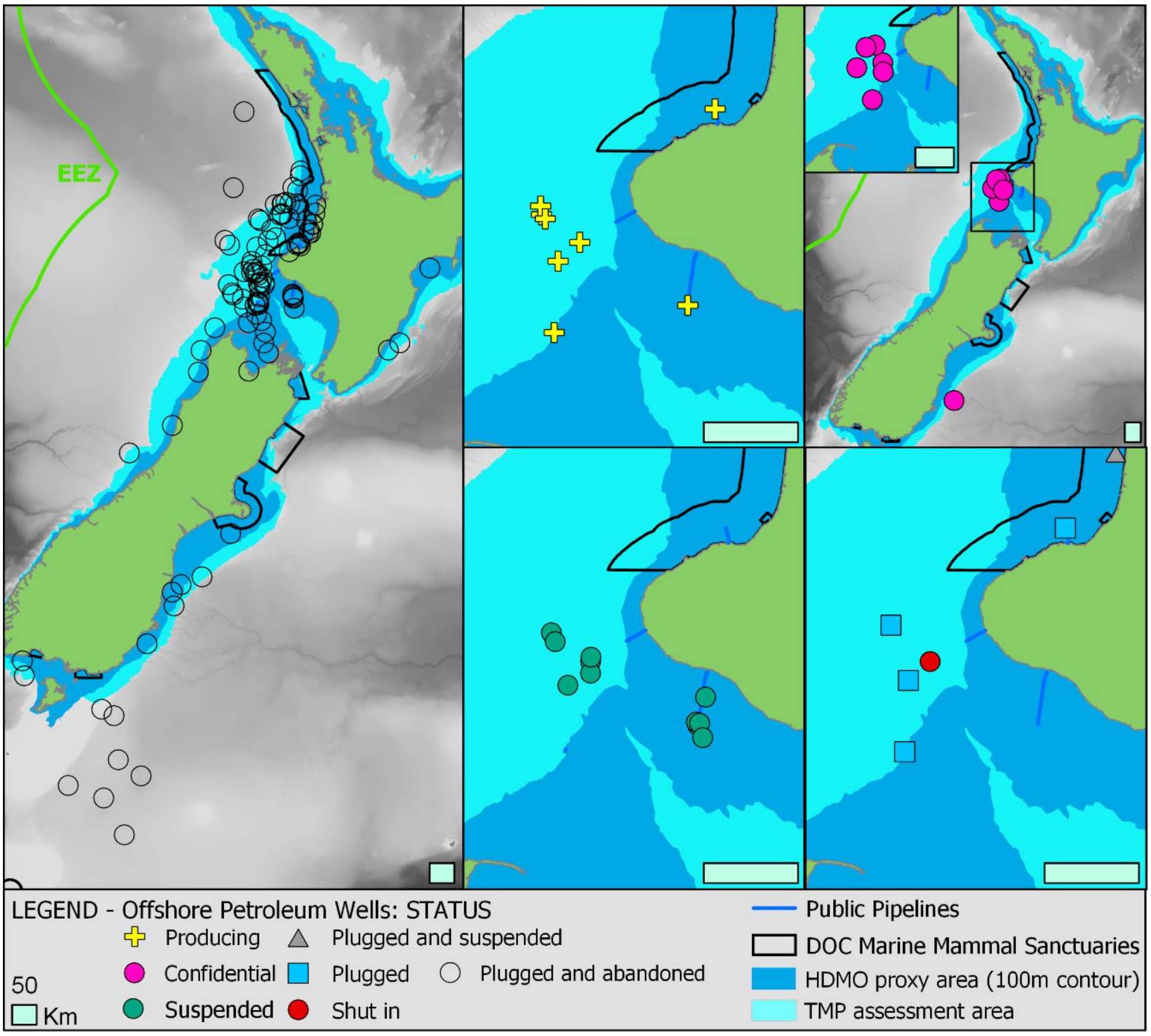

Figure 12. The spatial overlap between Hector's/Maui dolphin distribution zones and currently active permits / licenses for Oil & Gas (O&G) well sites. The spatial assessment area being considered by the Hector's/Māui dolphin Threat Management Plan (TMP) is shown in light blue and the HMD 100 m depth proxy distribution is shown in dark blue on top. The relevant marine mammal sanctuaries are represented with a black outline. Information supplied by the Ministry of Business, Innovation, and Employment (MBIE) December 2018.

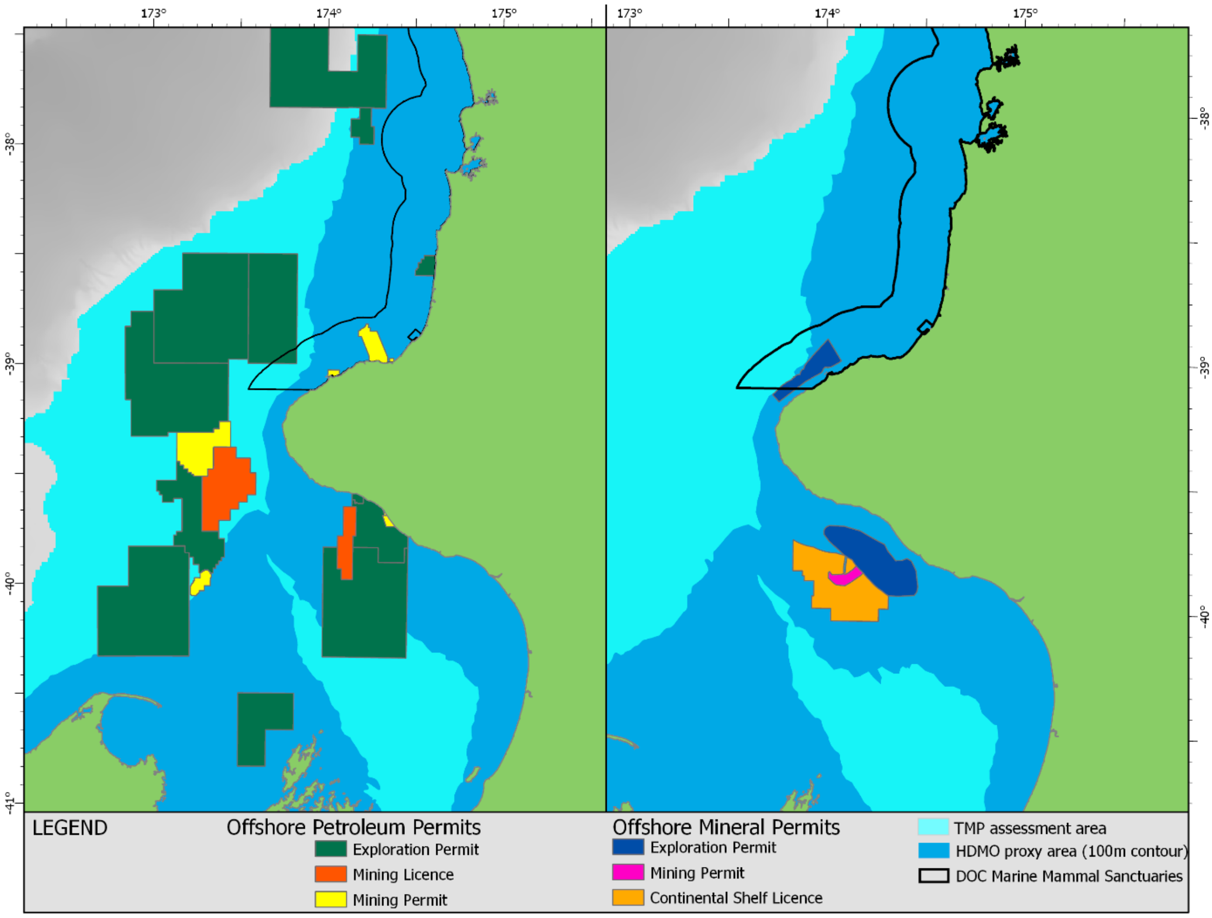

Figure 13. The spatial overlap between Hector's/Maui dolphin distribution zones and currently active permits / licenses for Oil & Gas (O&G) (left) and minerals (right). The spatial assessment area being considered by the Hector's/Māui dolphin Threat Management Plan (TMP) is shown in light blue and the HMD 100 m depth proxy distribution is shown in dark blue on top. The relevant marine mammal sanctuaries are represented with a black outline. Information supplied by the Ministry of Business, Innovation, and Employment (MBIE) December 2018.

Table 1 includes the total length (2-D) or area (3-D) of seismic surveys undertaken around New Zealand. The length and area consider the physical footprint of these activities, not the potential acoustic footprint. While some exclusions existed before 2008, only surveys conducted after 2008 are quantified for overlap with Hector's and Māui dolphin distribution. This was the year when current regulations around O&G activity for the North Island Sanctuary and the majority of fisheries exclusion zones for Hector's and Māui dolphins were enacted.

Figure 14 highlights the few areas in which 2-D seismic surveys have overlapped with the distribution of both Hector's and Maui's dolphins since 2008, as most of these surveys occurred in more offshore waters. A larger portion of 3-D seismic areas permitted since 2009, however, have taken place within or near the North Island Sanctuary, mainly concentrated between Raglan and New Plymouth (Figure 14).

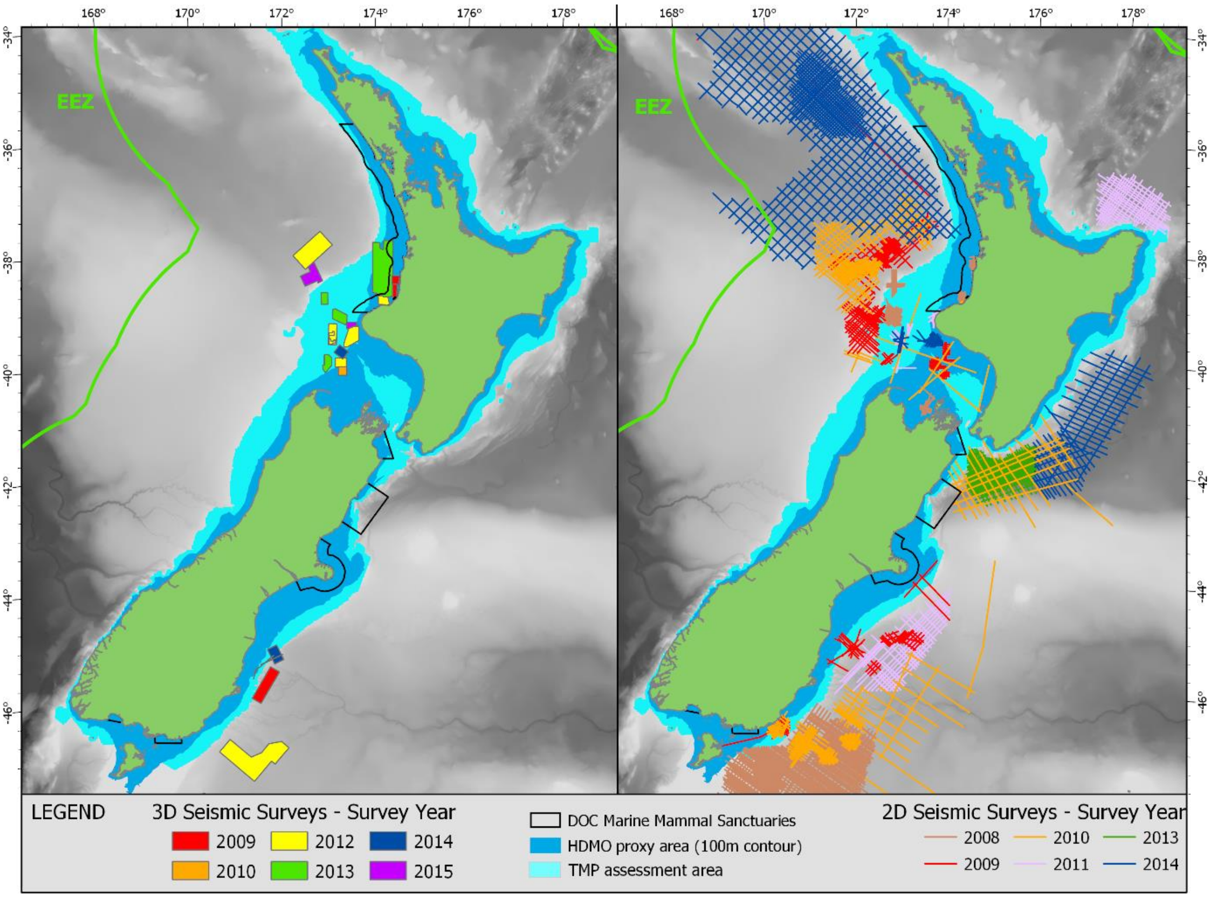

Figure 14. The spatial overlap between Hector's/Maui dolphin distribution zones and 3-D seismic surveys (left) and 2-D seismic surveys (right) undertaken since 2008 within New Zealand's Exclusive Economic Zone. Surveys have been colour coded by year. The spatial assessment area being considered by the Hector's/Māui dolphin Threat Management Plan (TMP) is shown in light blue and the HMD 100 m depth proxy distribution is shown in dark blue on top. The relevant marine mammal sanctuaries are represented with a black outline. Information downloaded from New Zealand Petroleum and Minerals (NZPAM) webmaps, November 2018.

Table 1. A summary of oil and gas activities and their area of overlap within three regions: 1) New Zealand's Exclusive Economic Zone (EEZ), 2) the area under consideration by the Hector's/Māui dolphin Threat Management Plan (TMP), and 3) the area within the 100 m depth contour–precautionary proxy for current Hector's/Māui dolphin (HMD) distribution. Petroleum and mineral activities are considered separately and broken down into type (see explanation in Section 2.3). Seismic surveys were calculated by length of survey transect for two-dimensional (2-D) seismic surveys and by survey area for three-dimensional (3-D) seismic surveys (MBIE supplied the O&G and mineral data, and GNS supplied the seismic survey data).

Type of oil and gas activity		Total area in EEZ		TMP assessment area		HMD proxy area	
		km^2	No. of wells	km^2	No. of wells	km^2	No. of wells
Petroleum							
Exploration and production well sites*	Producing or suspended	55	70	55	70	10	13
	Confidential	19	24	18	23	0	
	Plugged (suspended or abandoned)	116	147	108	137	42	54
Permits and/or licences	Mining permits/licences	1874		1874		479	
	Exploratory permits	99,380		16475		4875	
Production pipelines		87		87		50	
		101,529		**18,616**		**5458**	
Minerals							
Permits and/or licences	Mining permits/licences	893		66		66	
	Exploratory permits	983		983		859	
	Continental shelf licence†	3718		816†		816†	
		5596		**1865**		**1741**	
Seismic surveys							
2-D surveys, all years (km length)		446,787,292					
2-D surveys, post-2008–2014 (km length)		95,913,000		8453		3850	
3-D surveys, all years (km^2)		35,797					
3-D surveys, post-2009–2014 (km^2)		21,751		10,286		5730	

* The area of well site footprint was based on research on the benthic effects of drilling in New Zealand waters (Elvines et al. In draft-a). The worst effect of 500 m from the drill site was used to create a 0.785 km^2 buffer around each site.
† The Trans-Tasman Resources Limited continental shelf licence (815.7 km^2) is listed as pending on land decision.

3. Potential and/or Perceived Impacts on Hector’s/Māui dolphins

Hydrocarbon (O&G) activities and mineral mining are the two core activities assessed in this report. They are intrinsically linked to a large number of associated activities over the entire lifecycle, from prospecting and exploiting to decommissioning. Supporting logistics, such as port construction and pipeline laying, are also considered in this context. Tables 2 and 3 provide extensive (but not exclusive) lists of relevant activities and associated emissions or stressors potentially affecting the marine environment. There is also potential for unwanted/unplanned effects associated with O&G and mineral extraction, such as accidental spills, dropped objects, and marine vessel accidents. Pile driving maybe required during exploratory drilling and the construction phase to create anchor points for drill rigs. It may also be required during the construction of on-, near-, and offshore installations. The main effects of pile driving are related to sound, presence, toxins, and turbidity.

Table 2. List of activities related with extraction of hydrocarbons in marine offshore areas and associated emissions (in alphabetical order per category, not ranked by severity of effect or contamination); presence: physical presence of vessel or structure, toxins: toxic chemical release.

Petroleum extraction phases and processes[1]	Emissions and/or potential stressors
Acoustic prospecting and seismic surveying	
Seismic airgun array	Sound
Single and multibeam echo sounder	Sound
Ship activities	Sound, light, toxins, presence
Exploratory drilling	
Drill cuttings piles	Sound
Drilling activities	Sound, toxins
Platform structure	Sound, light, presence, biofouling
Seafloor structures (including anchors and moorings)	Sound, presence, biofouling
Sediment plume	Turbidity, toxins
Shallow hazards surveys (Boomer, CHIRPs, sparker or shallow seismic)	Sound
Ship activities	Sound, light, toxins, presence
Support vessel activities	Sound, light, toxins, presence
Swath mapping site surveys	Sound
Underwater lights	Light
Field development	
Construction of field structures	Sound, toxins, biofouling, presence
Construction of port structures	Sound, toxins, biofouling, presence
Ship activities	Sound, light, presence
Underwater pipeline laying, trenching, inspection and maintenance	Sound, turbidity, presence
Oil or gas production	
Platform flood lights and sound	Sound, light
Platform, Floating Production Storage Offload (FPSO), Floating Production Unit (FPU), Floating Storage Offload (FSO) (with/without dynamic positioning system)	Sound, presence, toxins, biofouling
Seabed structures (choke valves, pipelines, etc.)	Presence, sound, biofouling
Sediment plume	Turbidity, chemicals
Ship activities	Sound, light, toxins, presence
Support vessel activities	Sound, toxins, presence
Toxic discharge	Chemicals
Underwater lights	Light, presence
Abandoning and Decommissioning	
Abandonment, sinking of platform and equipment	Sound, presence, biofouling
Material degradation	Toxins
Recovery of all equipment, plant and machinery	Sound, light, chemicals, presence
Ship activities	Sound, light, toxins, presence
Support vessel activity	Sound, light, presence
Underwater lights	Light, presence
Wellcapping	Sound, presence
Pile driving	
Abandonment, sinking of platform and equipment	Sound, presence, toxins, and turbidity

[1] Modified from MacDiarmid et al (2011).

Table 3. List of activities associated with mineral exploration and extraction in marine offshore areas (in alphabetical order per category, not ranked by severity of effect or contamination); presence: physical presence of vessel or structure, toxins: toxic chemical release.

Mineral exploration and extraction phases and processes	Emissions and/or potential stressors
Prospecting	
Acoustic swath mapping	Sound
Airgun seismic surveys	Sound
Core drilling over a wide area	Sound, presence, turbidity
High resolution seismic surveys (such as shallow hazards, using boomers, CHIRPs, sparkers (shallow seismic airguns)	Sound, light, presence
ROV and other imaging surveys	Sound, light, presence
Spot sampling (using ROVs and AUVs)	Sound, light, turbidity, toxins, presence
Spot sampling (using ROVs, submersibles, or rock dredges)	Sound, light, turbidity, toxins, presence
Sub-bottom profiling (using boomers, CHIRPs, or sparkers)	Sound
Survey vessel activities	Sound, light, toxins, presence
Towed magnetometer surveys	Sound
Exploration	
Bulk sampling	Turbidity, sound, toxins
Construction of port structures	Sound, toxins, biofouling, presence
Core drilling at fewer sites	Sound, turbidity, toxins
Mining vessel activities	Sound, light, presence
Sediment plume	Turbidity, toxins
Ship activities	Sound, light, presence
Site surveys (using swath mapping)	Sound
Sub-bottom profiling (using boomers, CHIRPs, or sparkers)	Sound
Survey vessel activities	Sound, light, toxins, presence
Support vessel activities	Sound, light, toxins, presence
Test drilling	Sound, turbidity, toxins
Test extraction methods	Sound, turbidity, toxins
Test pit excavation (using different methods)	Sound, turbidity, toxins
Mining	
Bulk ore carrier	Sound, light, toxins, presence
Deposition of tailings in stock piles or pits	Sound, turbidity, toxins, presence
Deposition plume	Turbidity, toxins
Extraction plume	Turbidity, toxins
Mining vessel activities	Sound, light, toxins, presence
Mooring blocks or anchors	Presence, biofouling
Sea floor slurry pipes	Sound, presence
Seafloor cutting, fragmentation	Sound, turbidity, toxins
Seafloor mining	Sound, turbidity, toxins
Seafloor slurry pipes	Sound, presence
Seafloor suction	Sound, turbidity, toxins
Slurry pipes	Sound, presence
Support vessel activities	Sound, light, toxins, presence
Swath mapping to determine change in bathymetry	Sound
Toxic chemical release	Toxins
Wash water return	Toxins

[1] Modified from MacDiarmid et al (2011).

3.1. Potential Effects of Stressors

There are numerous potential impacts of the stressors related to mineral exploration and mining on marine mammals that can also compound and/or accumulate in their effects. The main concerns are focussed on:

- Vessel strikes (see Sections 3.1.1 and 4.3.6),
- Physical effects (see Section 4.3.6) and noise-induced physical effects (see Section 4.3.5),
- Auditory masking (see Section 4.3.4),
- Behavioural effects and stress (see Section 4.3.3),
- Cumulative effects from repeated or aggregate exposure (see Section 7),
- Pathological effects caused by increased uptake of toxins through the food chain (see Section 3.1.3), and
- Changes in species composition and abundance (see Section 3.1.3.4).

3.1.1. Vessel strikes

The presence of fast-moving vessels increases the risk for collisions with Hector's/Māui dolphins. While Hector's dolphins approach boats more readily (Dawson et al. 2000) than Māui dolphins (R. Constantine pers. comm), there have been very few cases of vessel strike or collision with this species. Young and inexperienced animals may face a higher risk of collision with vessels (Stone and Yoshinaga 2000). Not all collisions with vessels (and/or structures) are fatal. Animals may suffer some degree of injury but survive such collisions. While the risk for vessel strikes depends on the context (location, type of craft, type of activity, number of vessels, number of dolphins) the overall risk for vessel strikes related to O&G and mineral mining activities for Hector's/Māui dolphins is likely to low.

3.1.2. Acoustic-related effects

Section 4.3 discusses the entire range of potential noise-induced effects likely applicable to Hector's/Māui dolphins (i.e., impairment of the auditory system via temporary or permanent threshold shift, (TTS or PTS, respectively), spatial and/or temporal avoidance of areas, auditory masking, and stress). Due to the scarcity or lack of scientific or even anecdotal information, an assessment of the risk and potential extent of noise-related effects must rely on information gathered in other species or deduced from indirect information.

3.1.3. Non-acoustic effects

Because marine mammals are at the top of the marine food chain, they accumulate some of the highest levels of environmental contaminants of all marine wildlife. They can be exposed to oil and oil-derived compounds via several routes of exposure. These include direct contact, ingestion of oil or oil-contaminated prey, inhalation of volatilized or aerosolized oil and/or oil components, and aspiration of oil directly into lungs (Godard-Codding and Collier 2018, Murphy et al. 2018). Contaminants resuspended in the water column through dredging or offshore construction activities are similarly taken up by marine mammals. Individually or interactively, these contaminants can lead to a systemic suppression of the immune function of marine mammals (Desforges et al. 2016). Section 5.2.1 discusses the effects of pollution on harbour porpoises as proxies for Hector's/Māui dolphins.

The following sections provide specific information on the effects of contaminants released by offshore drilling, dredging, and O&G production related discharges as well as community changes observed in relation to these activities.

3.1.3.1. Actual water quality effects from drilling and production related discharges

Discharges associated with drilling for hydrocarbons primarily consist of used drilling fluids (typically synthetic based [SBF]; generally, ester, ether, acetyl or olefin based) and water-based fluids (WBF, fresh or salt water based; Ellis et al. 2012) and drill cuttings (crushed rock or sediment brought up from the well hole). Drilling fluids also contain clay or organic polymer weighting materials (e.g., barite [$BaSO_4$] and ilmenite [$FeTiO_3$]), as well as various inorganic salts, solids and organic additives (Neff 2005). The use of oil-based fluids (OBF) has been discontinued in many countries (including New Zealand) due to the negative ecological effects associated (Neff et al. 2000, Neff 2005, 2008, Ellis et al. 2012).

Hydrocarbon production from an established offshore facility produces an array of operationally derived discharges and produced water, with the latter being the most significant production discharge volumetrically (Patin 1999). Produced water (PW) is predominantly comprised of formation water from the reservoir itself. This is particularly true in older wells, where more formation water is displaced as the reservoir depletes. As such, the chemical make-up of production-related discharges is wide-ranging, site specific, and temporally variable. The main contaminants associated with PW are usually derived from formation water, oil separation, and production additives such as biocides and corrosion inhibitors. Of most concern are water-soluble low-molecular-weight organic acids, aromatic hydrocarbons, and higher molecular weight alkylphenols and heavy metals (Neff 2002).

The fate of production discharges is not limited to deposition and precipitation of contaminants, but also dilution or dispersion within the water column (Neff et al. 2011, Niu et al. 2016). The exact pathway for contaminants in produced water (to the seafloor sediments) depends on the PW plume characteristics (Niu et al. 2016). Most modelling studies carried out in other oil production regions (Neff et al. 2011) have predicted rapid dilution of produced water by 30- to 100-fold within the first few tens of metres of the outfall followed by a slower rate of dilution at greater distances.

Long-term field monitoring programmes which have been carried out in major oil and gas production areas (e.g., North Sea, Norwegian Shelf, Gulf of Mexico) have not revealed elevated levels of contaminants from produced water in fish tissues except in resident animals close to the discharge point (IAOG 2005), which suggests that food chain transmission of contaminants via phytoplankton and zoo-plankton is slight, if at all.

3.1.3.2. Actual benthic effects from drilling and production related discharges

Recent studies of drilling and production discharge effects in the Taranaki offshore region (Elvines et al. In draft-a) showed that benthic communities tolerate localised impacts within 100, 250, and 500 m radii of the discharge source for exploration drilling, production discharges, and developmental drilling (around permanent operating facility structures) respectively. The most extreme community shift was observed at the exploration drilling well-head station, one month after drilling had ceased. Such extreme community shifts were not apparent when surveys were conducted two months or more after cessation of drilling. Community recovery took longer at already impacted production sites which were subjected to developmental drilling (up to 24 months). These trends were overshadowed by the regional-scale background spatial variation, with non-parametric multivariate regression showing geographical position accounting for 26% of the community variation and metals, particle grain size and depth collectively accounting for 10%. Results highlight the importance of site-specific assessments and regionally comparable control sites for assessing drilling- and production-related discharge effects.

3.1.3.3. Indirect effects of dredging

Indirect impacts from dredging on marine mammals stem from changes to their physical environment or to their prey. Physical characteristics, such as topography, depth, waves, tidal currents, sediment particle size, and suspended sediment concentrations are altered by dredging (see review by Tillin et al. 2011), but such changes also occur naturally as a result of disturbance events such as tides, waves, and storms. Consequently, small changes are unlikely to have a substantial effect on the marine ecosystem, and can even increase biodiversity, but large-scale repeated alterations have potential to affect the entire food web, right up to marine mammals.

Positive effects can include enhanced diversity and abundance of benthic fauna near dredged channels (Jones and Candy 1981, Poiner and Kennedy 1984, van Dalfsen and Essink 2001, Newell et al. 2004, Claveleau and Desprez 2009). This is potentially caused by the release of organic nutrients from the sediment plume (Ingle 1952, Biggs 1968, Sherk Jr 1972, Oviatt et al. 1981, Walker and O'Donnell 1981). This rise in species abundance has potential to temporarily increase the amount of food available to certain marine mammal species. For example, Anderwald et al. (2013) reported higher numbers of bottlenose dolphins during construction activity around Doonanierin Point, Ireland, North Atlantic. It cannot be said with certainty that increased prey numbers, as a result of seabed disturbance, attracted the dolphins, as other factors were not explored, but it is a possibility.

Changes in topography could also affect marine mammals positively (if all other factors being equal). Some fish larvae seem to benefit from sediment being brought back into suspension which, in turn, can provide more prey for marine mammals. Boehlert and Morgan (1985) reported that at suspended sediment concentrations of 500–1000 mg/l, feeding rate of larval Pacific herring (*Clupea pallasii*) was increased significantly above the control (0 mg/l). Increased turbidity could also increase protection against visual predators, which will find it harder to hunt. Positive effects of suspended sediment are often observed only up to a certain concentration, so it is possible that extensive dredging could increase suspended sediment concentrations above those that appear positive, and negative effects will resume.

Benthic and demersal fauna is at risk of being taken up (entrained) by dredges. Entrainment rates depend upon several factors including depth, dredger type, speed, and strength of suction field. For example, hydraulic dredgers create stronger suction fields than mechanical ones, so are more of a risk to marine life (Reine and Clarke 1998, Nightingale and Simenstad 2001). Susceptibility also depends on species. Benthic fauna and demersal fish that are associated strongly with bottom substrates are considered more at risk from entrainment than highly mobile species. Overall, general consensus is that entrainment of adult fish and many shellfish species has minimal population level effects (Reine and Clarke 1998, Drabble 2012); however, dredging-related entrainment is more of an issue for young fish, and the eggs and larvae of marine organisms, as their reduced swimming ability means they are unable to actively avoid the suction field (Reine and Clarke 1998, Nightingale and Simenstad 2001, Drabble 2012).

Given that effects are greatest during the egg and larval stages, impacts can be reduced by implementing temporal restrictions on dredging activity, known as environmental windows, which ensure activity is restricted in spawning and nursery grounds at critical times[9]. To put into context of marine mammals, provided that risk assessments are carried out prior to dredging, and activities are well managed, reduction in prey numbers are unlikely to be high enough to have substantial population-level impacts.

Over time, sediments accumulate toxins and pollutants such as hydrocarbons and heavy metals (Cundy et al. 2003, Taylor et al. 2004). Dredging disturbs sediments and can release contaminants into the water column, which has potential to change chemical properties of sediment and reduce water quality at both extraction and dumping sites for some time after dredging has ceased. Once suspended, contaminants can become available to marine organisms, and potentially accumulate up the food chain. Remobilisation and bioavailability of contaminants is site-specific, complex, and affected by many factors. The fate of remobilised contaminants has not been discussed here, but see reviews by Eggleton and Thomas (2004) and Roberts (2012) for details. Literature on dredging release of contaminants suggests that remobilisation is restricted in both time and space, and as long as highly contaminated sediments are managed strictly, concentrations are not expected to be high enough to have significant detrimental effects on the environment (Roberts 2012).

Turbidity has potential to impact fish feeding ability, although piscivorous fish that feed on larger prey, detected visually over longer distances, are affected to a greater extent than planktivorous fish, that detect prey visually over short distances (Hecht and van der Lingen 1992, Utne-Palm 2002, de Robertis et al. 2003). Other behavioural alterations include changes in habitat choice (e.g., Wenger and McCormick 2013), altered predator-prey relationships (e.g., Wenger et al. 2013), and increased anti-predator responses (Leahy et al. 2011). High suspended sediments can also cause gill damage in fish (Herbert and Merkens 1961, Lake and Hinch 1999, Au et al. 2004, Wong et al. 2013).

[9] This effect is context specific: A nursery area for blue cod, for example, might be an offshore horse mussel bed or a bryozoan bed. Temporal restrictions won't achieve the same effect for biogenic nursery habitats that are long lived

Veer (1979) cited in Veer et al. (1985) recorded suspended sediment concentrations of 6300 mg/l in the outwash of a suction dredger, whilst Hitchcock and Dearnaley (1996) reported lower concentrations of 80–340 mg/l (upper water column) and 480–611 mg/l (lower water column) within 100 m of a dredger. Levels reported by Hitchcock and Bell (2004) were in-between at 5500 mg/l close to a dredger, reducing to 450 mg/l with distance, and Reine et al. (2007) stated that maximum concentrations, recorded in close proximity to a bucket dredger in Maumee Bay, USA, were 800 mg/l, although levels decreased rapidly, and were closer to 300 mg/l at a distance of 24 m.

Increases in suspended sediment concentrations on invertebrates include abrasion, decreased respiration rates due to clogging of filtration mechanisms, or behavioural alterations. Change in conditions can also affect feeding efficiency of filter feeders, as the food-to-sediment-ratio is decreased, meaning more energy is required to sort through additional material and may impact fitness over extended periods (Last et al. 2011).

Impact of suspended sediment on eggs and larvae of marine organisms has been addressed in several studies under laboratory conditions (e.g., Auld and Schubel 1978, Kiørboe et al. 1981, Morgan et al. 1983, Griffin et al. 2009, Suedel et al. 2012). Griffin et al. (2009) found that if Pacific herring eggs were exposed to suspended sediments of 250 mg/l or 500 mg/l within 2 hours of dispersal, sediments adhered to the outside of eggs, which led to increased egg-to-egg attachment, and abnormal larval development; ability to attach to surfaces could also be compromised. Outside of the initial two hours, no significant effect was recorded. The majority of data are collected in laboratories under set conditions that vary from those in the wild where current strength, temperature and contaminant levels may all have an effect.

Change in sediment structure as a result of dredging has been reported frequently (e.g., Kenny and Rees 1996, Desprez 2000, van Dalfsen et al. 2000, Weller et al. 2002, Hitchcock and Bell 2004, Boyd et al. 2005, Cooper et al. 2005, Robinson et al. 2005, Desprez et al. 2010, Barrio Froján et al. 2011); a fining of the sediment is most common due to the winnowing effect of dredging, especially where screening is carried out. Extent of change, and ability to recover, varies substantially, and depends upon area, hydrodynamics and type of sediment deposited. In general, regularly-disturbed habitats characterised by fine sands and fast growing opportunistic species are affected less, and recover quicker, than stable habitats monopolised by coarse gravels and slow growing sessile fauna and flora (Tillin et al. 2011). Coarse sediment habitats are also likely to see a greater change in species composition over the long-term, as the new finer sediment suits a different range of species than those that occupied the coarser sediments, although it should be noted that sediment composition is not the only driver in determining benthic community composition.

In addition to changing community structure, sediment deposition can smother or bury marine organisms associated with the seabed. Non-mobile organisms and early life stages that are unable to move out of the path of dredgers are most at risk. Impacts are highly species-specific and depend upon a species' ability to either tolerate or escape burial, both of which vary with sediment characteristics and temperature. This variation is demonstrated by Last et al. (2011) through laboratory experiments on several species. Some can survive prolonged periods buried in the sediments (e.g., Ross worm, *Sabellaria spinulosa*), whilst some are able to emerge from relatively deep sediments (e.g., green sea urchin, *Psammechinus miliaris*); other species, however, suffer high mortality if buried.

Smothering of eggs can cause mass mortality, delayed hatching (see for example Berry et al. 2011) or added sediment could reduce the number of settlement locations available to larvae, which increases level of competition (see review by Wilber et al. 2005).

Given that effects of sedimentation vary massively, putting them into context of potential indirect impacts on marine mammals is challenging, although a reduction in the health of benthic communities signifies a reduction in the amount of food available to higher trophic levels, including marine mammals if all other factors remain equal. Sedimentation will have some level of impact on marine organisms and could result in mortality or long-term changes in the environment; however, dredged areas are colonised quickly by opportunistic species, which likely attract higher trophic level species. If re-colonisation includes those species consumed by marine mammals, then impact on prey availability should be short-term only, in which case long-lasting, population-level effects are unlikely, but short-term changes to feeding, or distribution are possible. In general, avoidance of spawning or nursery areas during dredging is beneficial, and minimises large-scale losses of species, as will minimising dredging-related sedimentation around oyster beds or other sensitive habitats.

3.1.3.4. Changes in species composition and abundance

In areas dominated by soft bottom substrates, the installation of hard substrate structures such as platforms or new harbour installations can provide habitats ('artificial reefs') for species that were not present before. Invertebrates species are known to settle on hard substrate within relatively short periods (weeks/months) thereby providing food and shelter for small zooplankton species which, in turn, provide the basis for sustaining larger predators (e.g., fish) and likely changing the species composition on all trophic levels over a small to moderate spatial scale (depending on the size, number and type of installations). Such effects on the local ecosystem can lead to positive effects through increased biodiversity and prey abundance. Similarly, these effects can have the opposite effect through driving important prey species from important feeding habitats of, e.g., the Hector's/Māui dolphins (see also Sections 5.1.2–5.2.2 for further examples and discussion).

Disturbing the bottom sediment through dredging and mining or installation of structures can also crush benthic organisms or flush (in-)bottom living animals into the water column. This, in turn, is likely to attract predators and scavengers and thereby potentially changing the local species composition and abundance.

3.2. Acoustic Characterisation of Sound Sources

Based on their frequency of occurrence or duration and/or their source level and frequency range and spectrum (but in no particular order), the following sound sources/activities have the highest potential for disturbing Hector's/Māui dolphins or physically harming (auditory) them:

1. Seismic airgun surveys,
2. Pile driving – nearshore and offshore,
3. Offshore drilling,
4. Dredging – nearshore and offshore,
5. Vessel operations,
6. Vessel echosounders, and
7. Geophysical survey techniques.

The following sections provide generic sound spectra and source levels for the sound sources emitting broadband sound (sound sources 1–5). Sound sources 6 and 7 emit signals (high or low-frequency) that are narrowband at high acoustic levels. A comprehensive overview of the acoustic characteristics of all these sources is given in the 'Report of the Non-Standard Surveys Technical Working Group', part of the 2015–2016 Seismic Code of Conduct Review process (edited by DOC (Ed)2016b). As their nominal frequency can vary widely between systems and application these sources are collectively assessed without referring to a particular frequency or source level.

As discussed in Sections 4.1 and 4.3, the hearing sensitivity of marine mammals is species-specific and has to be approximated for Hector's/Māui dolphins from indirect information. However, sufficient information is available to assume that Hector's/Māui dolphins are high-frequency (HF) specialists and at least for assessing the auditory effects (such as TTS/PTS), it seems justified to use weighting functions developed for HF cetaceans (NMFS 2018)

Behavioural effects can only be elicited if the sound is audible to the animals. Therefore, the same logic of applying weighting functions may be used also for assessing the risk of disrupting Hector's/Māui dolphins' behaviour through any of the activities listed above. However, contrary to auditory effects, there is insufficient scientific information on onset thresholds for behavioural reactions to allow for applying weighting functions. Instead, unweighted spectra and sound levels will be used to assess this type of effect.

3.2.1. Sound propagation

Propagation of sound in water is highly dependent on environmental characteristics such as bathymetry, seabed type, water depth, temperature, and salinity. These factors are highly variable at sea and affect how the sound pressure waves are reflected, refracted, and scattered (i.e., the potential for reverberation) and interference due to multipath propagation. In addition, the source levels, frequency bandwidth, and frequency content of the sounds emitted by the activities listed above are also highly variable, as they depend on the scale and exact type of activity. A more detailed overview of the considerations for propagation modelling are in the 'Report of the Sound Propagation and Cumulative Exposure Models Technical Working Group', Part of the 2015–2016 Seismic Code of Conduct Review process (DOC (Ed) 2016a). The following are a few examples:

- Geophysical survey sources range from narrow-band sonars to broadband low-frequency seismic sources of various sizes.
- Sound related to offshore pile driving, e.g., vary with the pile dimensions (widths ranging from <1 m to >6 m and length depending upon requirement), the sediment it is driven into, water depth, and several other factors.
- Vessel sound strongly depends on the speed, propeller size and number of blades, the size and load of the vessel, as well as meteorological and oceanographic parameters such as wind and sea state.

These examples are intended to illustrate why only examples of source levels are referred to in this report. These examples are indicative only for a very specific activity, location, and time. Values cannot be extrapolated to other conditions and locations.

The same problem arises with regard to the sound level received by an animal in the water column. While low frequencies propagate over long distances in deep water, they do not propagate well in shallow water and will attenuate faster. High frequencies propagate well in shallow waters, but their propagation range is limited as they get increasingly absorbed with increasing frequency. Headlands, islands and seamounts can block or attenuate the propagation of underwater sound. Many other parameters (such as the seafloor sediment composition, sound speed profile, and surface wave height) influence the sound over its entire journey from its source to a receiver (an animal).

Another important aspect influencing the detection range for a sound is the directionality of the sound source. Some sound sources (such as pile drivers) emit sound into the water column almost evenly in all directions. Seismic airgun arrays, echosounders, and geophysical survey sources have a directionality pattern, which can be apparent in the horizontal and/or vertical direction. Directionality is often correlated with the frequency content of the emitted signal. Seismic airgun signals have a broad spectrum, including frequencies from below 10 Hz to over 25 kHz (Goold and Fish 1998, Martin et al. 2017, MacGillivray In press). Ship echosounders use high-frequency signals (Lurton and DeRuiter 2011). Even though both types of signals are directional, the high-frequency echosounder signal has a much more downward focussed 'beam' (comparable to the light beam emitted by a torch) so less acoustic energy is emitted horizontally. Accordingly, echosounder signals are undetectable in the horizontal direction by an animal over similar distances as compared to seismic airgun signals. McPherson et al. (2018) provides an informative example of the (modelled) propagation of different types of sound (seismic airgun and vessel) and the potential noise exposure to Māui dolphins; this study however did not consider echosounders.

3.2.2. Sound sources

The following section provides an overview of sounds emitted by some of the major activities and their acoustic spectra (i.e., the distribution of acoustic energy over the entire range of frequencies are displayed in Figures 16–19 and 22–23). The results are displayed as unweighted and HF-weighted (NMFS 2018) to account for the presumed hearing sensitivity of Hector's and Māui dolphins.

3.2.2.1. Impulsive sound sources

Seismic airguns

Airguns are used during seismic surveys to investigate potential O&G reserves located in strata beneath the sea floor structure. They are essentially steel tubes charged with high-pressure air via a compressor, towed behind a seismic vessel in arrays. Impulsive sounds are generated by releasing air underwater at very high pressures which expands and contracts rapidly creating a sound wave that travels through the water column and reflects off different layers of rock and sediment. Echoes from reflected geological discontinuities are received by sensitive hydrophones towed behind the seismic vessel and provide information about the sediment structure of the seabed. Conventional seismic sources include air and water guns, sparkers, boomers, and chirp sonar, which each produce frequencies from several Hertz to >10 kHz (DOC 2016b).

Airgun signatures (Figure 15) consist of a strong primary peak, related to the initial release of high-pressure air, followed by a series of pulses associated with bubble oscillations. Most energy is produced at frequencies below 600 Hz, although this is different for each array, with noticeable differences between the broadside (perpendicular to tow direction) and endfire (directly aft of the array) signatures. Frequency-dependent peaks and nulls in the spectrum result from interference among airguns in the array and correspond with the volumes and relative locations of the airguns to each other. The source signatures for two airgun arrays that have been used in New Zealand were presented in McPherson et al. (2018). One of these signatures is shown in Figure 15, and the 1/3-octave-bands for two airgun arrays considered in McPherson et al. (2018) are shown Figure 16.

A significant number of measurement studies have been published in both peer-reviewed and grey literature about the acoustic properties of seismic airgun sound. These studies have been conducted using data from seismic streamers (e.g. Crone et al. 2014), autonomous recorders (e.g. Guan et al. 2015, Martin et al. 2017), real-time telemetered recorders (e.g. Racca et al. 2015) and acoustic tags on marine fauna (e.g. Madsen et al. 2006a). Some grey literature available includes detailed characterisation of individual surveys to assist with permitting (McPherson and Warner 2012), while other reports compare modelling and measurement data from a range of sources to characterise an entire region (Wisniewska et al. 2014). Studies have also quantified sound levels very close to the array (Mattsson and Jenkerson 2008), examined different metrics and the contribution from higher frequency components of the airguns to the environment (Greene and Moore 1995, Martin et al. 2017), to low level long range impulses (Guerra et al. 2011, McPherson et al. 2016, Guan 2018), and sound levels in relation to marine fauna behaviour (Blackwell et al. 2015, Dunlop et al. 2017a).

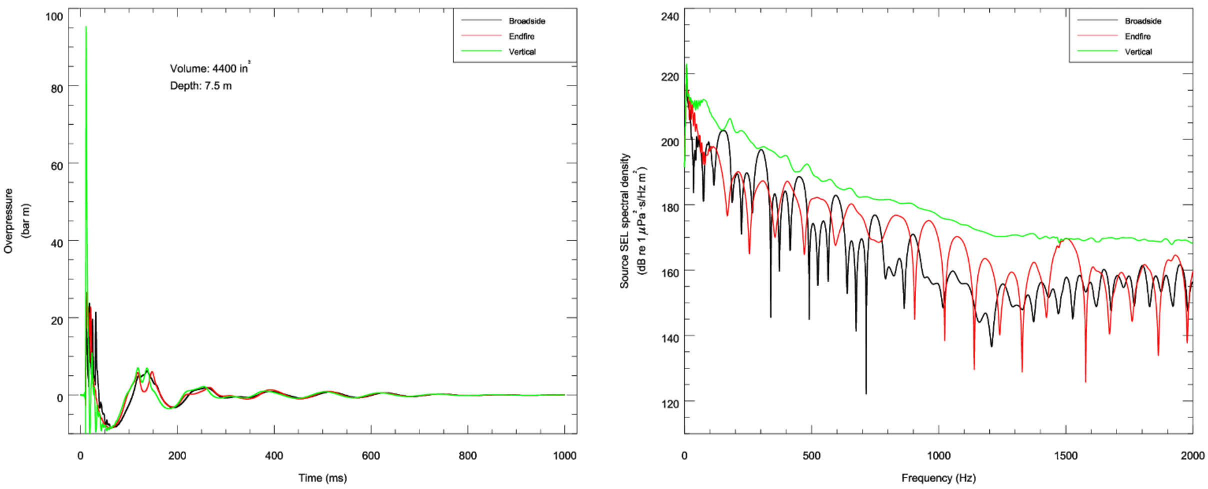

Figure 15. Predicted source level details for the 4400 in3 array towed at a depth of 7.5 m (Figure E-2 in McPherson et al. (2018)). (Left) the overpressure signature and (right) the power spectrum for broadside (perpendicular to tow direction) and endfire (directly aft of the array) directions, and for vertically down.

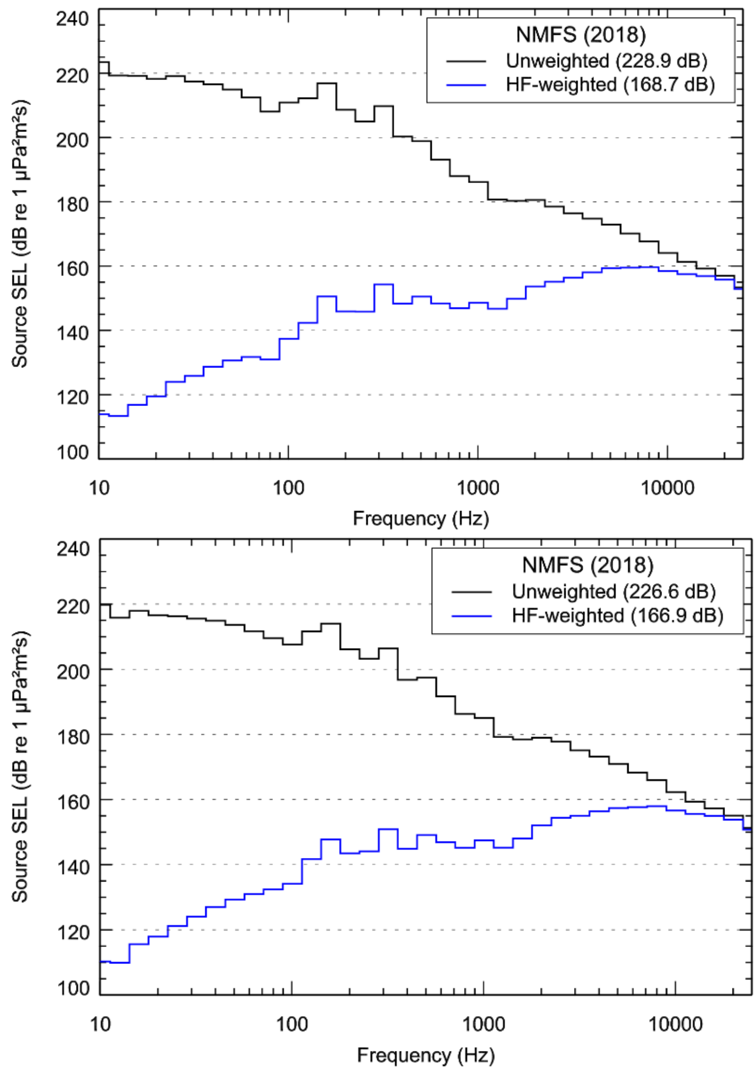

Figure 16. Frequency spectra of impulse emitted by a 3460 in^3 seismic airgun array (top) and 4400 in^3 airgun array (bottom). The black line shows the unweighted spectrum, the blue line the high-frequency (HF) weighted (NMFS 2018) spectrum.

Pile driving

Impact pile driving is carried out using an impact hammer, which consists of a falling ram that strikes repeatedly the top of a pile and drives it into the ground. The ram is lifted or driven by one of several methods, including mechanical winching, diesel combustion, pneumatic air pressure, or hydraulic pressure. When the ram strikes the pile, the impact creates stress waves traveling down the length of the pile, which couples with the surrounding medium, radiating acoustic energy into the water. Pile driving also generates vibration waves in the sediment, which can radiate acoustic energy back into the water from the seabed. The sound from impact pile driving is transient, repetitive, and discontinuous (Reinhall and Dahl 2011, McPherson et al. 2017b). Pile driving can be conducted both above the surface and subsea and is often required to install anchor points for floating offshore facilities or drill rigs, foundation support for permanent facilities, conductor casings, and jetty / wharf infrastructure. Typical examples of impact hammers for offshore work include the MENCK range (https://www.menck.com/pilesize), and the IHC hydrohammer range (https://www.ihciqip.com/en/products/piling-equipment/hydrohammer). These hammers have a typical strike interval of 1.5 to 2 seconds.

Sound levels produced depend upon several interdependent factors such as pile size, hammer strike energy, and type of seabed. Field measurements of pile driving show that source, or near-source levels are typically in the range of 210 to 250 dB re 1 µPa (McHugh 2005, Tougaard et al. 2009b, Bailey et al. 2010b) and frequency is predominantly <1 kHz (Robinson et al. 2007, Tougaard et al. 2009a), although they can extend to much higher frequencies (MacGillivray 2018), including at least

100 kHz (Tougaard et al. 2009a). Deep and shallow-water conductor driving generate similar sound pressures; however, in deep water the pile is much longer so the ensonified area is greater (MacGillivray 2018).

To provide context, one-third-octave-band levels for the point in the water column with highest SEL at 10 m horizontal range for impact pile driving are shown in Figures 17 and 18 for nearshore and offshore pile driving operations, respectively. The nearshore piling spectra were derived from Guan (2018), who presented a generic piling Power Spectral Density (PSD) based upon three different measurement programs. The generic piling PSD was converted to one-third-octave-band levels and then frequency weighted. The offshore piling spectra used as an example represents the possible spectra for a 500-kJ subsea hammer driving a typical subsea anchor pile of ~30 m length and 3 m diameter.

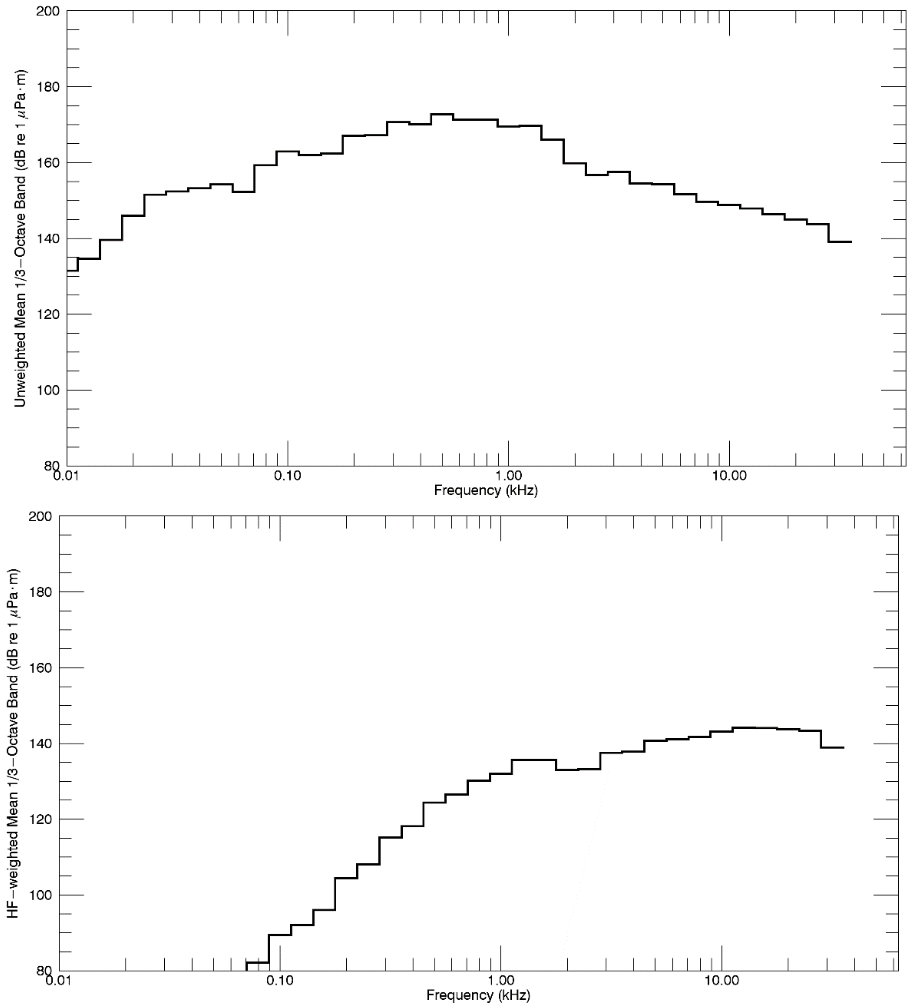

Figure 17. *Nearshore pile driving*: One-third octave band levels at 10 m horizontal range for impact pile driving (Guan 2018). Top graph is showing the unweighted spectra, the bottom the high-frequency (HF) cetacean weighted (NMFS 2018) spectra.

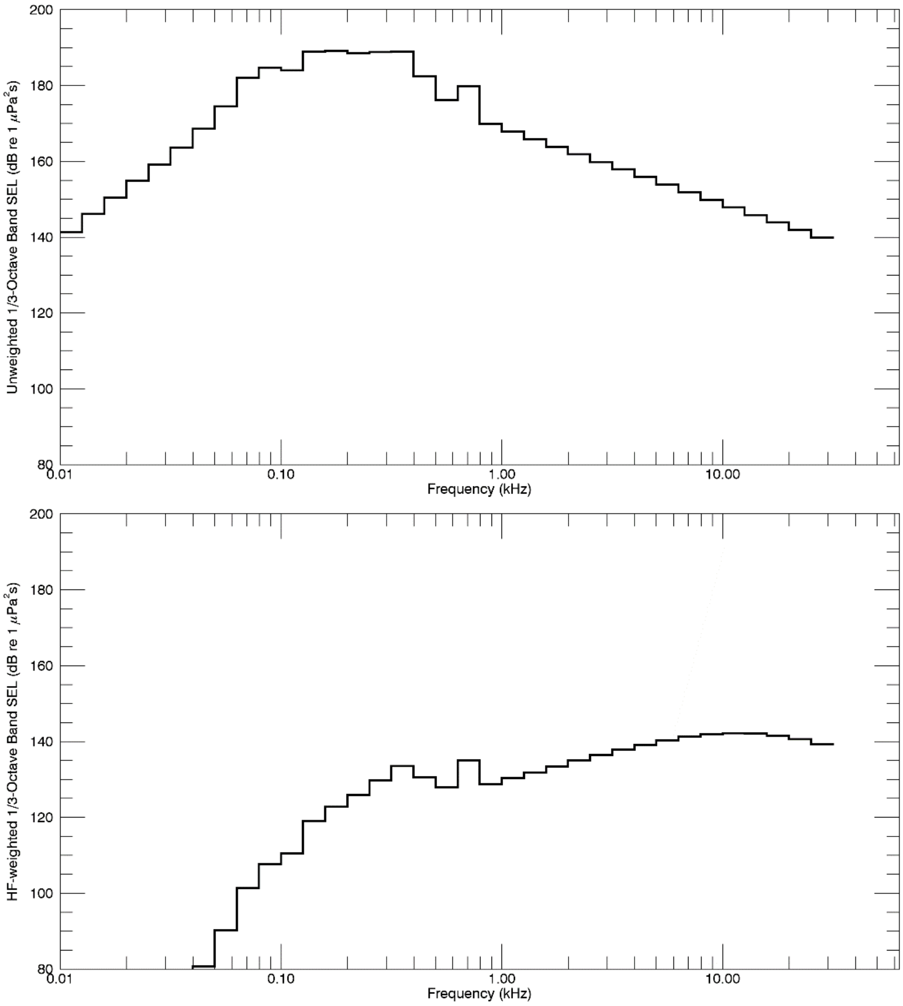

Figure 18. *Offshore pile driving*: One-third octave band levels at 10 m horizontal range for example subsea impact pile driving operation. Top graph is showing the unweighted spectra, the bottom graph showing high-frequency (HF) cetacean weighted (NMFS 2018) spectra.

3.2.2.2. *Non-impulsive sound sources*

Offshore drilling

Offshore drilling is a mechanical process where a wellbore is drilled into the seabed. Drilling can be done to explore for or extract hydrocarbons (oil and gas) from the ground. Drilling operations are typically conducted by Mobile Offshore Drilling Units (MODU's), which can be hull-based vessels equipped with drilling derrick or platforms, or self-propelled drill ships. Drilling sound usually exhibits tones below 2 kHz, with harmonics present to 10 kHz and can vary substantially between operations (Kyhn et al. 2014, Austin et al. 2018). These two studies are the most recent and detailed published studies on noise from offshore drilling operations, and provide information about the current fleet of larger drilling units, as opposed to older, smaller units (Gales 1982, Greene 1987, Richardson et al. 1995), and supplement grey literature (MacDonnell 2017). The possible footprint from drilling operations and associated vessel activity has also been investigated (Quijano et al. 2018), which provides a detailed example of methods to examine the extents of noise footprints from drilling operations. The large offshore units are quite different in terms of their scale, operations involved and sound emitted compared to the smaller geotechnical drill rigs (Erbe and McPherson 2017).

To provide an example of operations from offshore drilling, one-third-octave band source sound levels were extracted from a recent publication examining the activities of three different drill ships (Austin et al. 2018), and frequency weighted (Figure 19).

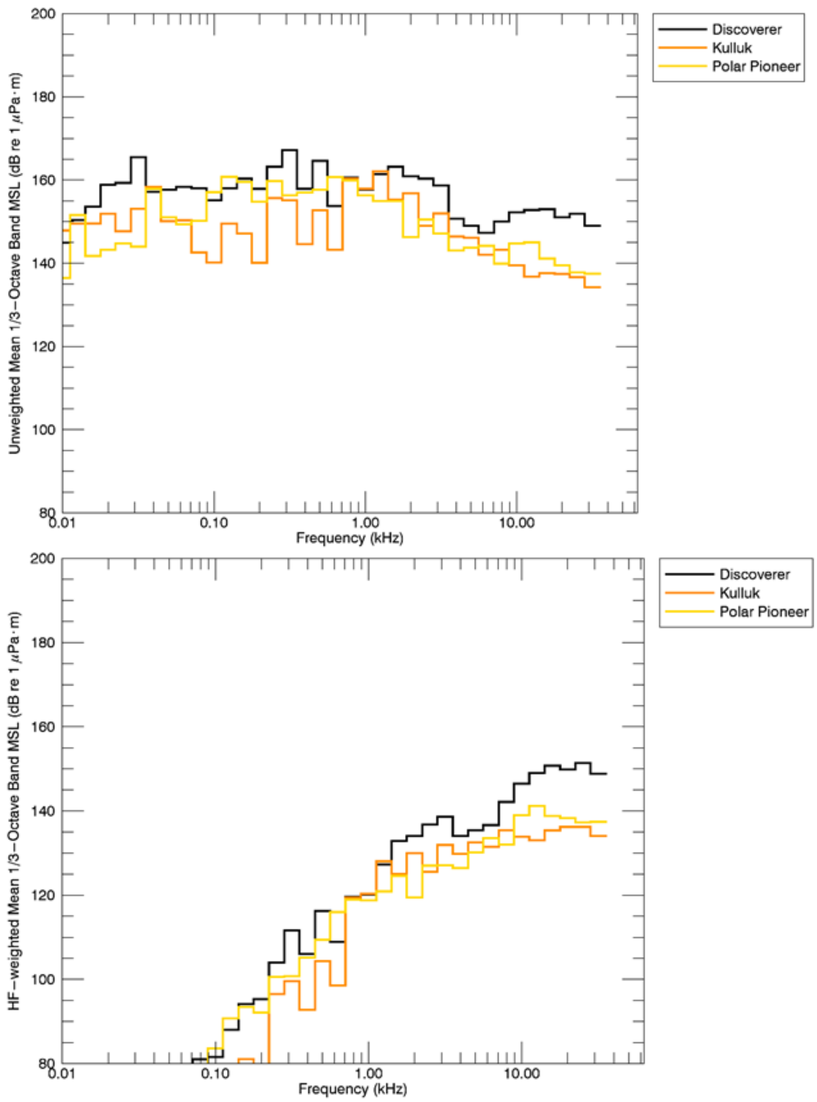

Figure 19. *Offshore drilling operations*: Frequency-dependent source levels in 1/3 octave bands (Austin et al. 2018). Top graph is showing the unweighted spectra, the bottom graph showing high-frequency (HF) cetacean weighted (NMFS 2018) spectra.

Offshore dredging

Offshore dredging is conducted to remove material from one location and relocating it to another (e.g. harbour dredging) or for resource use (e.g. iron sand mining). The excavation is typically done from a floating plant, known as a dredger. The main objective for dredging in New Zealand's water is to recover material that has some value or use, or to create a greater depth of water. Uses are diverse and include construction of ports, waterways, dykes, and other marine infrastructure; land reclamation; flood and storm protection; extraction of minerals; and environmental remediation of contaminated sediments (see reviews by Brunn et al. 2005, Thomsen et al. 2009, CEDA 2011, Tillin et al. 2011, WODA 2013). This report focuses on dredging in the marine environment for mineral or harbour/port related activities; those related to fisheries are not considered. Todd et al. (2015b) presents a thorough discussion of this topic. The four main types of dredge are the Cutter Suction Dredgers (CSD), Trailing Suction Hopper Dredgers (TSHD), grab dredgers, and backhoe dredgers (Figure 20).

Dredging generally produces continuous, broadband sound with main energy below 1 kHz (Thomsen et al. 2009, CEDA 2011, WODA 2013). Sound pressure levels can vary widely with dredger type and power, operational stage or sediment type.

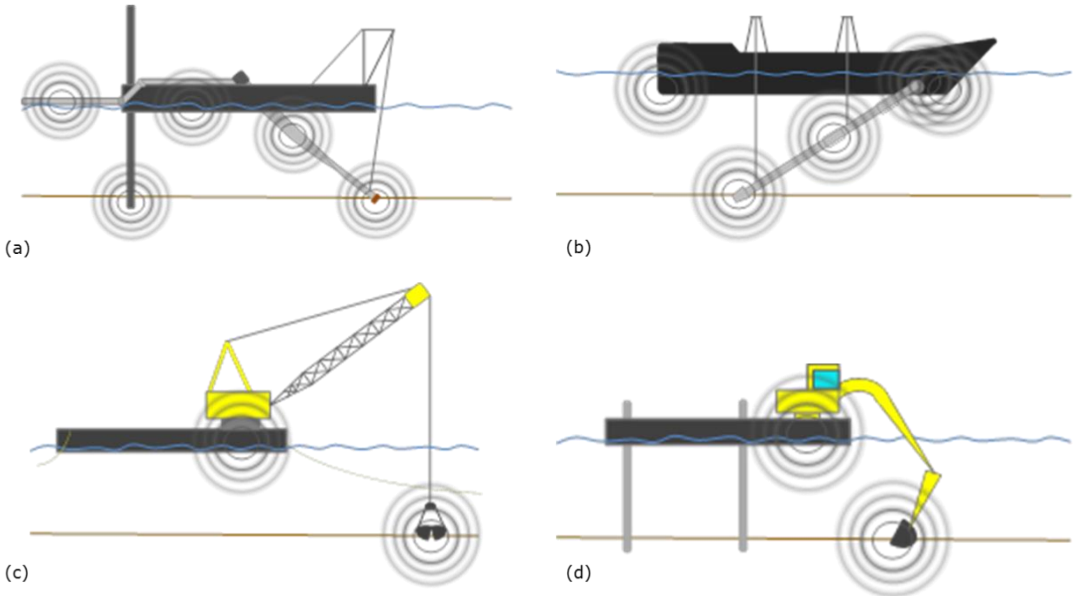

Figure 20. Common examples of dredgers and possible sound sources. (a) Cutter Suction Dredger (CSD), (b) Trailing Suction Hopper Dredger (TSHD), (c) grab, (d) backhoe. *Source*: Todd et al. (2015b).

A number of studies have quantified the sounds from dredges and estimated source levels. Less information is available than for seismic sources. Sound produced by TSHDs has been measured on several occasions. Reported sound levels are generally higher than those documented for CSDs. Robinson et al. (2011) measured six TSHDs, stating that source levels below 500 Hz were in line with those expected for a cargo ship travelling at modest speeds (8–16 kn). The maximum broadband SPL was calculated to be 189.9 dB re 1 $\mu Pa^2 m^2$. Estimated 1/3-octave-band source levels above 1 kHz were relatively high, which was probably a result of the coarse aggregate pumped through the dredge pipe. Using an identical approach, de Jong et al. (2010) found very similar results to Robinson et al. (2011), but 1/3-octave-band source levels clearly showed a steady decline beyond 1 kHz, likely because the material dredged was sand as opposed to gravel. This information was extrapolated to look at offshore sound levels (de Jong et al. 2016).

Other dredges have been studied in less detail, including one study on CSD's in harbours conducting rock fracturing (Reine et al. 2012), and grab dredgers (Dickerson et al. 2001). The study on grab dredges found that sound varies substantially with the operational stage, with the loudest stage being when the bucket made impact with the sea floor. Large offshore dredges which use dynamic positioning to maintain station share many similarities in their noise profiles with large support vessels and drill ships using the same technology.

One proposed method of extracting iron-ore sediment in New Zealand waters involves the use of a large (450t) remotely operated seabed crawler which drives along the sea floor sucking sediment up and pumping it to a large ship at the surface (Trans Tasman Resources Limited, TTRL); https://www.ttrl.co.nz/). Another proposal is for the extraction of phosphate nodules using a specialised offshore dredge (Chatham Rock Phosphate, CRP); http://www.rockphosphate.co.nz/). In both projects, iron-rich sediments or phosphate nodules are proposed to be separated and retained for further processing, and unwanted sediments returned to the sea floor via a re-deposition pipe on the opposite end of the ship (Figure 21). The mining activities can last for extended periods, with the TTRL operation proposed to last 35 years.

Examples of the sounds from the CRP dredge as submitted during the application process (Ketten 2014a, 2014b, McPherson et al. 2014a) are shown in Figure 22. The sound from the proposed TTRL operation was contentious in terms of source levels and particular sounds according to the submitted evidence (Duncan et al. 2017), and conditions were set for sound levels not to exceed (Mitchell 2017). Expert witnesses of significant experience did not think these sound levels were achievable (Duncan et al. 2017) and questions were raised if dynamic positioning and offload were properly considered when compared to operations of Floating Production Storage Offload (FPSO) facilities measured elsewhere in the world (Erbe et al. 2013).

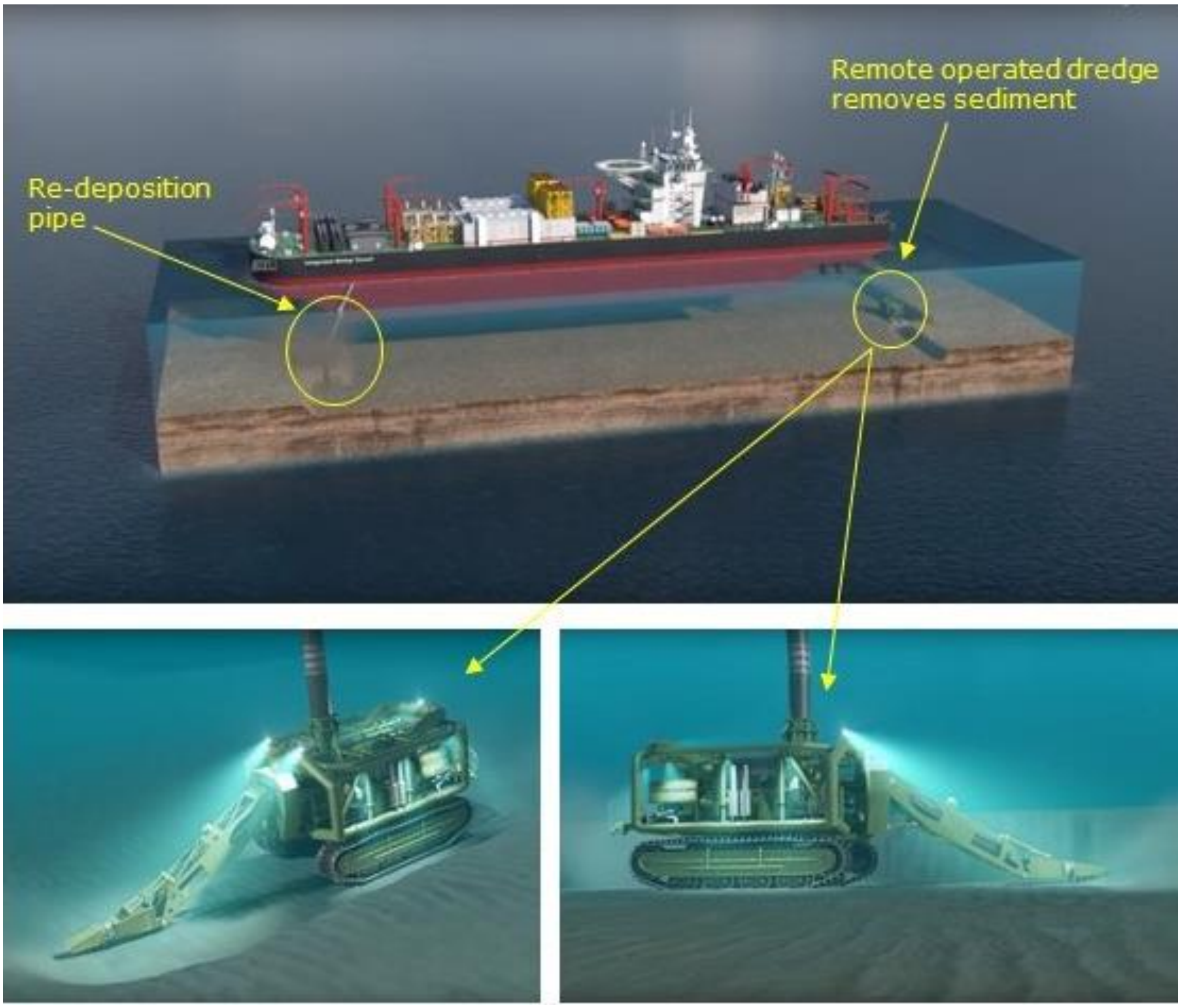

Figure 21. Remote operated dredge proposed to be used for seabed iron ore mining in South Taranaki Bight, New Zealand. Source: Trans-Tasman Resources Limited iron ore animation available at: https://tinyurl.com/y7p4lk4a.

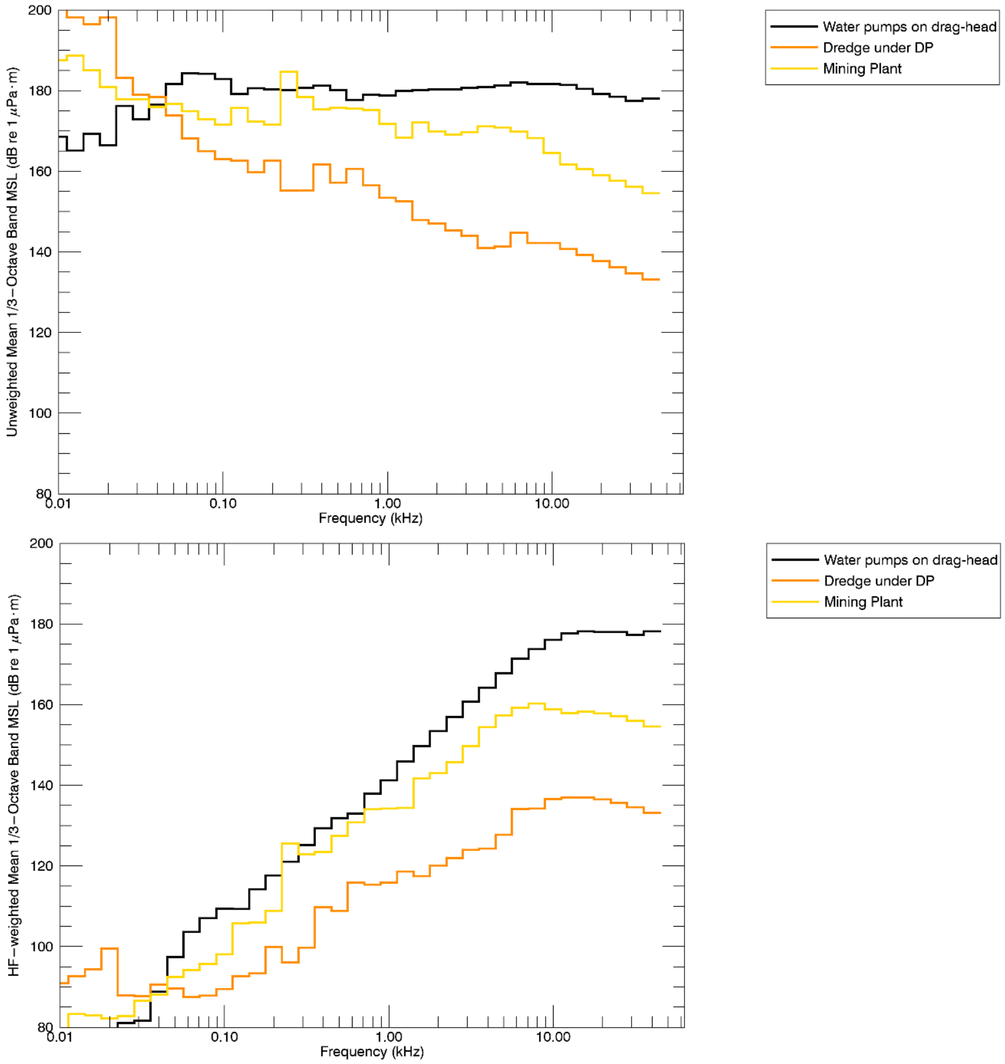

Figure 22. Example frequency-dependent source levels in 1/3 octave bands for noise emitted by an offshore dredging operation (Chatham Rock Phosphate application) under dynamic positioning (DP) and from operating associated infrastructure (water pumps, mining plant). Top graph is showing the unweighted spectra, the bottom graph showing high-frequency (HF) cetacean weighted (NMFS 2018) spectra.

Vessel operation

The operation of motorised vessels involves numerous mechanical processes which create underwater sound as a by-product; these range from sound of the propeller, cavitation caused at the propeller edges, machinery or simply the flow noise of the vessel moving through the water. Sound emitted from vessel differs strongly depending mainly on size, speed, load, type and state of propulsion system, meteorological and oceanographic factors such as sea surface conditions and currents (MacGillivray et al. 2018) (Figure 23).The authors classified vessels according to vessel category information embedded in the Automatic Identification System (AIS) logs (taken from McPherson et al. (2018)). Appendix C contains more detailed discussions on vessels. Pipelay vessels and highly task-specific oil and gas service vessels have not been included due to limited information.

This literature review did not look at the noise from smaller vessels without AIS. Smaller vessels such as these were recently investigated by (Wladichuk et al. 2018) who measured sound levels produced by whale watch boats and other small vessels (from 5.2 to 17.4 m in length) using Autonomous Marine Acoustic Recorders (AMARs). This study is the most comprehensive small vessel acoustic emission study to date, and the measurements followed the ANSI S12.64-2009 standard. (Wladichuk et al. 2018) focuses on the potential effects on killer whales, and also compares the vessel characteristics to those for large commercial shipping . The results show a clear positive correlations of source levels with speed for all of the vessels; however, the speed trends for small vessels were not as strong as those of large commercial vessels.

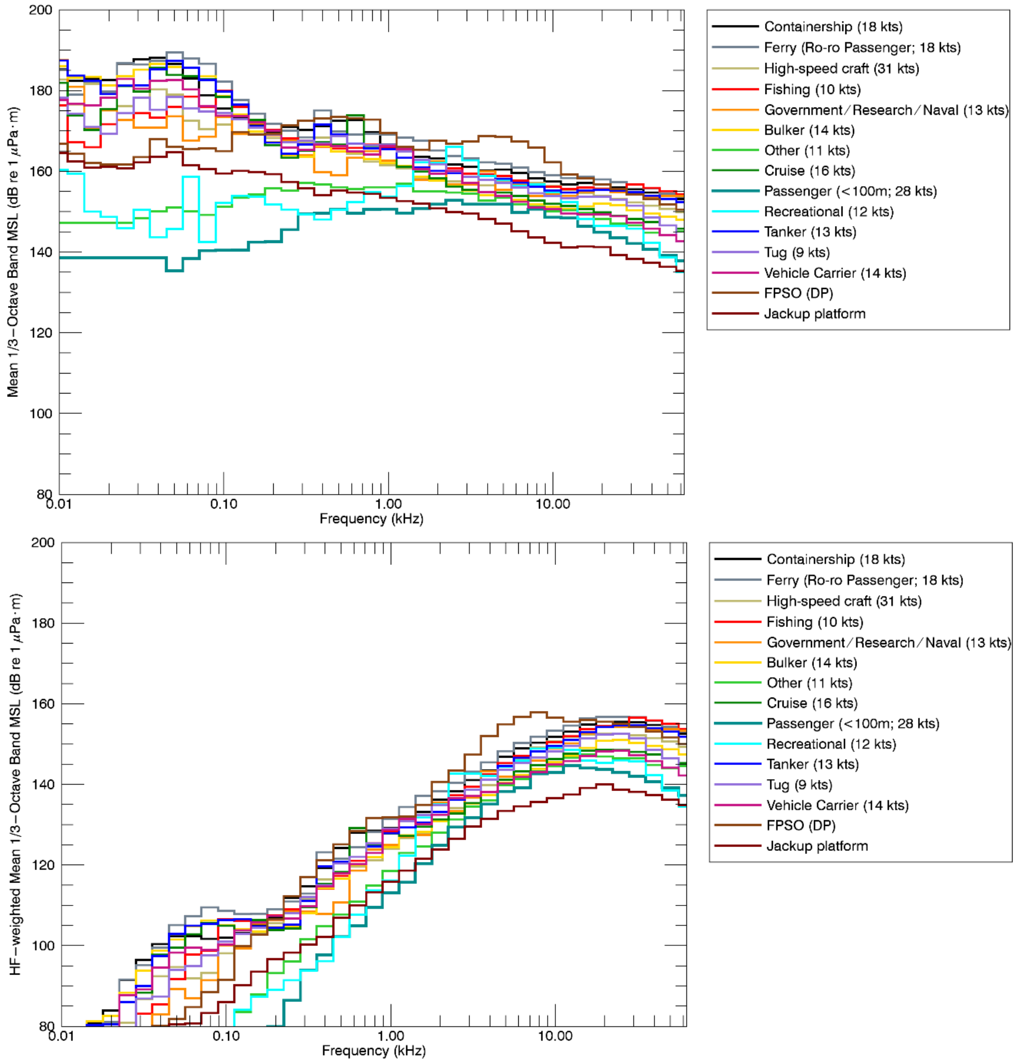

Figure 23. Frequency-dependent source levels by vessel category in 1/3 octave bands (McPherson et al. 2018). Top graph shows showing the unweighted spectra, the bottom graph showing high-frequency (HF) cetacean weighted (NMFS 2018) spectra.

3.2.2.3. Other types of sound sources

Explosions

The loudest sound generated by human activities at sea are caused by explosions for removal of seabed or existing industrial structures and seabed clearance (Unexploded Ordnance, UXO). Underwater explosions are characterised by a near-instantaneous rise from ambient pressure to an extremely high peak pressure generating an explosive shock wave. Farther from the explosion, the peak pressure decays and the explosive wave propagates as an impulsive, broadband sound.

The source level (PK and SEL) of explosions scales with the size of the charge. For example, a 10,000 lb explosive produces sound with a (back-calculated) source level of 304 dB re 1 µPa and frequency of 0.5–50 Hz and a 98 lb explosive produces sound with an SL of 289 dB re 1 µPa at 10–200 Hz (Hildebrand 2009). Much smaller charges in seal bombs (used to deter marine mammals) of only 2.3 g can still produce sound with SL = 205 dB re 1 µPa at 15–100 Hz (Hildebrand 2009).

Sonar

Sonar is a technique that uses sound to emit non-impulsive sound waves into the water to detect objects, safely navigate, and communicate. Sonars signals are typically emitted at high or very high frequencies (tens to hundreds of kilohertz). Higher frequencies allow for greater resolution and, due to their greater attenuation, are most effective over shorter distances. Commercial and private vessels employ navigational sonars including speed logs, Doppler sonars for ship positioning, and fathometers. These sources are typically highly directional to obtain specific navigational data (US DoN 2017). Bathymetric surveys are conducted to image the topography of the seafloor; single or multibeam echosounders, side-scan sonar, and swath bathymetry systems are used for these surveys using frequencies from 10 kHz to 1 MHz (DOC 2016b).

Side-scan sonar systems are commonly used for bathymetric surveys or for mapping objects on the seafloor. These systems operate at frequencies between 70–440 kHz with source levels typically ranging between 210 and 220 dB re 1 µPa. Multibeam echosounders emit signals in a fan shape (fan width: 100−130°) beneath a ship's hull at signal frequencies usually ranging from 100–900 kHz. Some high-power systems used for deep water profiling, however, operate at 10–20 kHz with a calculated per pulse source level of 224 dB re 1 $\mu Pa^2 \cdot s$ SEL (DOC 2016b).

4. Relevant Factors of Hector’s/Māui Dolphin Biology

4.1. Foraging and Diet

Miller (2014) was the first study to quantify the diet of Hector’s/Māui dolphins using both stomach content and stable isotope analyses since the original description of the species’ diet by Slooten and Dawson in 1988. The Miller (2014) study focused on 63 dolphins bycaught or beachcast around New Zealand between 1984 and 2006[10]. Of these dolphins, 79% were known to have been bycaught, and were found either entangled in nets or with significant net marks indicating entanglement as the cause of death (Miller 2014). None of the carcasses were known to have stranded alive. Less than 15% of the dolphins used in the study were found outside of spring and summer.

Based on the earlier Slooten and Dawson (1988) findings, this species has been characterised as an opportunistic feeder taking a wide range of prey, mainly fish and squid, throughout the water column. Both studies noted that most of these dolphins’ diet is comprised of juvenile fish (i.e., less than 10 cm long) with prey ranging in length from less than 1 to 60 cm (Slooten and Dawson 1988, Miller 2014). Important prey species (by mass and number) include red cods (*Pseudophycis bachus*), ahuru (*Auchenoceros punctatus*), arrow squid (*Nototodarus sp*.), sprat (*Sprattus sp*.), sole (*Peltorhamphus sp*.), and stargazer (*Crapatalus sp*.) (Miller 2014).

Miller et al. (2013) found significant differences between the diets of east and west coast Hector’s dolphins around the South Island. The west coast diet relied more on epipelagic fish (e.g., live/feed in surface waters), in particular javelinfish (*Lepidorhynchus denticulatus*). The east coast diet was dominated by fish that live at or near the bottom (demersal). There were too few stomach samples from the North Island’s west coast Māui dolphins or South Island’s south coast Hector’s dolphins for further regional comparisons, although similar prey species were present.[11] Miller (2014) noted that diet differences likely reflected varied prey availability along those regions, given the extended continental shelf off the east coast compared to the closer shelf and canyon waters along the west coast.

However, the main bias of stomach content analyses for determining a species’ diet is that it only provides information on what has recently been ingested. Miller (2014) noted that most of the dolphins were bycaught near fishing areas over spring and summer, which introduces large spatial and temporal biases to the diet data. Additionally, the digestibility of prey types can affect results. Squid beaks are hard and remain within the stomach longer than cartilage or bones. Fish remains in the stomach are identified by their otoliths (i.e., their earbones). Small fish have quite delicate and fragile otoliths that can be more digestible or lost earlier compared to larger fish remains.

A stomach content study done in combination with stable isotope analyses can help elucidate dietary preferences over a much longer timescale of months to decades (depending on the age of animal). Miller (2014) collected bone collagen (calibrated against muscle tissue when possible) from the dolphin carcasses found or caught between Kaikoura and Timaru along the east coast of the South Island between 1973 and 2006, as this region had the largest sample size (n = 40). The analysis of bone collagen is more indicative of diet over years rather than smaller seasonal time scales.

Isotope results suggest that bony fish contribute the most to Hector’s dolphin diet in this region (Miller 2014). However, unlike the stomach content findings, stable isotope results suggest that epipelagic species (e.g., sprat, *Sprattus muelleri*, pilchards, *Sardina pilchardus*, and anchovy *Engraulis australis*) contributed the most to the dolphins’ diet along the east coast over time, rather than more demersal fish such as red cod. The isotope data also support a moderate contribution from cartilaginous fish (e.g., dog fish, *Squalus acanthias*, rig, *Mustelus lenticulatus*), particularly within male dolphins. No remains of cartilaginous fish (e.g., dorsal spines) were found in the dolphins’ stomach contents. Any diet differences between males and females might be explained by group segregation by sex, which Webster et al. (2009) observed occurring around Banks Peninsula waters, especially over the summer calving season.

[10] North Island west coast (n = 2); South Island east (n = 36), west (n = 23), and south (n = 2) coasts.

[11] The two North Island dolphin diets consisted of similar prey species; ahuru, red cod, and sole, but also flounder (*Rhombosolea sp.*) not found in South Island Hector’s dolphin diets.

Overall, the diet of Hector’s dolphins (and by presumption Māui dolphins) relies on a variety of species, albeit smaller in size, found throughout the water column. Their diet appears to have been largely dependent on epipelagic bony fish over the past several decades. Larger, more demersal fish also contribute to their diet, but perhaps more seasonally over warmer months when both co-occur within more inshore waters (e.g., Beentjes et al. 2002). Miller (2014) also highlighted the significance that previously unknown prey species, such as cartilaginous fish, may contribute to sexual differences in the dolphins’ diet along the east coast.

4.2. Cetacean Acoustics

The following sections provide a concise description of the most relevant factors and concepts for the assessment of effects of underwater sound on cetacean hearing (i.e., auditory effects).

4.2.1. Hearing in marine mammals

Sound travel underwater better than any other form of energy. Assessing the effects of sound on marine life requires a good understanding of the principles governing the physics of underwater sound. Ketten (2014c) provides an excellent overview of underwater acoustics (see Appendix C for an excerpt of the relevant section from her report).

An animal will only respond to acoustic signals it can detect. The sensitivity of an animal’s auditory system (i.e., hearing) is commonly described as a function of sound frequency. The hearing threshold is determined by the lowest intensity of a sound at a particular frequency that an individual can detect. A hearing curve, or audiogram, is the graphical representation of these thresholds over the range of frequencies that are audible to the individual (Figure 24). However, only a few individuals in a relatively small number of the 133 marine mammal species have been tested to date.

There are two methods to measure direct information on marine mammal hearing sensitivity: the psychophysical approach (i.e., conducting behavioural hearing experiments) and electrophysical methods (e.g., auditory evoked potential (AEP) measurements).

Alternatively, information on the frequency range and hearing of marine mammals can be estimated from:

- The species’ acoustic emissions (vocalisations and other sounds, such as echolocation signals).
- Morphology or functional models of different components of their hearing system (Ketten and Mountain 2009, Tubelli et al. 2012, Ketten and Mountain 2014, Cranford and Krysl 2015).
- Their behavioural reactions to sound exposure (Dahlheim and Ljungblad 1990, Richardson et al. 1995, Reichmuth 2007).
- Extrapolation of auditory information between species.

Such indirect information has been used to predict the sensitivity of marine mammal species to underwater sound that have not been available yet for direct hearing measurements.

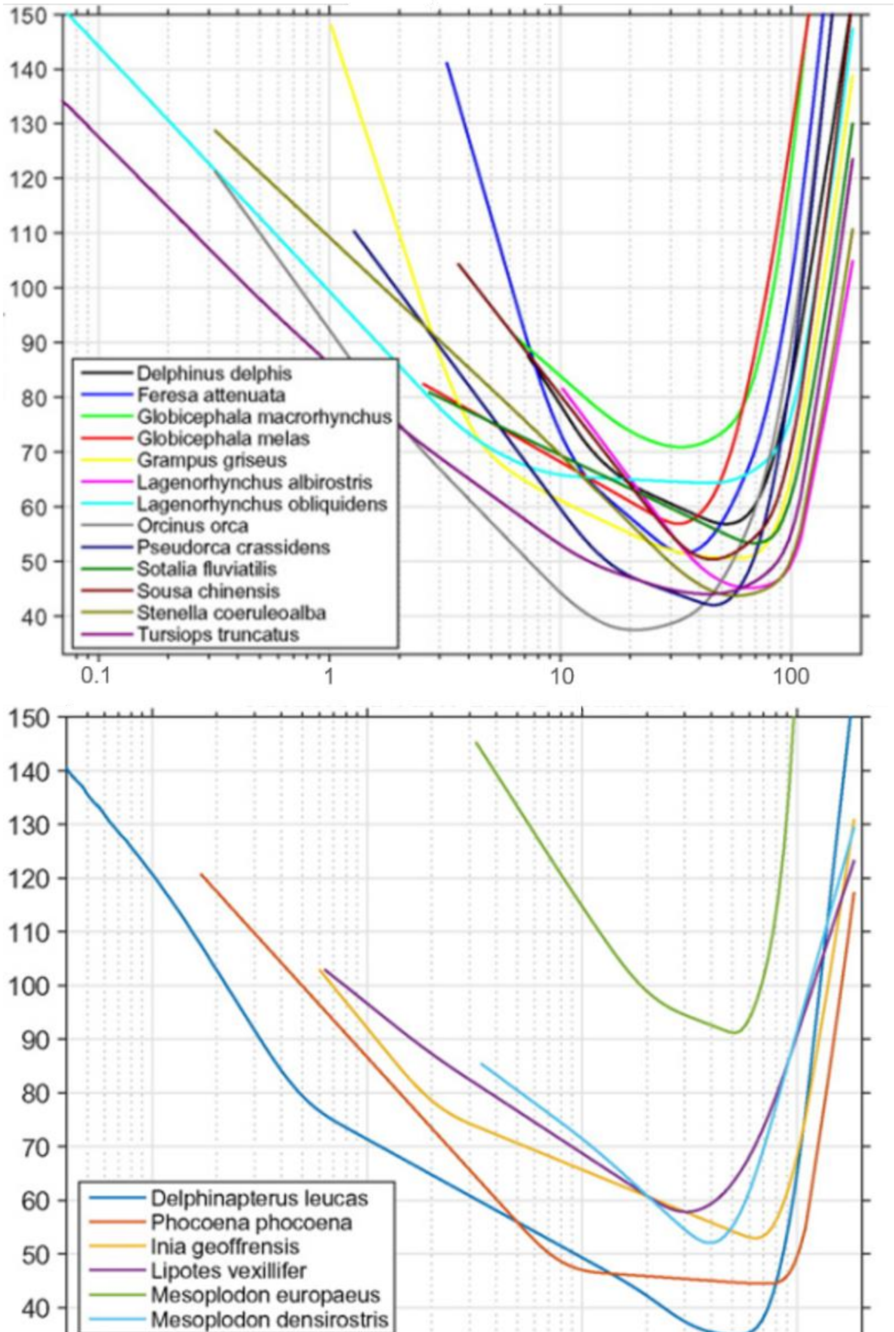

Figure 24. Minimum underwater audiogram levels measured for various dolphin species (top) and other toothed whale species (bottom) ; graphs taken from Erbe et al. (2016).

Phylogenetically closely related species often show auditory similarities, but on a higher taxonomic level, species groups can also show significant differences in terms of their hearing range and sensitivity. To better reflect these similarities and differences in marine mammal species, Southall et al. (2007) assigned the extant marine mammal species to functional hearing groups based on their hearing capabilities and sound production. This classification, recently revised by NMFS (2018), categorises Hector's/Māui dolphins as a high-frequency (HF) cetacean species (Table 4) and will be used in this report.

Table 4. Marine mammal functional hearing groups and their generalised hearing ranges (NMFS 2018).

Functional hearing group	Acronym	Generalized hearing range
Low-frequency cetaceans (mysticetes or baleen whales)	LF	7 Hz to 35 kHz
Mid-frequency cetaceans (odontocetes: dolphins, toothed whales, beaked whales, bottlenose whales)	MF	150 Hz to 160 kHz
High-frequency cetaceans (other odontocetes: true porpoises, Kogia, river dolphins, cephalorhynchid [including Hector's dolphins], Hourglass dolphins, Peale's dolphins)	HF	275 Hz to 160 kHz
Phocid pinnipeds (underwater) (true seals, including all Arctic and Antarctic ice seals, harbor or common seals, grey seals and inland seals, elephant seals, and monk seals)	PW	50 Hz to 86 kHz
Otariid pinnipeds (underwater) (eared seals: fur seals and sea lions)	OW	60 Hz to 39 kHz

4.2.2. Metrics

The publication of ISO 18405 Underwater Acoustics–Terminology (ISO 2017) (see Table 5) provided a dictionary of underwater bioacoustics. The relevant metrics to describe underwater sound in relation to its effects on marine mammals are the sound pressure level, peak pressure, and sound exposure level.

The sound pressure level (SPL) is the ratio of the time-mean-square sound pressure, in a stated frequency band, to the square of the reference sound pressure (ANSI S1.1-1994 R2004). Unless otherwise stated, SPL refers to the root-mean-square (rms) pressure level.

The peak pressure level (PK) is the maximum instantaneous sound pressure level, in a stated frequency band, within a stated period; it is also called zero-to-peak pressure level.

The sound exposure level (SEL) is a cumulative measure related to the sound energy in one or more acoustic pulses. SEL is expressed over the summation period (e.g., per-pulse SEL [for airguns], single-strike SEL [for pile drivers], 24-hour SEL[12]). SEL is the time integral of the square pressure over a time window long enough to include the entire pressure pulse. SEL is therefore the sum of the acoustic energy over a measurement period, and effectively takes account of both the level of the sound, and duration over which the sound is present in the acoustic environment.

Table 5. Metrics used to describe underwater sound.

Metric	Commonly used (before 2017)	ISO (2017)/NMFS (2018)	
		Main text	Tables/equations
Sound Pressure Level	SPL_{rms}, SPL_{RMS}	SPL	SPL (L_p)
Peak Pressure	SPL_{pk}	PK	PK (L_{pk})
Sound Exposure Level	SEL_{cum}	SEL_{24h}	SEL_{24h} ($L_{E,24h}$)

[12] The Sound Exposure Level metric (SEL_{24h}) describes the sound energy received by a receptor over a period of 24 hours. Prior to 2017, SEL_{cum} has been used as metric to denote the same.

4.2.3. Noise exposure criteria and frequency weighting functions

The division into functional hearing groups (Table 4) was intended to provide a realistic number of categories for which individual noise exposure criteria were developed. These criteria are implemented by national regulatory bodies and intended to prevent marine mammals being exposed to intense and potentially harmful sounds from human activities. The first criteria for underwater noise exposure for marine mammals were set by the U.S. National Marine Fisheries Service (NMFS 1995). Similar thresholds have been developed in various countries, were revised based on new research several times and the most recent set of thresholds for onset of TTS and PTS was published in 2018 (NMFS 2018)[13]. The main component of underwater exposure criteria are maximum allowable noise thresholds which are often tailored for each functional hearing group applying frequency weighting functions. These functions are used to emphasize frequencies where the animals' hearing sensitivity to sound is high and de-emphasize frequencies where sensitivity is low in each functional hearing group.

Frequency weighting functions were initially measured and developed for humans. The development of marine mammal weighting functions is directly adapted to the processes and parameters used in human audiology. As Ketten (2014c) pointed out, the functions are still speculative; however, a comparative analysis of existing weighting functions (unpublished, see next Section) has shown that the most recent set of weighting functions (implemented by NMFS 2018) provides the best match to direct results gained from scientific studies in marine mammals.

Weighting functions have relevance for assessing some types of effects of acoustic exposure on marine mammals which are discussed in Section 4.3.

4.2.3.1. Frequency weighting

Species and individuals are sensitive to sound at different frequencies. In humans, it has been shown that variance in sensitivity is related to an individual's perception of loudness of a sound. To account for differential sensitivity in humans, measures of sound may be normalised or 'weighted' by applying a filter that matches plots of perceived loudness. Weightings are applied numerically by adding or subtracting specific values on the decibel scale. There are two weighting functions in use for humans: A-weighting (for quiet signals) and C-weighting (for intense sounds).

Southall et al. (2007) produced a comprehensive review of impacts of underwater noise on marine mammals and proposed criteria for preventing auditory injury based on both PK and SEL. The authors assigned the extant marine mammal species to functional hearing groups based on their hearing capabilities and sound production (with three groups for cetaceans: low- (LF), mid- (MF), and high- (HF) frequency cetaceans). To account for wide frequency dependence in the auditory response of marine mammals, M-weighting functions (adapted from human C-weighting functions) were proposed for each functional hearing group. Onset levels for TTS and PTS have been estimated for these groups based on measurements in marine mammals as well as extrapolation from terrestrial mammals; a caveat is that these marine mammal criteria are based on audiograms and noise exposure experiments of only a few species.

Weighting functions should, ideally, be determined based on TTS results for each species. As there are insufficient TTS data to inform all parameters necessary to determine the weighting functions, equal-loudness (EQL) and equal-latency (EL) data have been used as a first and second order approximation. This approach is similar to how human exposure guidelines were developed (NIOSH 1998). EQL weighting is based on equal loudness contours that are calculated from subjective loudness measurements (Finneran and Schlundt 2011) and EL weighting is based on an individuals' reaction time in response to a stimulus in a psychoacoustic (behavioural) hearing test (Wensveen et al. 2014, Mulsow et al. 2015).

Southall et al. (2007) proposed dual criteria for onset of TTS and PTS taking PK and SEL in cetaceans into account; the lower (more conservative) of the criteria applies for any application. More recently, the U.S. criteria for assessing risk of marine mammal auditory injury were updated based on the latest scientific knowledge (NMFS 2018), including new weighting functions which are based on TTS measurements as well as EQL and EL data. The NMFS (2018) weighting functions, which are different to the M-weighting functions suggested by Southall et al. (2007), are presented in Table 6.

[13] The NMFS (2018) criteria do not provide thresholds levels for onset of behavioural effects.

Relevant NOAA (NMFS 2018) acoustic thresholds for PTS are listed in Table 6. Note there is a slight change in semantics between old and new criteria in that levels for onset of ‘Auditory Injury’ (Southall et al. 2007) has now been renamed ‘PTS onset’ (NMFS 2016, 2018), and levels for onset of ‘Behavioural Disturbance’ to be called ‘TTS onset’ levels.

Table 6. Noise exposure criteria for onset of TTS and PTS for the three cetacean functional hearing groups for different types of sound as suggested by NMFS (2018). For impulsive sounds a dual metric is given (PK, SEL).

Hearing group	**PTS onset thresholds (received level)**		**TTS onset thresholds (received level)**	
	Impulsive	Non-impulsive	Impulsive	Non-impulsive
Low-frequency cetaceans	L_{pk}, flat: 219 dB $L_{E,LF}$, 24h: 183 dB	$L_{E,LF}$, 24h: 199 dB	L_{pk}, flat: 213 dB $L_{E,LF}$, 24h: 168 dB	$L_{E,LF}$, 24h: 179 dB
Mid-frequency cetaceans	L_{pk}, flat: 230 dB $L_{E,MF}$, 24h: 185 dB	$L_{E,MF}$, 24h: 198 dB	L_{pk}, flat: 224 dB $L_{E,MF}$, 24h: 170 dB	$L_{E,MF}$, 24h: 178 dB
High-frequency cetaceans	L_{pk}, flat: 202 dB $L_{E,HF}$, 24h: 155 dB	$L_{E,HF}$, 24h: 173 dB	L_{pk}, flat: 196 dB $L_{E,HF}$, 24h: 140 dB	$L_{E,HF}$, 24h: 153 dB

If a non-impulsive sound has the potential to exceed peak sound pressure level thresholds associated with impulsive sounds, these thresholds should also be considered. Peak sound pressure is defined by American National Standards Institute standards (ANSI S1.1-1994 R2004) as incorporating frequency weighting, which is not the intention for this technical guidance. Hence, the subscript ‘flat’ is being included to indicate that peak sound pressure should be flat weighted or unweighted within the generalised hearing range. The recommended accumulation period is 24 hours. The cumulative sound exposure level thresholds could be exceeded in a multitude of ways (e.g., varying exposure levels and durations, duty cycle). When possible, it is valuable for impact assessments to indicate conditions under which these acoustic thresholds will be exceeded.

In a recent study for Fisheries and Oceans Canada that tried to better understand limitations of existing noise exposure criteria (ongoing, still unpublished), the original recordings from Lucke et al. (2009) were used to compare various noise exposure criteria. The outcome of this analysis clearly showed that HF-weighted NMFS criteria (NMFS 2018) and the (unpublished) New Zealand criteria ([NZDOC] New Zealand Department of Conservation 2017) showed the best overall match to the original TTS results. The development of these weighting functions is based on procedures which are established in human audiometry (i.e., the medical assessment of hearing sensitivity). The thresholds and weighting functions for marine mammals are derived from the best available scientific information on sensitivity of these animals to noise. Accordingly, the NMFS criteria and associated weighting functions are applied in this report in addition to providing unweighted results.

Southall et al. (2019) published an updated set of noise exposure criteria for onset of TTS and PTS in marine mammals. While the authors propose a new nomenclature and classification for the marine mammal functional hearing groups, the thresholds and weighting functions proposed do not differ substantially from those proposed by NMFS (2018).

4.2.4. Cetacean acoustic signals

Toothed whales (odontocetes) are capable of producing short impulsive signals ('clicks') at ultrasonic frequencies. These signals are used for echolocation, i.e., the localisation and characterisation of objects in their underwater environments by means of analysing echoes reflected from objects denser than water. Many odontocete species also emit vocalisations, such as whistles, for communication purposes, but these social sounds can also resemble moans, cries, and other types of sounds. Odontocete vocalisations and clicks can be acoustically characterised in terms of the frequency range they cover, their peak frequency, and their source level. Figures 25 and 26 show the waveform and spectra of some representative odontocete click types and provide the acoustic characteristics of odontocete species closest related to the Hector's/Māui dolphins. Hector's/Māui dolphins belong to a subset of dolphin species that evolved Narrow-Band High-Frequency (NBHF) signals (Figure 25C).

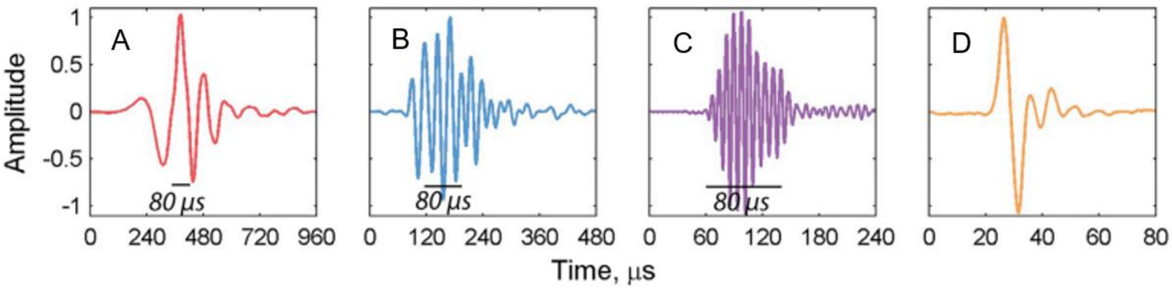

Figure 25. (A-D) Waveforms of on-axis biosonar search signals for four cetacean species: Sperm whale, *Physeter macrocephalus* (A; red), Cuvier's beaked whale, *Ziphius cavirostris* (B; blue), Harbour porpoise, *Phocoena phocoena* (C; purple), and Indo-Pacific bottlenose dolphin, *Tursiops aduncus* (D; orange).

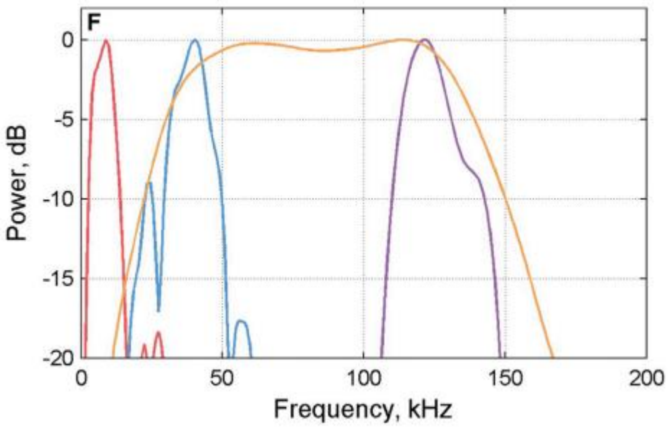

Figure 26. Normalized power spectra of odontocete clicks corresponding to waveforms shown in Figure 25 (taken from Jensen et al. 2018).

4.3. Effects of Underwater Sound on Marine Mammals

Underwater sound generated by anthropogenic (i.e., man-made) offshore activities has capacity to impact marine fauna. Potential direct effects include damage to auditory systems, avoidance of habitats, behavioural alterations, and masking of biologically important sounds (Southall et al. 2007, Branstetter et al. 2013, Tougaard et al. 2016, Mikkelsen et al. 2017). Exact effects of anthropogenic sound on marine mammals are often unknown. Reviews (e.g., Richardson et al. 1995, Nowacek et al. 2007, Southall et al. 2007, Wright et al. 2007, Andersen et al. 2012, Johnston et al. 2012) highlight that increased background noise and certain sound sources might impact marine mammals in several ways: (1) death; (2) hearing loss (temporary or permanent); (3) auditory masking (4) alterations in behaviour (including displacement from feeding/breeding/migration habitat); (5) chronic stress; and, (6) indirect effects including displacement of prey species (Section 2.1.2; Packard et al. 1990, Mooney et al. 2010, Simpson et al. 2010, Radford et al. 2011, Holles et al. 2013). These effects are described in more detail below 4.3.

Animals are expected generally to move away from noise and disturbing sound sources thereby reducing their exposure. There are a variety of reasons why this might not be the case if the advantages of remaining in an ensonified area outweigh the cost. One of which is the ‘dinner bell’ effect, in which some sounds, for example adding acoustic alarms or pingers to fishing nets, can signal locations of prey availability but also attract predators (Dawson 1994). California sea lions (*Zalophus californianus*) are attracted to fishing nets equipped with pingers (Carretta and Barlow 2011). This result has also been suggested for bottlenose dolphins (López and Mariño 2011). In addition, it has been suggested that grey seals use sound signals produced by acoustically tagged fish to locate prey (Stansbury et al. 2015). The complexity of behavioural reactions is discussed in more detail below (4.3.3)

Exposure to underwater sound can affect marine mammals in a variety of ways. The nature of a sound, the behavioural context a sound is perceived in, the novelty of a sound, and experience from previous exposures can all shape the effect of such an exposure. The severity of noise-induced effects is roughly correlated to the received acoustic power, scaling from mere perception, to stress and acoustic masking, to behavioural and physiological or physical effects.

Concepts described below are based on best available science on noise-induced effects in marine mammals. Regulation of underwater noise (such as NMFS 2018) uses weighting functions to assess risk of causing behavioural reactions or physical (auditory) impairment. This concept has also been used by McPherson et al. (2018) in their report on vessel and seismic noise in New Zealand waters and its potential effect on Hector’s/Māui dolphins.

4.3.1. Audibility

At the lowest detectable level, a sound can be perceived by an animal if the sound exceeds its detection threshold. Recognition and discrimination of sounds, as well as comfortable acoustic communication, requires levels clearly above the detection threshold (Dooling and Blumenrath 2016).

4.3.2. Stress

Stress is an integral, natural reaction of the body to external stimuli. While certain stress levels are tolerable, at higher levels, if repeated too often or continued over long durations, stress can negatively affect the body. The effects of increased stress levels (acute or chronic) can be expressed through a variety of metabolic and/or physiological factors. This can be expressed in a variety of symptoms, from disruption of immune systems to changes in growth rate, diurnal rhythms, and behavioural changes (e.g., Slabbekoorn et al. 2010, Kight and Swaddle 2011). To this date, stress effects have not widely been studied in marine mammals, and our understanding of such effects is in its infancy. There is, however, concern that a cascade of stress-related effects may reduce an individual’s fitness through alterations in reproduction (e.g., Sierra-Flores et al. 2015) and, ultimately, survival (see review by Slabbekoorn et al. 2010).

4.3.3. Behavioural reactions

To cause behavioural reactions, sound must be audible, i.e., it must be detectable above background noise and exceed the animal’s hearing threshold.

Context

The nature and extent of behavioural responses differs between species, as well as between individuals of the same species. Responses are strongly determined by the context in which the sound is received by an animal (Southall et al. 2007, Ellison and Frankel 2012, Southall et al. 2016). The activity state of animals exposed to different sounds, the nature and novelty of a sound, spatial relations between a sound source and receiving animals (i.e., its proximity or direction of travel), and the gender, age, and reproductive status of the receiving animal are all contributing factors.

Severity

Severity of behavioural responses of marine mammals to sound exposure can vary strongly, from subtle responses, which may be difficult to observe and have little implications for the affected animal, to obvious responses, such as avoidance or panic reactions. Southall et al. (2007) developed a severity scale for behavioural reactions in marine mammals containing ten categories.

Due to the complexity of behavioural responses to sound and in the absence of sufficient relevant information on the levels eliciting responses, Finneran et al. (2017) divided behavioural reactions into three categories of low, moderate and high severity. Following his classification, low severity responses are those too subtle to significantly alter natural behavioural patterns. Such responses would include the following:

- Orientation response.
- Startle response.
- Change in respiration.
- Change in heart rate.
- Change in group spacing or synchrony.

Behavioural responses would be classified as moderately severe if the response is sustained over a longer duration. According to Finneran et al. (2017), what constitutes a long-duration response is different for each situation and species. It would be considered 'long-duration' if it lasted long enough to substantially disrupt an animal's daily routine. Such responses would last at least a few tens of minutes to a few hours. Non-significant behavioural responses would last for a short duration, and the animal would immediately return to its pre-response behaviour. Behavioural responses of moderate severity include the following:

- Alteration of migration path.
- Alteration of locomotion (speed, heading).
- Alteration of dive profiles.
- Cessation/alteration of nursing behaviour.
- Cessation/alteration of breeding behaviour.
- Cessation/alteration of feeding/foraging behaviour.
- Cessation/alteration of sheltering/resting behaviour.
- Cessation/alteration of vocal behaviour.
- Avoidance of area near sound source.

High severity responses are those with possible immediate consequences to the fitness of an animal (i.e., directly affecting animal's growth, survivability, and reproduction). Severe responses include those affecting animals in vulnerable life stages (i.e., calves), and would always have to be considered a significant behavioural reaction. They include the following:

- Long-term or permanent abandonment of area.
- Prolonged separation of females and dependent offspring.
- Panic and flight.
- Stranding.

Numerous cases of mass stranding events of cetaceans (predominantly beaked whale species) occurred worldwide over the past decades which are suspected to be caused by exposure to human-made underwater noise (mainly naval sonars). While the correlation between the noise emissions and stranding events was accepted in several cases, clear evidence was not established, and the cause-effect relationship remained mostly speculative.

The current understanding of the complexity of behavioural responses in marine mammals to underwater sound (for reviews, see Southall et al. 2007, Ellison and Frankel 2012, Southall et al. 2016) and the lack of quantitative data (sound levels) in this context make it impossible to determine robust onset levels for functional hearing groups or even particular species. Moreover, there is not yet consensus within the scientific community regarding the appropriate metric useful for assessing behavioural reactions.

Behavioural noise exposure criteria

Most often, the approach by Wood et al. (2012) is used: a graded probability of response for impulsive sounds using a frequency weighted SPL metric. They also designated behavioural response categories for sensitive species (such as harbour porpoises and beaked whales) and for migrating mysticetes (Table 7).

Table 7. Predicted probability of behavioural response in marine mammals as a function of frequency-weighted sound pressure level (SPL, dB re 1 µPa) (Wood et al. 2012); probabilities are not additive.

Marine mammal group	Probability of response to frequency-weighted SPL (dB re 1 µPa)			
	120	140	160	180
Sensitive species	50%	90%		
All other species		10%	50%	90%

Terminology

The terms describing the different qualities of noise-induced behavioural effects are sometimes used in an incorrect and confusing way. To mediate a clear understanding and discussion of these effects, the most relevant terms are briefly explained in the following paragraph.

Any kind of behavioural reaction an animal shows following exposure to sound can be considered a behavioural response. We can observe behavioural responses that may or may not constitute behavioural disruption – while a behavioural response can be a change in direction relative to the sound source with no apparent change to the behaviour itself, a disruption would be the change from one behavioural state to another. Some noise regulations prohibit behavioural disruption but not behavioural response (e.g., MMPA, United States Congress 1972).

A term that is often used synonymously with behavioural reactions is behavioural disturbance. It is, however, not to be confused with behavioural disturbance diagnosed by psychiatrists, e.g., in humans. With regard to noise-induced behavioural effects in marine mammals, a behavioural disturbance constitutes any kind of interruption of an ongoing behaviour and can result in a continuation of the behaviour after a short duration or a change to a different behavioural state.

An extreme form of behavioural disturbance that can be seen in marine mammals is avoidance, i.e., if an animal leaves the area in response to the sound exposure. The spatial and temporal extent of this reaction can vary, from short-lived and/or short-range avoidance to permanent and/or long-range evasion from an area.

Deterrence, finally, is a term describing the intentional use of a (typically) sound stimulus to elicit an avoidance reaction in an animal. Deterrence devices such as acoustic pingers are often used to mitigate the potentially adverse effects of sounds emitted from human activities (e.g., offshore pile driving) or deter marine mammals away from fish farms. The efficiency of these devices in terms of driving animals out of a dangerous area differs between different types and is, once more, strongly context specific.

Response of harbour porpoises to acoustic disturbance is thought to be representative (if not conservative as they are known to be ‘nervous’ animals, i.e., showing strong behavioural reactions to novel stimuli at low exposure levels) of other high-frequency cetacean species. Understanding impacts on this species can provide precautionary baselines for other species of cetacean (Southall et al. 2007). However, harbour porpoises can potentially be at risk of increased exposure to sound when compared with other cetacean species because of their high energetic demands (Santos et al. 2004, Lockyer 2007, Jones et al. 2014, Wisniewska et al. 2016b, Rojano-Doñate et al. 2018). They may remain in areas of disturbance for longer or return sooner to disturbed areas if those areas provide good foraging opportunities. This can increase their noise exposure and potentially affect their hearing.

4.3.4. Auditory masking

The hearing threshold for perceiving or detecting a signal of interest can be reduced by the simultaneous presence of another sound (termed ‘masking noise’), a process called auditory masking (Erbe and Farmer 1998, Erbe 2008, Erbe et al. 2016). For this to occur, the masking noise must be loud enough, have similar frequency content to the signal of interest, and must happen at the same time. Both anthropogenic and natural marine sound can mask auditory perception of sounds for marine mammals.

The severity and extent of auditory masking depends on the spectral and temporal characteristics of both signal and noise. It can be reduced if the signal and noise are separated in time, frequency, or direction (space). The zone of auditory masking can maximally be as large as the zone of audibility, i.e., a faint noise might mask a faint signal. Auditory masking ends immediately after the masking sound ceases. Marine mammals can reduce the masking effect by various active or passive mechanisms, so-called masking-release mechanisms Active strategies to reduce auditory masking include alterations of the characteristics of vocalisations in the presence of noise (Lombard effect, see Erbe et al. 2016 for details). Marine mammals have been reported to raise the amplitude of their communication signals in the presence of ship noise (Scheifele et al. 2005, Holt et al. 2011), increase the source level of their songs or echolocation clicks (Au et al. 1974, Dunlop et al. 2014) or alter the frequency content of their calls (Ansmann et al. 2007, Parks et al. 2007). Passive mechanisms include, e.g., Spatial Release from Masking (SRM) or Co-modulation Masking Release (CMR) and (Erbe et al. 2016). SRM describes a mechanism where directional hearing abilities enhance the listener’s ability to detect a signal if the signal and the noise arrive from different directions. If the noise is amplitude modulated across multiple frequency bands, the listener can correlate information from multiple bands to help determine when the signal occurs (CRM, (Hall et al. 1984). The effects of auditory masking range from behavioural disruption or lack of appropriate behavioural reactions, increased vulnerability to predators or reduced access to prey, changes in vocal behaviour to reduced communication space (Clark et al. 2009) or listening range (Pine et al. 2018). These effects can be detrimental to the fitness and survival of individuals.

4.3.5. Noise-induced threshold shift

Exposure to intense levels of noise can lead to an increase in hearing threshold in humans as well as in marine mammals (Finneran 2015). Such an increase in hearing threshold is called a threshold shift (TS) and means that the hearing becomes less sensitive (i.e., worse). If this effect is reversed and the hearing threshold returns to its normal sensitivity, the TS is called a temporary threshold shift (TTS). If the threshold shift remains permanently and does not return completely to normal, the residual TS is called a permanent threshold shift (PTS). TS can be caused by exposure to intense sound of short duration, as well as exposure to lower level sounds over longer time periods (Houser et al. 2017). The metrics commonly used to assess the risk of impairment or injury to the hearing system are the sound exposure level (SEL), which considers the sound level and duration of the exposure signal as well as the peak pressure (PK).

The biological significance of TTS and PTS depend on the amount of TS caused, the frequency band that is affected, and the duration of the recovery (except for any residual PTS) and the importance of hearing as sensory modality in the affected animal(s). For marine mammals such as Hector’s/Māui dolphins, a loss of hearing sensitivity can be negligible if only small amounts of TS are caused or frequencies outside their range of vocalisation or echolocation frequencies are affected. If, however, frequencies important for vocalisation or echolocation are affected, even a small TS can have severe implications for the fitness and survival of an animal.

Lucke et al. (2009) measured TTS in a harbour porpoise exposed to seismic airgun signals. Onset of TTS at 4 kHz was measured at received levels above 164 dB re 1 µPa^{2}s SEL and 200 dB re 1 µPa (peak-peak, p-p). No TTS was observed at 32 kHz or 100 kHz (the latter frequency of which porpoises are most sensitive to). Received levels >174 dB re 1 µPa p-p also elicited an avoidance response (Lucke et al. 2009).

Using behavioural and auditory evoked potential (AEP) methods, TTS from impulsive sound has been measured to occur in harbour porpoises between 162–197 dB re 1 µPa^{2}s SEL at frequencies between 1.5 and 6.5 kHz. Ethical considerations prevent measuring PTS experimentally, but for harbour porpoise it is expected to occur at 177–213 dB re 1 µPa^{2}s SEL for frequencies between 1.5 and

90 kHz (Finneran 2016). Generally, for lower frequency sounds, the SEL needs to be higher to cause TTS or PTS in harbour porpoises. For example, sound at 1.5 kHz caused TTS/PTS onset at 191–197 and 207 dB re 1 µPa^{2}s SEL respectively (Kastelein et al. 2014a) and sound at 6.5 kHz caused TTS/PTS at 161–182 and 197–204 dB re 1 µPa^{2}s SEL respectively (Kastelein et al. 2014a, Kastelein et al. 2014b).

Existing regulations of underwater noise differ in their thresholds for onset of TTS (and PTS) but have in common that onset levels for HF cetaceans are substantially lower than those of other functional hearing groups. The HF-weighted noise exposure criterion suggested by NMFS (2018) for onset of TTS is 153 dB re 1 µPa^2·s SEL.

4.3.6. Mortality

At extreme levels, exposure to underwater sound can lead directly to mortality of an exposed animal. Mortality is either a direct effect of the exposure (in case of severe injury) or indirect (if an animal is moderately injured). Evidence on sound-induced mortality in marine animals is scarce and based on indirect information (Ketten et al. 1993).

4.3.7. Indirect effects

Noise-induced effects on the abundance, distribution, and/or fitness of Hector's/Māui dolphins' prey (or the lower trophic levels, i.e., the marine food chain) can have indirect consequences for the dolphins.

Like marine mammals, fish use sound to acquire information about the environment around them, making them susceptible to anthropogenic noise. Extensive variability exists between hearing sensitivity of fish species. In general, they are sensitive to low frequencies (Popper et al. 2003, Popper and Fay 2011). In laboratory experiments, TTS has been reported in freshwater and marine fish exposed to low-frequency white noise (e.g., Scholik and Yan 2001, Amoser and Ladich 2003, Smith et al. 2004a, 2004b) and vessel noise (e.g., Scholik and Yan 2002, Codarin et al. 2009).

Potential noise-induced effects on fish, reviewed in detail by Thomsen et al. (2006) and Popper and Hastings (2009), include mortality (Caltrans 2001), injuries including hematomas and organ haemorrhage (Halvorsen et al. 2012, Casper et al. 2016), damage to auditory tissues and hearing loss (Casper et al. 2013), and behavioural changes (Mueller-Blenkle et al. 2010). Not all studies, however, report an impact. For example, Nedwell et al. (2003) reported no apparent behavioural impacts or injuries to caged brown trout (*Salmo trutta*), located 400 m from pile driving operations where they were exposed to estimated received levels of 134 dB re 1 µPa (PK). Likewise, Ruggerone et al. (2008) reported no injury or behavioural changes in caged coho salmon (*Oncorhynchus kisutch*) located up to 15 m from pile driving activity.

Small-scale avoidance of noise is unlikely to have any long-lasting effects on fitness. If noise was to occur in breeding or feeding grounds, then fish might relocate to other areas. More research is required to assess this possibility. Other behavioural effects include increased motility (Buscaino et al. 2010), reduced feeding efficiency (Voellmy et al. 2014), and masking of communication signals (Codarin et al. 2009).

Noise also has the ability to impact larval organisms that use sounds to orientate towards settlement locations (Simpson et al. 2010, Radford et al. 2011, Holles et al. 2013). Masking of these sounds could prevent larvae settling in ideal locations, or prevent them from finding a place to settle at all (e.g., Simpson et al. 2010, Simpson et al. 2011, Holles et al. 2013).

McCauley et al. (2017) found that after exposure to seismic airgun signals zooplankton abundance decreased and mortality in adult and larval zooplankton increased. Richardson et al. (2017) simulated the large-scale impact of a seismic survey on zooplankton using the mortality rate found by McCauley et al. (2017) and concluded that depending on ocean-circulation the effect-ranges could be on a realistic scale but due to fast growth rates, dispersal and mixing zooplankton populations should recover quickly after exposure and ocean ecosystem function and productivity would not be affected on a larger scale.

Exclusion of prey from foraging areas has potential to impact marine mammals negatively, but the extent to which this occurs depends upon significance of the feeding ground, ability to switch prey species, and availability of alternate foraging areas. The level of effect is therefore species and context dependent.

4.4. Acoustics of Hector’s/Māui Dolphins

Assessing the effect of noise exposure on Hector’s/Māui dolphins requires knowledge about their auditory sensitivity. However, there is no direct audiometric data available for this species. In the absence of such data, valuable insights are provided from indirect information such as their acoustic signals and vocalisations, the anatomy of their hearing apparatus, and auditory information from related species.

4.4.1. Hearing sensitivity and echolocation signals

No studies have directly measured Hector’s/Māui dolphin hearing as this involves conducting the necessary hearing tests on a live animal that is restrained or captive. Only four Hector’s dolphins have ever been captured and kept in aquaria, all in the early 1970s at Marineland in Napier of Hawke Bay, New Zealand.

The first studies focused on recording and describing the vocal repertoire of Hector’s dolphins began in the late 1970s to early 1990s (e.g., Watkins et al. 1977, Dawson 1988, Dawson and Thorpe 1990). At that time, studies on this species’ vocalizations were considered difficult given the lack of sophisticated high-frequency recording equipment suitable for the marine environment and the fact that this species is thought to be unusually quiet relative to other species (Dawson 1990).

The sounds of all of the *Cephalorhynchus* species (i.e., the taxonomic unit or ‘genus’ Hector’s/Māui dolphins belong to) seem very similar (Dawson 2017, Jensen et al. 2018). Dawson (1990) found most of the sounds emitted by Hector’s/Māui dolphins were within a narrow range of high frequencies, mainly clicks, centred around 120–125 kilohertz (kHz). Less than 2% of their vocalisation sounds occurred below 100 kHz, and the highest frequency was 141 kHz. Their clicks are considered simple in structure consisting of mainly single and double pulses. Dawson and Thorpe (1990) noted that these sounds were generally low level (i.e., source levels less than 160 dB re 1 µPa). Kyhn et al. (2009) documented click source levels around 177dB re 1 µPa.

These finding are similar to the vocalisation ranges of other relatively small dolphin species such as other *Cephalorhynchus* species (i.e., Commerson’s dolphins, *C. commersonii*, Heaviside’s dolphins, *C. heavisidii* and the Chilean dolphins *C. eutropia*), porpoises (e.g., harbour porpoises) and Kogia species (*Kogia sp.*) (NMFS 2018) (see also Table 8). Hector’s dolphin vocalisations differ to other dolphins in that they do not whistle but do have an audible ‘cry’ or ‘squeal’ resulting from clicks emitted at extremely high repetition rates. Despite their vocalisation repertoire mainly consisting of echolocation clicks, Hector’s dolphins appear to also use these sounds for communication, similar to harbour porpoises involving specific click patterns for short-range communication (Clausen et al. 2010). Preliminary work by Dawson (1991) suggested that more complex sounds were used more often in large, surface active groups, and ‘cries’ were more common with aerial behaviours (jumps and leaps) and ‘exciting’ social situations. The double pulse clicks were strongly associated with foraging type behaviours. Other signals such as broadband clicks are very occasionally recorded from Hector’s and Commerson’s dolphins, and whistles have only been recorded from Commerson’s dolphins (Dawson 2017). Based on observations, Dawson (1990) also noted that individual dolphins relied on ‘passive sonar’ (listening to their environment rather than continuously interrogating it with their echolocation) and hypothesized that groups of dolphins may ‘eavesdrop’ on other’s sonar echoes to gain information on the environment and each other.

Since the early 2000s, autonomous underwater acoustic detection and/or recording devices have been used to infer this species’ presence and movement patterns through the remote detection of their vocalisations. Example studies include monitoring dolphin use within a protected bay (Rayment et al. 2009c), quantifying the possible offshore extent of Māui dolphins (Goetz unpubl. data, DOC unpubl. data), and examining both Hector’s and Māui dolphins’ presence and seasonal use of various harbours (Rayment et al. 2011, Dawson et al. 2013, Pine 2018).

Beginning in 2014, these devices have also been used to collect information on the extent to which ambient and anthropogenic underwater sound levels might affect these dolphins. However, the only in situ underwater noise research to date on this species looking at potential effects has taken place within Lyttelton Harbour near Christchurch, home of New Zealand's third largest working port. These studies include a short-term study into the possible impacts of pile driving on Hector's dolphins in Lyttelton Harbour over the summer of 2014–2015 (Leunissen 2018, Leunissen and Dawson 2018). Since January 2017, a long-term monitoring programme has been underway by Lyttleton Port Company within the harbour collecting continuous underwater acoustic data on Hector's dolphin presence within and around the harbour entrance, and more recently, their possible foraging patterns (i.e., click trains and intervals). In addition, sound levels generated from simultaneous harbour activities (i.e., vessel noise, dredging, sediment disposal and pile driving) are also being recorded and monitored for further analyses (Clement & Pine, unpubl. data).

Hector's dolphin hearing capabilities and response levels to underwater noise are the current topic of many resource consent hearings around New Zealand under both the RMA and EEZ Acts. To establish possible noise thresholds for various development activities, Leunissen (2018) suggested using results published by Lucke et al. (2009) and Kastelein et al. (2013b, 2015a) as a proxy for Hector's dolphins.

Lucke et al. (2009) conducted a TTS study on a harbour porpoise using a seismic airgun as sound source. Their results showed that onset of TTS occurred after exposure to a single airgun impulse at a SEL of 164 dB re 1 µPa^2·s (unweighted). Kastelein et al. (2015a) exposed a captive harbour porpoise to playbacks of pile-driving impulses for 1 h and concluded an unweighted SEL of 146 dB re 1µPa^{2}s[14] as onset level for TTS. To account for cumulative exposure to repeated sounds such as those emitted by offshore pile driving or seismic airgun surveys, Leunissen (2018) and Leunissen and Dawson (2018) suggested using the TTS onset level determined by the latter study (Kastelein et al. 2015a) for Hector's dolphins. Kastelein et al. (2013b) also tested the onset of behavioural responses to pile driving in a playback experiment with a captive harbour porpoise. Leunissen (2018) proposed using the unweighted SEL threshold of 133 dB re 1µPa^2·s resulting from this experiment as a behavioural criterion for Hector's dolphins.

An alternative set of acoustic thresholds, mainly applied in the United States, parts of Australia and Europe, is defined in the NOAA *Revision to Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing (Version 2.0)* (NMFS 2018). These thresholds are weighted, meaning they are based on the functional hearing groups, and take into consideration the frequencies over which the majority of sound energy might be concentrated for a particular sound source and the ranges over which the hearing of individual species' is most sensitive. As there are currently no national or standard guidelines for pile-driving activities within New Zealand waters, the NOAA thresholds are often employed or used for guidance with regard to the effects of underwater noise on marine mammals in other New Zealand resource consent hearings.

4.5. Surrogate Species

There is no direct audiometric data available for Hector's/Māui dolphins, but they are considered to be particularly sensitive to high-frequency sounds (>100 kHz). Studies investigating the vocalisation and echolocation signals of these animals (Dawson and Thorpe 1990, Dawson 1991, Thorpe et al. 1991) provide indirect information indicating certain aspects of their hearing such as limitations of hearing range and frequencies of highest sensitivity. These studies provide the only species-specific information related to the auditory capabilities for Hector's/Māui dolphins.

Other aspects of Hector's/Māui dolphins' biology complement these studies by adding anatomical information (Finneran et al. 2017, NMFS 2018). The most appropriate and informative approach for assessing noise-related effects, in the absence of direct information on the hearing sensitivity and frequency range of hearing in Hector's/Māui dolphins, is to use physiologically and/or anatomically related species as proxies. Accordingly, to supplement the scarce information on Hector's/Māui dolphin acoustics and especially their auditory sensitivity, relevant information needs to be extrapolated from a surrogate species. Table 8 provides an overview of the acoustic characteristics of those cetacean species thought to match the acoustics of Hector's/Māui dolphins the closest.

[14] Leunissen and Dawson (2018) caution that 146 dB SEL re 1µPa^2·s should not be regarded as the threshold at which TTS is induced but the level at which TTS is occurring, based on limitations of the Kastelein et al (2015a) playback equipment. They note that the actual TTS threshold for harbour porpoise may be lower.

Table 8. Acoustic characteristics of cetacean species similar or comparable to Hector's dolphins. Dash means that no information is available for this species and parameter.

Taxonomic group Species	**Audiometry** (min to max in kHz)	**Echolocation/social sounds** (peak frequency in kHz †/ range/centroid frequency‡)	**Mean source level** (dB re 1 μPa pk-pk)	**Social sounds** (SPL: dB re 1 μPa)	**References**
Porpoises					
Vaquita (*Phocoena sinus)*	-	132.9 128–139	-	-	Silber (1991)
Burmeister's porpoises (*Phocoena spinipinnis*)	-	- -	-	-	
Dall's porpoises (*Phocoenoides dalli*)	-	137±4 121–147	-	-	Bassett et al. (2009); Kyhn et al. (2013)
Finless porpoises (*Neophocaena phocaenoides*)	<8 to >152	- 142	-	-	Popov et al. (2005); Popov et al. (2011); Akamatsu et al. (1998); Goold and Jefferson (2002); Kamminga et al. (1986); Pilleri et al (1980)
Yangtze finless porpoises (*Neophocaena asiaorientalis*)	-	125±7 100–135	197	-	Li et al. (2005); Li et al. (2007);
Harbour porpoises (*Phocoena phocoena*)	0.25–220	137±6, 129–145 125–200	191, 178–205	-	Clausen et al. (2010); Dubrovskii et al. (1971); Kastelein et al. (2002); Kastelein et al. (2010); Kyhn et al. (2010); Kyhn et al. (2013); Kastelein et al. (2015d); Popov and Supin (1990); Popov et al. (1986); Ruser et al. (2016), Villadsgaard et al. (2007)
Spectacled porpoises (*Phocoena dioptrica*)	-	- -	-	-	
Pygmy and Dwarf sperm whales					
Pygmy sperm whales (*Kogia breviceps*)	-	- 125–130	-	1.4–1.5	Madsen et al. (2005); Marten, (2000); Ridgway and Carder, (2001); Thomas et al. (1990)
Dwarf sperm whales (*Kogia sima*)	-	- -	-	-	

Taxonomic group Species	**Audiometry** (min to max in kHz)	**Echolocation/social sounds** (peak frequency in kHz †/ range/centroid frequency‡)	**Mean source level** (dB re 1 µPa pk-pk)	**Social sounds** (SPL: dB re 1 µPa)	**References**
Dolphins					
Hector's dolphins (*Cephalorhynchus hectori*)	-	129±5 125–132	177±6	-	Dawson and William, (1990); Kyhn et al. (2009); Thorpe et al. (1991); Thorpe and Dawson (1991)
Heaviside's dolphins (*Cephalorhynchus heavisidii*)	-	125±4 121–130	173±5	0.8–4.5	Morisaka et al. (2011); Watkins et al. (1977)
Commerson's dolphins (*Cephalorhynchus commersonii*)	-	132±6 120–171	177±5	0.2–16	Dziedzic and de Buffrenil (1989); Evans et al. (1988); Kamminga and Wiersma (1981), (1982); Kyhn et al. (2010); Reyes Reyes et al. (2015); Reyes Reyes et al. (2016); Watkins and Schevill (1980); Yeh et al. (1981); Yoshida et al. (2014)
Chilean (black) dolphins (*Cephalorhynchus eutropia*)	-	126±2 126	-	-	Götz et al. (2010)
Hourglass dolphins (*Lagenorhynchus cruciger*)	-	126±2 124–132	197±4	-	Kyhn et al. (2009); Tougaard and Kyhn (2010)
Peale's dolphins (*Lagenorhynchus australis*)	-	126±3 123–138	185±6	0.3–5	Kyhn et al. (2010); Schevill and Watkins (1971)

† highest frequency at the highest spectrum energy
‡ Centroid frequency (FC) defined as the frequency dividing the spectrum in two halves of equal energy

Of all high-frequency cetacean species, the auditory sensitivity and susceptibility to noise of harbour porpoises (*Phocoena phocoena*) have been studied in more detail than any other HF cetacean species. Several studies provide detailed information on sensitivity and frequency range of their hearing, source level of their echolocation signals, as well as susceptibility to intense sound. Harbour porpoises are similar to Hector's/Māui dolphins in terms of anatomical structure of the ear as well as acoustic characteristics of their echolocation behaviour. Based on these similarities in auditory and anatomical parameters, harbour porpoises are considered the closest comparison for Hector's/Māui dolphins and are used as proxies in this report for assessing the hearing sensitivity and susceptibility to noise for these two subspecies.

4.6. Biology of Harbour Porpoises

The following sections briefly compare the most relevant information on biological parameters for harbour porpoises and Hector's/Māui dolphins to illustrate similarities between the taxa.

Harbour porpoises have a widespread distribution along the continental shelves of the Northern Hemisphere (Hammond et al. 2008). They are the most common species of cetacean in the North Sea (Hammond et al. 2002, Marubini et al. 2009, Hammond et al. 2013, Hammond et al. 2017) with an overall population of over 400,000 animals in the North East Atlantic (Hammond et al. 2013, Hammond et al. 2017). They are present throughout the year in UK waters (Reid et al. 2003), although from land and vessel-based visual surveys they are thought to be most abundant during August and September (Weir et al. 2007, Marubini et al. 2009). Harbour porpoises have been exposed to a variety of offshore activities. They are expected to be present in most offshore development sites and thus susceptible to anthropogenic disturbance from a variety of sources. There have been multiple studies assessing potential effects of offshore industries on harbour porpoises including, inter alia, disturbance from pile driving during renewable energy developments, effects of sound on hearing thresholds, vessel traffic influencing behaviour, dredging, coastal construction, and potential attraction to O&G infrastructure. Additional threats faced by harbour porpoises briefly discussed in the following sections include climate change, pollution, and disease.

4.6.1. Size

Hector's/Māui dolphins are the smallest species of dolphin in the world, with a range in length of 1.2–1.6 m and weight of 40–60 kg (Slooten and Dawson 1994). Harbour porpoises are comparable in length and weight with females typically 1.5–1.6 m and 55 kg and males 1.4–1.5 m and 50 kg (Lockyer 1995, Lockyer 2003).

4.6.2. Echolocation signals and hearing sensitivity

Marine mammals, and in particular cetaceans (whales, dolphins, and porpoises), use different sound frequency bands for several activities, which include, but are not limited to: communication, navigation, foraging, and a range of activities within the wider social group such as cohesive actions, warnings, and maternal relationships (Southall et al. 2007, André et al. 2010). In most cases, it is generally assumed that cetaceans hear at least over similar frequency ranges to sounds they produce. Both Hector's/Māui dolphins and harbour porpoises echolocate using NBHF clicks with a main frequency of 125–130 kHz (Kamminga and Wiersma 1982, Dawson and Thorpe 1990, Au et al. 1999, Morisaka and Connor 2007, Rayment et al. 2009b, Kastelein et al. 2017a). Harbour porpoise hearing has been tested and found to have a range of best hearing between 16–140 kHz (Figure 27) with the frequency of their minimum (i.e., best) hearing threshold at 125 kHz (Anderson 1970, Bibikov 1992, Kastelein et al. 2002, Kastelein et al. 2010, Kastelein et al. 2015e, Kastelein et al. 2017a). There can be spatial variation in the click characteristics of harbour porpoises. For example, harbour porpoises in British Columbia, Canada, echolocate at higher frequencies (141±2 kHz) than harbour porpoises in Denmark, 136±3 kHz (Kyhn et al. 2013). It is expected that because Hector's/Māui dolphin and harbour porpoise hearing capacities are similar, their susceptibility to acoustic impairment will also be similar.

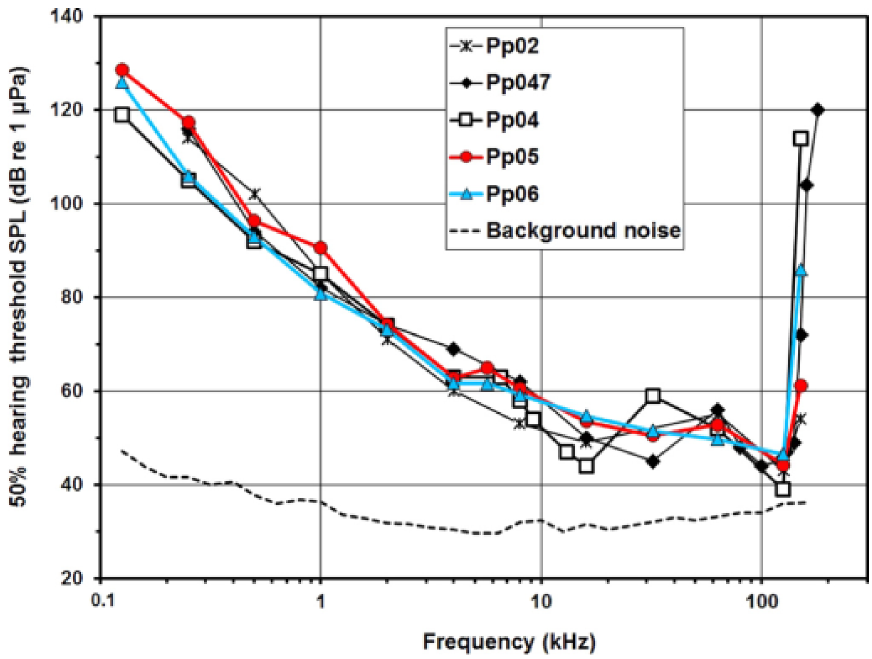

Figure 27. Mean 50% hearing thresholds for five harbour porpoises to narrow-band linear up-sweeps and frequency-modulated signals. Source: Kastelein et al. (2017a).

4.6.3. Biological parameters

The oldest recorded female Hector's dolphin was 19 years, and the oldest male was 20 years (Slooten 1991)[15]. Harbour porpoises typically live for 12–15 years but can live up to 20 years. The oldest recorded harbour porpoise from the North Sea was 24 years old (Lockyer 2003). Adult survival rates are expected to be between 0.87 to 0.96 (Roberts et al. in prep) based on demographic assessments of Banks Peninsula Hector's dolphins (Gormley et al. 2012) and 0.8[16] for harbour porpoises (Lockyer 1995).

Male Hector's dolphins reach sexual maturity at 6–9 years and females at 7–9 years (Slooten 1991). Harbour porpoises reach sexual maturity quite early for cetaceans (Read and Hohn 1995), with most male harbour porpoises becoming sexually mature at 3 years (Lockyer 1995) and females at roughly 3–3.5 years after which they can become pregnant each year (Read 1990, Read and Hohn 1995, Lockyer 2003).

4.6.4. Foraging

Since both Hector's/Māui dolphins and harbour porpoises have a small body size, they are unable to store a large amount of energy as blubber. Consequently they have a high metabolic rate and need to eat often (Santos et al. 2004, Lockyer 2007, Miller et al. 2013, Jones et al. 2014, Rojano-Doñate et al. 2018). Harbour porpoises may be particularly susceptible to potential anthropogenic disturbance because they must forage so frequently (Wisniewska et al. 2016a, Hoekendijk et al. 2018, Wisniewska et al. 2018). Their metabolic rate has been calculated to be over twice that of similarly sized terrestrial mammals. They can succumb to starvation in as little as a week (Rojano-Doñate et al. 2018).

Food consumption in porpoises varies between 4–10% of their body weight daily (Kastelein et al. 1997, Jepson 2001), representing between 8,000 and 25,000 kJ/day (Kastelein et al. 1997). The small size of porpoises does not enable them to carry large energy stores (Koopman 1994), so their patterns of movement are likely strongly related to distribution or availability of their prey.

Both Hector's/Māui dolphins and harbour porpoises appear to have a varied diet, primarily targeting prey species that are <10 cm long with regional variation in prey species consumed (Santos and Pierce 2003, Santos et al. 2004, Miller et al. 2013).

4.6.5. Predation

Hector's/Māui dolphins are predated upon primarily by orcas (*Orcinus orca*). Seven gill sharks (*Hexanchidae spp*.) have also been found to predate on the dolphins, and there is anecdotal evidence for predation by white sharks (*Carcharodon carcharias*) (D. Clement, pers. comm.).

Orcas and white sharks are the two main predators of harbour porpoises (Read 1999). Recently it has been reported that grey seals (*Halichoerus grypus*) also prey upon harbour porpoises (Jauniaux et al. 2014, Leopold et al. 2015). Harbour porpoises are also killed (but nor preyed upon) by bottlenose dolphins, *Tursiops truncatus* (Ross and Wilson 1996, Patterson et al. 1998).

Predation by orca might be a reason that both Hector's/Māui dolphins and harbour porpoises have evolved to use NBHF echolocation clicks and not whistles, as an anti-predator mechanism to be less detectable by orcas (Morisaka and Connor 2007)

4.6.6. Bycatch

Similar to Hector's/Māui dolphins (Slooten 2013a), entanglement in fishing nets is the single greatest anthropogenic source of mortality for harbour porpoises (Hammond et al. 2002, Bjørge et al. 2013, ASCOBANS 2014, Nabe-Nielsen et al. 2014). Reducing bycatch through the use of Acoustic Deterrent Devices (ADDs; see Section 6.6) and an independent surveillance program are the primary methods of mitigation. Observers are placed on vessels to assess the degree to which bycatch

[15] New data indicate that Hector's dolphins may life >20 years but this information was not officially available yet.

[16] A survival rate of 0.85-0.925 used for IPCoD by the Sea Mammal Research Unit, UK.

occurs; however, for the UK gillnet fleet alone, there is still an estimated bycatch of 1,200 to 1,500 porpoises per year (Northridge et al. 2017).

5. Empirical Studies on Effects

The primary threat to Hector's/Māui dolphins is entanglement in fishing nets (Currey et al. 2012, Slooten 2013a); however, little is known about their interactions with, and responses to, other anthropogenic activities. Without empirical studies on Hector's/Māui dolphins, the more common and better-studied species, the harbour porpoise, is used as a proxy to infer the potential impacts of O&G and mineral activities on Hector's/Māui dolphins (see Sections 4.5 and 4.6). The following sections provide an overview and discussion of information available on the empirical studies on acoustic characteristics of sounds emitted by marine industrial activities, and their effects on harbour porpoises as well as other marine mammal species.

5.1. Acoustic effects

5.1.1. Seismic Surveys

Detailed studies involving low-frequency cetaceans (humpback whales (*Megaptera novaeangliae*), gray whales (*Eschrichtius robustus*), and bowhead whales (*Balaena mysticetus*) and seismic surveys have contributed significantly to the understanding of potential effects. Primarily these have focused on behavioural responses. Example studies include Blackwell et al. (2013), Dunlop et al. (2013), Blackwell et al. (2015), Bröker et al. (2015), Dunlop et al. (2015), Muir et al. (2015), Racca et al. (2015), Ellison et al. (2016), Gailey et al. (2016), Muir et al. (2016), Racca et al. (2016), Dunlop et al. (2017a), Dunlop et al. (2017b).

Seismic surveys produce sound at quite low frequencies, which are outside the range of best hearing for harbour porpoises (16–140 kHz) and outside the peak frequency of their echolocation clicks (125–130 kHz). However, the scale of studies related to high-frequency cetaceans, such as harbour porpoise, are limited, and none exist for Hector's or Māui dolphins. From the research that is available, effects of short-term behavioural disturbance from seismic surveys appear to be generally short-lived in harbour porpoises (Thompson et al. 2010, Pirotta et al. 2014). In the North Sea, Thompson et al. (2013) used a combination of PAM and aerial surveys to assess effects of a 10-day seismic survey on harbour porpoises in a 2,000 km^2 area around the survey. Estimated source levels for the array were 242–253 dB re 1 µPa (PK-PK). It was estimated that a 200 km^2 area was exposed to airgun sound regularly over the survey. A decrease in density of harbour porpoises within 10 km of the operating seismic vessel suggests short-term avoidance, but animals returned within 19 hours of the survey finishing. Reactions also declined throughout the survey, possibly indicating habituation. Received levels 5–10 km from the vessel were 165–172 dB re 1 µPa (PK-PK), and thus similar to those reported by Lucke et al. (2009). Using the same data, Pirotta et al. (2014) reported a significant, yet short-term decrease in foraging buzzes detected within the ensonified survey area, suggesting more subtle reactions to disturbance than full displacement. Fixed echolocation detectors (C-PODs) deployed at control and impact sites show seasonal and interannual variability in harbour porpoise occurrence regardless of seismic activity. When compared to natural variation, alterations due to seismic surveys were minimal (Thompson et al. 2013).

What is possible with high-frequency cetaceans that isn't possible with low-frequency cetaceans is controlled exposure experiments. Lucke et al. (2009) measured TTS in a harbour porpoise exposed to seismic airgun signals. In this study, TTS was defined as a 'difference of twice the standard deviation from average hearing threshold at the particular frequency applied'. The level of TTS was measured at 4 kHz, 32 kHz, and 100 kHz following exposure to a small 20 in^3 airgun towed from a small boat past a sea pen containing a single harbour porpoise. Most energy was below 500 Hz. At 4 kHz, a TTS of 1.8 dB above the predefined limit (122.9 dB re 1 µPa SPL) was recorded following exposure to airgun signals with a received level of 200.2 dB re 1 µPa (PK-PK). This increased to 9.1 dB at a RL of 202.1 dB re 1 µPa (PK-PK). No TTS was observed at 32 or 100 kHz. Received levels >174 dB re 1 µPa (PK-PK) also elicited an avoidance response (Lucke et al. 2009).

Seismic surveys produce sound at quite low frequencies, which are outside the range of best hearing for harbour porpoises (16–140 kHz) and outside the peak frequency of their echolocation clicks (125–130 kHz). Thus, seismic signals are likely to have minimal impact on harbour porpoises' ability to echolocate and detect prey.

5.1.2. Dredging

It is difficult to elucidate specific dredging noise effects on marine mammals, given that many industrial activities occur concurrently. However, studies on vessel noise will be appropriate proxies for dredging given the similarity of the sound sources.

There are a few studies involving dredges, although these included very limited information about the sound levels during the exposures. Using fixed PAM (T-PODs), Diederichs et al. (2010) found short-term avoidance in harbour porpoises at ranges of 600 m from a TSHD dredger operating to the west of Sylt (Northern Germany, North Sea). Pirotta et al. (2013) also noted that presence of bottlenose dolphins in foraging areas in Aberdeen harbour, Scotland, declined as dredging intensity increased. Aberdeen Harbour is subject to high shipping activity year-round, and thus dolphins are accustomed to high levels of vessel disturbance. In this case, it was possible for the authors to link avoidance to dredging activity noise, and not vessel presence in general.

Seabed disturbance through extraction, rejection, and disposal of sediments, along with outwash of excess materials, can result in increased turbidity and create sediment plumes. Sediment plumes can extend the impact of dredging over larger areas that would otherwise remain unaffected physically (Hitchcock and Bell 2004). The effects are generally short-lived, lasting a maximum of four to five tidal cycles (Hitchcock and Bell 2004) and are confined mainly to an area of a few hundred metres from the point of discharge (Newell et al. 1998, Hitchcock and Bell 2004). Marine mammals often inhabit turbid environments and many use sophisticated sonar systems to sense the environment around them (see Au et al. 2000). There is no evidence that turbidity affects cetaceans directly. The limited available information indicates that increased turbidity, as a result of dredging, is unlikely to have a substantial direct impact on marine mammals that often inhabit naturally turbid or dark environments. This is likely because they use other senses and do not rely solely on vision.

Collision with vessels is a known cause of injury and mortality in marine mammals (see reviews by Laist et al. 2001, Jensen and Silber 2003, Van Waerebeek et al. 2007, Neilson et al. 2012), although this is uncommon for harbour porpoises. Vessel movement is associated with all stages of dredging, from transit to/from the extraction site and dumping grounds, to operation of the dredger itself. Thus, collision with dredgers is possible, but only one incident is reported in the literature. It resulted in the death of a southern right whale (*Eubalaena australis*) calf (Best et al. 2001).

Active dredgers are stationary, or move at slow speeds of 1–3 kts (Reilly 1950). If dredging is well managed and avoids critical habitats and areas where dolphin calves are abundant, there is a minimal risk of collision between marine mammals and active dredgers. Collision risk is perhaps greater when dredgers are in transit, as speeds can reach 12–16 kts (Brunn et al. 2005), but in areas already characterised by heavy shipping traffic, the addition of dredging vessels is unlikely to increase the collision risk substantially (Tillin et al. 2011).

5.1.3. Impact Pile Driving

The installation of offshore wind turbines in European waters triggered substantial research efforts into the potential auditory and behavioural effects of pile driving impulses on harbour porpoises. A dedicated research study was conducted in New Zealand trying to assess the potential impact of wharf pile driving on Hector's dolphins based on results from harbour porpoise studies (Leunissen and Dawson 2018).

Harbour porpoises have been measured to suffer TTS from playbacks of piling impulses. After an hour of exposure to the sound which had a single pulse SEL of 146 dB re 1 $\mu Pa^2 \cdot s$ and a cumulative SEL of 180 dB re 1 $\mu Pa^2 \cdot s$, the animals had a reduced hearing threshold at 4 and 8 kHz (Kastelein 2015). The harbour porpoises' hearing returned to pre-impact levels after 48 minutes and its hearing threshold in frequencies that they use for communication and foraging was not impacted (Kastelein 2015). Based on these values measured for a harbour porpoises, Leunissen and Dawson (2018) estimated the distances at which Hector's dolphins would suffer TTS and behavioural change when exposed to pile driving in Lyttelton Harbour, New Zealand. They predicted Hector's dolphins would suffer TTS if they were within 376 m of the pile driving over an hour (Leunissen and Dawson 2018).

In addition to affecting harbour porpoise hearing in the immediate vicinity of the source, pile driving sound can also disrupt behaviour at distances of around 20 km with the maximum theoretical distance of detection predicted to be 70 km (Madsen et al. 2006b, Tougaard et al. 2009b, Bailey et al. 2010b, Brandt et al. 2011, Tougaard et al. 2015). Harbour porpoises change their habitat use and vacate areas while pile driving is occurring (Carstensen et al. 2006). Harbour porpoise density has been found to decrease in areas of wind farm construction and the amount of time between detected click trains increases (Carstensen et al. 2006, Tougaard et al. 2009a, Brandt et al. 2011, Kastelein et al. 2013a). Hector's dolphins have been predicted to show behavioural changes from pile driving at over 1 km, although they would be able to hear the pile driving at a much larger distance (Leunissen and Dawson 2018).

Unlike pile driving for multiple turbine installations associated with development of a wind farm over a typical 30–60-day period, pile driving for the construction of an O&G platform has a typical one-off duration of only a few hours (depending on scale and depth); therefore, much less long-term effect.

Dähne et al. (2013) conducted an impact study on harbour porpoises during the installation of offshore wind turbines in shallow waters (<50 m) in the German Bight. They used a combination of visual aerial surveys and PAM systems. By comparing the visual results collected prior to with those recorded during the pile driving operations the authors concluded harbour porpoises showed a strong avoidance response within 20 km distance of the noise source. Statistical analysis of the PAM data showed a negative impact on harbour porpoise detection rates at distances within a 11 km radius around the sound source. Brandt et al. (2011) used PAM devices to study the spatial and temporal scale of harbour porpoise behavioural activity during another pile driving operation in the German Bight. They found that animal activity was reduced during the operation out to 18 km from the source; the animals' acoustic activity was reduced by 100% during one hour after pile driving and stayed below normal levels for 24 to 72 h at a distance of 2.6 km from the construction site. This period gradually decreased with increasing distance.

The effects of longer-term disturbance (e.g., construction of an offshore wind farm) can last for years. Density of harbour porpoises in the Nysted Wind farm in the Danish western Baltic Sea was still reduced from baseline levels after nearly a decade of operation (Teilmann and Carstensen 2012), even though this development used mainly gravity bases instead of pile driving, which is usually considered to reduce disturbance. This reduction in density could be due to disturbance from vessel traffic or operation. Alternatively, pile driving was employed for one pile foundation where the density of harbour porpoises in the area was roughly 8–10 times lower than in surrounding areas even during the baseline period (Teilmann and Carstensen 2012). This result possibly suggests the specific location was a less suitable habitat to start with; this also indicates that other studies investigating the period of avoidance after pile driving or other noisy activities may misinterpret the actual effect on the animals. Moreover, the animals that are detected after the cessation of the noise-emitting activities (see Brandt et al. 2011) may not be the same as those that left the area at the onset of the activities, i.e. they may be acoustically naïve and their return does not necessarily provide information about the duration of a behavioural disturbance or habitat exclusion. Without designated, well-controlled noise exposure experiments it is nearly impossible to conclude on the true avoidance effects of such activities.

5.1.4. Drilling

Studies conducted on the effects from drilling operations on the behaviour of marine fauna are very limited. The influence of noise from operations on vocalising bowhead whales has been investigated (Blackwell et al. 2017), which examined both the drilling noise and the whale vocalisations. There has been a few studies involving playback of drilling noise (Richardson et al. 1995, Dahlheim and Castellote 2016), however playback experiments are not the same as those using actual sources (Southall et al. 2016).

The studies involving drilling and high-frequency cetaceans are extremely limited, with the authors unaware of any study that examined drilling noise levels and high-frequency cetacean presence. While Todd et al. (2009) examined the echolocation behaviour of harbour porpoise using CPODs in the North Sea around a drilling operation, they were not able to conduct a before-after-control-impact (BACI) investigation, so it is not possible to comment on the potential effects.

5.1.5. Vessel Traffic

Cetaceans have been demonstrated to exhibit responses to vessel noise in a number of studies (Section 4.3), and there are implications for high-frequency cetaceans from the higher frequency components of the spectra (Hermannsen et al. 2014). This is partly because harbour porpoises have strong behavioural responses to these high-frequency components of vessel noise (Dyndo et al. 2015). It is possible that increased vessel traffic for construction or maintenance of O&G and renewable energy developments could increase disturbance to cetaceans (Culloch et al. 2016).

However, limited studies exist examining the effects of vessel noise specifically on high-frequency cetaceans. This is partly complicated by the behaviour of harbour porpoises, who are a naturally shy species and tend to avoid boats (in contrast to Hector's dolphins who are more boat positive). The foraging rate of harbour porpoises decreases with increasing disturbance from vessel traffic (Wisniewska et al. 2016a, Wisniewska et al. 2018).

5.1.6. Sonar

A number of studies have examined the potential effects of tactical sonar / echosounders on cetaceans (e.g. Miller et al. 2014, Kvadsheim et al. 2015, Miller et al. 2015, Curé et al. 2016, Sivle et al. 2016, Southall et al. 2016, Cholewiak et al. 2017, Harris et al. 2017). These studies have demonstrated the importance of using actual sources in exposure experiments, and the range of responses which occur. Reduction in vocalisation patterns in the presence of sonar for (behaviourally) sensitive mid-frequency cetaceans (Cholewiak et al. 2017) demonstrate the complexity of acoustic monitoring for the presence of fauna around active operations.

Studies have investigated the effects of sonar on harbour porpoise (Kastelein et al. 2015b, Kastelein et al. 2018), although these have all been controlled exposures with captive animals. There is a need for studies on high-frequency cetaceans involving a broader range of sonars, sonar type sources and echosounders in the wild.

5.2. Non-acoustic effects

5.2.1. Pollution

Marine pollution can occur from oil spills, vessels, increased rubbish at offshore locations (blown, swept or thrown overboard), and discharge from terrestrial sources. There is a vast amount of literature describing the levels of pollutants in the tissues of harbour porpoises (Holden and Marsden 1967, Morris et al. 1989, Aguilar and Borrell 1995, Jarman et al. 1996, Tanabe et al. 1997, Berrow et al. 1998, Berggren et al. 1999, Westgate and Tolley 1999, Ishaq et al. 2000, Bennett et al. 2001, Das et al. 2004, Das et al. 2006a, Das et al. 2006b). There is considerably less literature dealing with other pollution sources, such as plastics (e.g., Laist 1997), although this is gaining prominence for marine mammals (Derraik 2002, Poeta et al. 2017, Nelms et al. 2018).

Marine mammals are susceptible to bioaccumulation because they feed at high trophic levels, and have a high proportion of lipid-rich blubber, which accumulates certain contaminants readily (Vos et al. 2003). High contaminant levels have been linked to immune system depression, disease breakouts, reproductive effects, developmental effects, and endocrine disruption (see Vos et al. 2003 for a review of toxins and marine mammals).

Organochlorines (OCs) are prone to bioaccumulation because they are relatively resistant to biotransformation and not easily excreted (Hoekstra et al. 2003). In marine systems, these compounds have a tendency to persist in the environment for long periods, increasing in concentrations through food webs, and reaching particularly high levels in top-level marine predators such as harbour porpoises (Varanasi et al. 1992, Westgate et al. 1997, O'Shea 1999). Moreover, cetaceans appear to have lower metabolic capacities for the breakdown of organic contaminants compared to terrestrial mammals (Kannan et al. 1989, Berggren et al. 1999, Tanabe 2002). Several studies have reported levels of OCs in marine mammal tissue that greatly exceed those known to have significant negative impacts on immunity, nervous system function, and reproductive health of marine mammals (de Guise et al. 1994, deSwart et al. 1995a, deSwart et al. 1995b, Ross et al. 1995, Berggren et al. 1999, Schwacke et al. 2002, Tanabe 2002, Jenssen et al. 2003, Wells et al. 2005).

Only a few studies have quantified the levels of specific contaminants in New Zealand marine mammals (Buckland et al. 1990, Jones et al. 1996, Jones 1998, Stockin et al. 2007, Stockin et al. 2010). By-caught (e.g., accidentally killed in fishing activity) and stranded Hector's dolphins from around the South Island were used as a proxy during the 1990s to examine levels of local contaminants within New Zealand's coastal waters, and more recently, as a possible health reason for the failing recovery of the species. The earlier studies (Buckland et al. 1990, Jones et al. 1996, Jones 1998) focused on planar chlorinated hydrocarbons (i.e. PCDDs, PCDFs, PCBs). In general, Hector's dolphins accumulated much lower levels of PCBs than Northern Hemisphere comparisons (Jones 1998). These samples had increased levels of PCDDs and PCDFs relative to PCBs, which the authors suggested was an indicator of the species' shallow and more inshore residency.

The more recent studies examined organochlorine pesticides and chlorobiphenyls (CB) in both Hector's and Māui dolphin from around New Zealand (Stockin et al. 2010). The authors found that the total PCB concentrations in Hector's/Maui's dolphins (0.1 to 14 mg/kg lipid weight) were below the toxic effects threshold (17 mg/kg lipid weight) established by Kannan et al. (2000) through an experimental dose-response study on PCB-induced immunological and reproductive effects in marine mammals. However, ΣICES7CBs concentrations (a list of seven PCB congeners derived by ICES to specifically allow comparisons across different datasets) of the Hector's dolphins sampled indicated a 1.6 to 2.4-fold increase from dolphins sampled in the earlier Jones et al. (1996) study and were 1.9 to 2.5-fold greater than those reported in New Zealand common dolphins (Stockin et al. 2007). This potential increase from earlier studies is expected, as persistent compounds like PCBs, even though banned in most countries, is predicted to increase globally through progressive deposition from the atmosphere into the ocean until 2030 (Evans 2003).

The (Stockin et al. 2007) study revealed Hector's/Maui's dolphins had higher than expected concentrations of organochlorine pesticides present, in particular p,p'-DDE, p,p'-DDT and p,p'-DDD. The ΣDDT concentrations in Hector's dolphins (mean = 6,138 µg/kg wet weight, S.D. =1 3,020) were much greater than those found in New Zealand (mean = 1,302 µg/kg wet weight, S.D. = 1,263), United Kingdom or Australian common dolphins.

These higher concentrations of DDT were attributed to the historically heavier reliance on agriculture over industry in New Zealand compared to the greater use of industrial PCBs in Europe (Evans 2003, Stockin et al. 2007, 2010). The authors also noted that the ratio of DDE (the degraded product of DDT) to ΣDDT levels in all dolphins ranged from 0.7 to 0.95, suggesting that these contaminants were mostly from historical inputs of DDT, and may also reflect the large number of dolphin samples from the Canterbury region, one of New Zealand's most intensive agriculture areas (Stockin et al. 2010). The higher levels of total PCBs and ΣDDT in Hector's/Maui's dolphins compared to New Zealand common dolphins are perhaps indicative of a near-shore, coastal species that is closer to pollutant sources compared to a pelagic species that spends a larger portion of time in offshore, oceanic waters.

A comprehensive review of pollutant concentrations across Southern Hemisphere marine mammals found that the coastal, higher trophic level (fish-eating), and smaller species tended to have greater levels of most pollutants (Evans 2003). Intra-specific comparisons across general regions in the Southern Hemisphere reported lower levels in all New Zealand samples relative to South African, Australian, and/or South American samples, but not as low as those from the Antarctic/subantarctic.

In addition to chemical pollution, plastic debris are regularly encountered within the water column (see Dufault and Whitehead 1994, Derraik 2002, Poeta et al. 2017, Nelms et al. 2018). These plastics affect a large diversity of species, including marine turtles, birds, and marine mammals (see Laist 1997, Poeta et al. 2017). Since many cetaceans live in waters far from shore (and may sink upon death), opportunities to record instances of ingestion of marine debris are infrequent (Baird and Hooker 2000). Nonetheless, there are several documented cases where cetaceans ingested plastic or other marine debris (e.g., Baird and Hooker 2000). These authors document the third reported case of plastic ingestion by a male emaciated harbour porpoise found dead on a beach near Nova Scotia, Canada. Upon examination of the oesophagus, a balled-up piece of black plastic (measuring, when stretched out, about 5 by 7 cm and weighing 0.36 g) was found adjacent to the junction with the stomach. The ingested plastic probably blocked the oesophagus, leading to starvation. There are also two previous records of plastic ingestion for harbour porpoises (Walker and Coe 1990, Kastelein and Lavaleije 1992).

5.2.2. Structures as Artificial Reefs

Over the next twenty years, the O&G industry will decommission a growing number of redundant installations (e.g., Oil & Gas UK, Oil & Gas Authority, Decom North Sea). Decommissioning, especially complete removal is a highly complex activity that has currently unknown and unquantified Health, Safety, Environmental (HSE), financial, political, and social implications. Leaving O&G structures in situ as artificial reefs is a potential alternative and is known as a Rigs-to-Reefs (RTR) scheme.

The RTR concept began as early as 1975, when the Malaysia storm-damaged Baram-8 platform was toppled and made into an artificial reef (Zawawi et al. 2012). Since then, RTR schemes have been implemented successfully in Brunei (Twomey 2012) and the United States' Gulf of Mexico (Jørgensen 2009). RTR was legislated as an option in the State of California (and is gaining scientific credence from a variety of different research approaches), but opposition has prevented its implementation (Frumkes 2002, Rothbach 2007, Bernstein et al. 2010, Callahan and Jackson 2015).

Despite growing evidence that North Sea O&G installations aggregate and produce marine life (Picken et al. 2000, Baine 2002, Cripps and Aabel 2002, Sayer and Baine 2002, Soldal et al. 2002, Baine and Side 2003, Guerin et al. 2007, Guerin 2009, Macreadie et al. 2011, Jørgensen 2012, Macreadie et al. 2012, Bergmark and Jørgensen 2014, Fowler et al. 2014, Fujii et al. 2014, Fujii 2015), current Oslo and Paris Convention (OSPAR) legislation prevents any part of the structure being left in the marine environment at the end of an installation's operational lifetime, except for the derogation of some gravity-based installations (such as Shell's Brent Field). Removal policy is based on the assumption that 'leaving the seabed as you found it' will minimise negative impacts on the marine environment; however, potential disturbance to offshore ecosystems caused by mass removal of infrastructure has received little consideration. Aging hydrocarbon fields have already necessitated mass removal of offshore infrastructure.

Sub-sea anthropogenic infrastructure often provide structurally-complex-hard substrata in contrast to the relatively featureless and sedimentary seafloor (Larcom et al. 2014). In turn, this can accommodate diverse sessile invertebrate communities comprising anemones, hydroids, bryozoans, sponges, mussels, barnacles, soft corals, and even hard corals (Freeman 1978, Forteath et al. 1982, Guerin et al. 2007, Guerin 2009, Bergmark and Jørgensen 2014, Larcom et al. 2014, Todd et al. 2018). Motile invertebrates are also associated with sub-sea infrastructure, using abundant refuge and food availability (Page et al. 1999, Guerin 2009, Langhamer and Wilhelmsson 2009, Krone et al. 2013, Lengkeek et al. 2013, Schrieken et al. 2013, Ashley et al. 2014, Todd et al. 2018). Commercially important fish have also been observed living in association with sub-sea infrastructure (Olsen and Valdemarsen 1977, Valdemarsen 1979, Jørgensen et al. 2002, Løkkeborg et al. 2002, Soldal et al. 2002, Guerin 2009, Friedlander et al. 2014, Fujii et al. 2014), many of which are juveniles that preferentially select structurally complex habitats (Sayer et al. 2005). Marine mammals have also been reported to aggregate around, rest on, and preferentially forage around structures and pipelines (Todd et al. 2009, Russell et al. 2014, Todd et al. 2016b, Orr et al. 2017, Delefosse et al. 2018).

A localised increase in abundance of potential megafaunal prey species (and 500 m fishing exclusion zones) make rigs and platforms potential foraging locations for top level predators protected from incidental catch in fishing nets. Harbour porpoises regularly forage near routine O&G installation activities, such as drilling, cementing and casing, and supply boat operations (Todd et al. 2009). These installations are well established in the environment of the North Sea, many having been in situ for the entire life cycle of harbour porpoises in the region. Drilling/production and conductor hammering sound forms a part of everyday life for a North Sea harbour porpoise. Moreover, many well-placed O&G installations act as 'artificial reefs', providing a plentiful and reliable food source for species (Cripps and Aabel 2002, Todd et al. 2015a, Delefosse et al. 2018), so incentive to remain close is considerable, especially if prey species are scarce in the surrounding habitat. This 'recolonization' effect has been shown to some extent for harbour porpoises during seismic surveys (Thompson et al. 2013).

The reef effect of rigs and platforms, coupled with the 500 m fishing exclusion zone, renders installations potential foraging habitats for marine megafauna. Presence of harbour porpoise feeding buzzes in datasets of echolocation detections reported by Todd et al. (2009) and Todd et al.(2016a) have shown that harbour porpoises are potentially feeding around the legs of platforms in the North Sea. A similar behaviour has also been observed in satellite tagged seals, some of which systematically visited each pile in a wind farm and foraged around the base (Russell et al. 2014). Todd et al. (2009) also showed that harbour porpoises are more active acoustically around installations at night. Harbour porpoises are small, with limited body fat, and relatively high metabolic rates compared to other similarly sized mammals (Rojano-Doñate et al. 2018), therefore it is expected that their distribution reflects the distribution of their prey.

6. Mitigation and Monitoring

There are several techniques used to mitigate the effects of acoustic disturbance on cetaceans. One is the use of MMOs (Section 6.2) or PAM equipment operators (Section 6.3) who observe/listen for marine mammals in the area around the vessel or installation and take appropriate mitigation action when mammals are present in the monitoring zone. Methods to deter marine mammals from the vicinity of a development include using a soft start procedure (Section 6.5) or acoustic deterrent devices (ADDs, Section 6.6).

Underwater-noise mitigation around developments prior to sound entering the water column is another option to reduce impact to marine mammals. This generally requires use of noise-dampening technology (Section 6.7) or alternative mooring methods (Section 6.8).

6.1. Noise Modelling

Typically, as part of the approval process, modelling of acoustic propagation is performed to assess the degree to which sound from the development will propagate through the marine ecosystem (Nowacek and Southall 2016). Sound propagation varies between locations due to the complexity of underwater environments and can be affected by, *inter alia*, geographic, bathymetric, oceanographic, and climatic conditions. Numerical modelling is a considerably less expensive way to provide prediction of underwater acoustic fields, which can then be used to assess theoretical impacts on marine life; however, modelled data ground-truthed with empirical environmental data and in-field noise measurements, are the most effective method to quantify potential effects of anthropogenic noise sources on marine mammals. This can then be used to inform further management and mitigation measures required to keep noise below levels which would cause disturbance to marine mammals and other species of concern.

6.2. Visual Observations and Safety Zones

Seismic airgun operations are currently the only industrial offshore activity in New Zealand required to apply uniform mitigation measures under the 'Code of Conduct for Minimising Acoustic Disturbance to Marine Mammals from Seismic Survey Operations' (DOC 2013), mitigation for pile driving is determined on a case-by-case basis. In the UK, the Joint Nature Conservation committee (JNCC) developed guidelines for both pile driving operations and geophysical surveys enforcing a 500 m mitigation zone around the sound source (JNCC 2017). Under these JNCC guidelines, all marine mammals have the same mitigation zone; however, in New Zealand, they can be treated differently. Hector's/Māui dolphins are listed as species of concern; therefore, for seismic surveys a 600–1000 m mitigation zone is required (dependent on survey level) which increases to 1–1.5 km if a calf is present (DOC 2013). The level of a survey is determined by volume of airgun array used. A Level-1 survey (with the most stringent regulations for mitigation) has a total combined operational capacity over 7 l (>427 in^3). A Level-2 survey is between 2.5–6.99 l (153-427 in^3), and a Level 3 survey is less than 2.49 l (<153 in^3) (DOC 2013). Level-3 surveys are not covered by the code as they are considered to be of low impact and risk (DOC 2013).

JNCC geophysical and pile driving guidelines (JNCC 2010, JNCC 2017) both stipulate that if an animal is sighted during the pre-watch period, a delay of 20 minutes will be implemented based upon time of last sighting. Once the mitigation zone is clear for at least 20 minutes, a soft-start may begin (Section 6.5). A soft start must occur for at least 20 minutes and should be a gradual build-up in power of the sound source[17]. This is performed to warn animals to move away from the sound source before it is operated at full scale to reduce chance and/or severity of exposure.

Mitigation guidelines for seismic operations in New Zealand are well established (DOC 2013), and conditional on survey level. The mitigation zone alters depending on if it is a level-1 or level-2 survey, varying between 600 and 1500 m for Hector's/Māui dolphins. In addition, prior to the start of operations there must have been good sighting conditions for the 30 minute-pre-watch period. If

[17] This is not to be confused with the soft start which are an operational requirement for pile driving for mechanical safety reasons.

operating in poor conditions or at night, there must have been good conditions for the previous two hours or the five conditions listed on page 15 of DOC (2013) must be met. As both Hector's and Māui dolphins are species of concern, they require delays or shutdowns during seismic surveys.

It is only possible for Marine Mammal Observers (MMOs) to watch for marine mammals in good weather conditions and during daylight. This has necessitated the implementation of other monitoring techniques such as Passive Acoustic Monitoring (PAM) which can be performed during night and in poorer weather conditions, allowing vessels to begin seismic surveys or pile driving during conditions that they would be prevented from when using MMOs alone.

6.3. Passive Acoustic Monitoring for Mitigation

PAM is used to passively detect the vocalisations of marine mammals (i.e., listen without creating any noise). PAM for mitigation is a requirement under New Zealand's seismic code of conduct for all level 1 surveys (DOC 2013). While optional for Level 2 surveys, if incorporated the system should meet the specifications and performance standards outlined in the Code. If not incorporated, the survey can only proceed in poor visibility and at night in limited circumstances.

PAM is used predominately in times of poor visibility and night operations. The range of acoustic detection is theoretically far greater using PAM than visual sightings (certainly in unfavourable conditions or higher sea states), as many species are audible for a greater proportion of time than they are visible at the surface, and monitoring can continue during hours of darkness and unfavourable weather conditions (Gordon et al. 2003); however, a downside to PAM is that not all marine mammals vocalise, and those species that do, may only vocalise at certain times of day or year or in association with specific behaviour patterns, e.g., Risso's dolphins (*Grampus griseus*) in the Southern California Bight vocalised significantly more at night than during the day due to an increase in foraging behaviour (Soldevilla et al. 2010). Similarly, harbour porpoises in the North Sea have been shown to have a pronounced diel pattern in echolocation activity that can also depend on habitat (Todd et al. 2009, Williamson et al. 2017).

Best practice is to use both MMO and PAM observers (PAMO) together for most surveys and use only one method if there is a valid reason for doing so (e.g., foul weather or lack of daylight). Alternative monitoring methods are in development, such as use of thermal imaging cameras (Zitterbart et al. 2013, Verfuss et al. 2018) which can have detection range of up to 5 km for large whales and an increased number of detections of blows and surfacing compared to MMOs (see also following section).

6.4. Other Real-Time Monitoring Methods

Visual and passive acoustic monitoring are the standard methods/techniques used for real-time monitoring of cetaceans. There are a number of alternative monitoring tools such as:

- Thermal imaging (thermal IR),
- Radio Detection and Ranging (RADAR),
- Active Acoustic Monitoring (AAM, e.g. using sonar),
- Spectral camera systems (excluding thermal IR), or
- Light Detection and Ranging (LIDAR).

Verfuss et al. (2017) reviewed which monitoring tools have the greatest potential for detection of animals during low visibility conditions, when the ability of visual monitoring (typically conducted by MMOs) is reduced. They conclude that PAM techniques are a key modality for making detections of cetaceans underwater. The extent to which these techniques are useful for real-time monitoring varies considerably between species (due to differences in vocal behaviour) and is influenced by local sound propagation. PAM techniques provide best results in low background noise fields as high levels of sound can mask the vocalisations produced by the target species when overlapping in frequency and time (thereby limiting the efficiency of acoustic PAM techniques). Thermal imaging systems allow 360°detection of cetaceans at the surface and work best with short-diving, large animals in cold waters. This technique has mainly been performed in cold to moderate water temperatures; detection ranges in tropical regions and for small marine mammals such as Hector's/Māui dolphins are largely unknown. Vessel-mounted RADAR is equally limited in its capability for detecting small cetaceans at the surface and has a high false detection rate and lower sensitivity. Vessel-mounted AAM system have been shown to be able to detect larger cetaceans at the ranges required for real-time mitigation purposes. They allow localising and tracking of animals; classification to either taxa or species level, however, is currently not possible. It is also important to note that this technique has the potential for additional impact as a result of the acoustic emissions. LIDAR, spectral imagery and satellite systems are currently limited in their applicability or not suitable for real-time monitoring though future advancements in technology and the availability of satellite data may improve their potential utility.

The authors conclude that any real-time monitoring methodology can be optimised to attain the best possible detection probability by improving its internal functionality and no single monitoring technology or method is able to detect all animals in all conditions and environments.

6.5. Soft Start

A soft-start or ramp-up procedure can be implemented to gradually increase the Source Level (SL) to deter marine mammals from the impact zone before full-scale firing of airguns, pile driving or sonar occurs (Tougaard et al. 2003, JNCC 2004, Von Benda-Beckmann et al. 2014). A soft-start procedure is a gradual increase in power output either as a gradual increase in the number and size of airguns firing, or in the hammer energy for pile driving. This allows any marine mammals within the vicinity to leave before full power is reached and they might suffer hearing damage. While reducing the risk of TTS or PTS occurring, this approach does not address behavioural effects including displacement.

(Robinson et al. 2007) report measurements of a soft start for driving of a 2 m test pile at a wind farm site in the UK. The proportional difference in levels between the start and end of the soft start was 13 dB SPL and 8 dB SEL with energy levels building up fairly evenly over the first 600 strikes. However, soft starts lengthens the pile driving operation, and may therefore increase the extent of behavioural disruption and habitat exclusions. JNCC guidelines for minimizing the effect of explosives (JNCC 2010) as well as the NZ seismic code (New Zealand Department of Conservation 2013), request a soft-start where possible.

The effectiveness of soft-start procedures for tactical SONAR has been modelled for killer whales (*Orcinus orca*) and is expected to reduce the noise levels they would be exposed to below those that would cause hearing damage (Von Benda-Beckmann et al. 2014).

6.6. Acoustic Deterrent Devices

Acoustic Harassment Devices (AHDs; also referred to as Acoustic Deterrent Devices, ADDs) and pingers are used to deter marine mammals from the vicinity of industrial operations, fishing gear or aquaculture to minimise risk of injury to cetaceans or damage to fish (Quick et al. 2004, Northridge et al. 2010, Brandt et al. 2013). AHDs are used widely to deter predation at aquaculture facilities where pinnipeds are generally the target species, but cetaceans can be disturbed incidentally. Another use of AHDs is on fishing nets; this serves a two-fold purpose of reducing both predation and entanglement of cetaceans in the nets themselves. Use of AHDs in fisheries is a legal requirement for certain vessel and net types in some areas of the world and has potential to disturb cetaceans in areas with fishing. A third use of AHDs is around offshore construction activities (e.g., pile driving) to scare cetaceans out of the area to prevent them suffering temporary or permanent hearing damage.

Frequency spectra and source level (SL) of different types of AHD can vary widely, often with different measurements (and thus results) for the same type of device. Moreover, frequencies and SLs produced by manufacturers are often assumed, but unverified. For example, most reported SLs for the Airmar AHD range between 178 and 206 dB re 1µPa, with one report as low as 132 dB re 1µPa (Jacobs and Terhune 2002, Lepper et al. 2004, Shapiro et al. 2009, Brandt et al. 2012, JNCC 2018). In addition, while most devices emit low-frequency sounds intended to target seal hearing, some AHDs produce higher frequency harmonics that can be heard by other species. The Airmar, for example, produces harmonics up to at least 40 kHz, Lofitech up to and between 135–150 kHz, and Ace-Aquatec and Terecos can produce harmonics up to approximately 65 kHz (Coram 2014). These devices, particularly Lofitech, can be detected by non-target species such as harbour porpoise, which have a range of best hearing between 16–140 kHz, and peak sensitivity at 120–130 kHz (Kastelein et al. 2002, Kastelein et al. 2008, Kastelein et al. 2017a). Consequently, while Hector's/Māui dolphins and harbour porpoises may not be particularly sensitive to primary working frequencies of most AHDs, they can be sensitive to high-frequency harmonics if present.

AHDs are used at approximately half of Scottish aquaculture sites (Quick et al. 2004, Northridge et al. 2010) and may represent a significant, yet often overlooked, source of displacement for non-target marine mammals (Morton and Symonds 2002, Findlay et al. 2018). AHDs are intended to cause discomfort and deter pinnipeds (Johnston 1998) by producing intense (≥185 dB re 1 μPa) low-frequency (2–40 kHz) sound (Lepper et al. 2014). An unintended consequence is the potential for AHDs to deter non-target species from the ensonified area, such as harbour porpoises (Johnston 2002, Olesiuk et al. 2002, Robertson 2004, Brandt et al. 2013, Hermannsen et al. 2015), bottlenose dolphins (López and Mariño 2011), or others. This is becoming more of an issue in the aquaculture industry, since AHD usage is on the increase, introducing anthropogenic sound to large swathes of coastal habitat (Findlay et al. 2018). No AHDs have been approved for use on fish farms in New Zealand waters.

Behavioural changes and exclusion from habitat at varying levels have been reported for harbour porpoises exposed to AHDs (Culik et al. 2001, Carlström et al. 2002, Johnston 2002, Gönener and Bilgin 2009, Mikkelsen et al. 2017). Johnston (2002) noted that harbour porpoises stayed approximately 990 m away with a closest observed approach of 650 m from an Airmar DB II AHD in the Bay of Fundy, and Mikkelsen et al. (2017) reported a deterrence range of 525 m from a 12 kHz underwater loudspeaker that simulated a Lofitech AHD. Brandt et al. (2012) reported a significant decrease in porpoise detections at a range of 7.5 km from a Lofitech AHD resulting in this brand being selected to deter harbour porpoises from areas where pile driving is about to start. However, these results are contrasted by other studies reporting apparent tolerance to AHDs or possible habituation (Northridge et al. 2010). Research by Kastelein et al. (2015c) and (2017b) showed behavioural changes in surfacing and swimming patterns as well as breathing rates of harbour porpoises exposed to an AHD in a pool.

Several studies (mostly on harbour porpoises) have measured behavioural effects including habitat exclusion (Johnston 2002, Morton and Symonds 2002, Olesiuk et al. 2002).

Olesiuk et al. (1995, 2002) investigated the effects of an AIRMAR AHD on harbour porpoises during a series of controlled experiments extending over 18 weeks at Retreat Passage, British Columbia, Canada. The study was sub-divided into three, six-week periods within each of which the AHD was inactive for three weeks then active for three weeks. They found that there was a complete exclusion of porpoises within a 200 m radius of the source. Only 1 % of the expected number of porpoises was observed within 600 m and densities were 8.1 % of those expected at a range of 2.5–3.5 km. The greatest range at which observations could be made was 3.5 km, and it is likely that effects extended beyond this range. Their observations also implied that porpoises did enter the area ensonified by the AHD but spent a shorter period within compared to when the AHD was inactive. No evidence of habituation was discerned over the 18-week period of the study.

In the Bay of Fundy, Canada, Johnston (2002) found complete exclusion of porpoises out to a range of 645 m from an AIRMAR db II Plus AHD, at which the received level of the AHD was calculated to be 128 dB. Animals approached within 6 m of an inactive AHD. The mean closest approach of all tracks while the AHD was active was 991 m, with a calculated received level of 125 dB (the mean closest approach for tracks when the AHD was not active was 364 m). Presumably, the data for active AHDs will include tracks when the animals were still moving away from the device and so may underestimate the effective range.

A study in the Orkneys, UK, found that fewer harbour porpoises were detected acoustically in an area considered to be affected by an AHD when the device was active, than when it was inactive (Robertson 2004).

Aversive responses in cetaceans are not restricted to harbour porpoises. Observations of killer whales in British Columbia (Morton and Symonds 2001, 2002) indicated a reduction in the use of feeding areas in the Broughton Archipelago at a scale of tens of kilometres, which continued without the animals showing any sign of habituation over the six years that AHDs were in use. When the AHDs were removed the whales started to use this habitat again.

It is thus clear from these studies that AHDs can potentially be an effective method of deterring porpoises and other cetaceans from the immediate vicinity of a sound source. Conversely, AHDs used for another purpose (e.g. deterring seals from a fish farm) may have incidental effects on cetaceans through disturbance and displacement.

Most studies agree that, during short-term experiments, pingers definitely reduce harbour porpoise bycatch in fishing nets (e.g., Kraus et al. 1997, Larsen 1999, Gearin et al. 2000). In the pinger trials of Laake et al. (1998), porpoise distribution changed in response to nets being alarmed. The authors determined that the acoustic buffer (exclusion zone) had a radius of at least 125 m, and potentially more. Culik et al. (2001) also showed that their single PICE pinger created a total exclusion zone of 130 m, with a mean closest approach distance of tracked harbour porpoise groups to the pinger of 414 m (median 364 m, range 130 m to 930 m). The authors compare this with a Lien pinger tested by Koschinski and Culik (1997), which forced harbour porpoises to remain outside a mean closest approach distance of 133 m around the pinger. Kastelein et al. (2001) found that tests of three different pingers using captive porpoises, all resulted in the animals consistently swimming as far away from the devices as possible (approximately 32 m within the confines of a 34 m pen).

While not of particular concern for short-term mitigation purposes, the long-term implications for porpoises are not so clear and the animals may habituate to pingers. For example, in one captive experiment, the reactions of two animals to pingers diminished rapidly in following trials over a period of about five days of four to five sessions per day (Teilmann et al. 2006). The authors suggested that should the waning of responsiveness apply to wild animals, porpoises may adapt to the sounds but still avoid nets, or that bycatch may increase after some time. Similarly, Cox et al. (2001) found that harbour porpoises habituated to a pinger in inshore waters. Whilst animals in that study were initially displaced by 208 m from the pinger, this effect diminished by 50% in four days and distributions during exposures were not significantly different from the controls within 10–11 days. Thus, the success of long-term use of pingers may then depend on the variety of sounds, rates and duration of exposure.

6.7. Noise Reduction Methods

Methods of reducing the noise produced during construction have been developed (with more currently in development). Noise dampening technologies can be used at the source to reduce the initial sound production (primary noise mitigation) or placed in the path of propagating sound to reduce intensity (secondary noise mitigation). Reducing the hammer energy, using BLUE piling or using alternate mooring methodologies are the primary means of reducing noise at the source (see Section 6.8). Methods of secondary noise mitigation can include bubble curtains, Hydro Sound Dampers (HSDs), isolation casing, fabric barriers, coffer dams, etc. (e.g., Würsig et al. 2000, Stokes et al. 2010, Lucke et al. 2011, Saleem 2011, Koschinski and Lüdemann 2013, 2015, Dähne et al. 2017).

Hammer cushions (cylindrical cushions made of high impact plastic) can also be used to reduce noise created during conductor driving. These have been measured to reduce the SPL by 1.5 dB and the per-pulse SEL by 1.8 dB (MacGillivray 2018) but use of this technique may lead to an increase in hammer strikes needed to drive the pile into the ground.

For a thorough review of noise dampening technologies, see Koschinski and Lüdemann (2013).

6.7.1. Bubble curtains

The acoustic properties of water can be drastically modified by a small amount of air content in the fluid (Hwang and Teague 1999) due to the impedance mismatch between the two media (Graves 1968, Jacobsen 1972). The presence of air bubbles within a body of water can inhibit propagation of sound emanating from pile driving operations due to density mismatch and concomitant reflection and absorption of sound waves (Würsig et al. 2000). A bubble curtain is essentially a curtain or sheet of bubbles rising from, e.g., a perforated hose laid along the seabed. Bubbles travel up the water column and reflect, refract and absorb sound energy from activities such as pile driving, or shockwaves produced during sub-aqueous blasting.

Würsig et al. (2000) used a 160 m perforated hose and air compressor with an output of 750 ft^3/min to create a bubble curtain which encapsulated an entire pile driving operation for a period of 7 months. Würsig et al. (2000) demonstrated that at a depth of 6–8 m, a bubble curtain could provide a reduction of 3–5 dB in overall broadband sound level; however, when considered in one octave-bands a reduction of 8–10 dB was observed between 400–800 Hz and 15–20 dB at 1.6–6.4 kHz. Similarly Lucke et al. (2011) observed a reduction in pilling impulses of 14 dB for peak-peak and 13 dB for SEL values when a bubble curtain was active. In this study, harbour porpoises housed in a facility in the direct line of acoustic emissions from pile driving for harbour construction showed behavioural avoidance of the unmitigated sound; however, when the bubble curtain was used, the animals no longer reacted to pile driving noise.

More recently, bubble curtains have been shown to reduce sound produced by 7–14 dB SEL (Lucke et al. 2011, Koschinski and Lüdemann 2013, Dähne et al. 2017). Multiple rings of bubble curtains can be used together to further reduce sound emissions; two concentric rings of bubble curtains reduced the sound emission by 14–18 dB SEL (Bellmann et al. 2017). In an open-water environment, harbour porpoise detections decreased up to a distance of 12 km from pile driving for a wind farm with the use of bubble curtains as opposed to a decrease at 18–25 km without the use of bubble curtains (Dähne et al. 2017). Use of the big bubble curtain (with a radius of ~70 m) during construction of a wind farm in the North Sea has been shown to reduce both the area of disturbance and the number of animals disturbed by 90% compared to pile driving without mitigation (Nehls et al. 2016). This system is by now established and used as standard practice in offshore pile driving operations in German and adjacent waters.

Large quantities of small bubbles are more effective at attenuating sound when compared to fewer larger bubbles, which are also inherently less stable and more difficult to control as a curtain. Current bubble curtain designs generally do not consider bubble size, the expansion of gas as it ascends, the consequent collapse of bubbles and ineffectiveness of such an inconsistent bubble curtain to retain (or attenuate) propagating sound level. A drawback of bubble curtains is that they can be affected by strong currents and other environmental factors which can decrease their effectiveness.

A study of pile driving noise in the San Francisco Bay (Caltrans 2001) involved using a confined bubble curtain[18] where air bubbles are confined over the entire water column between two sheets of fabric surrounding the foundation pile. This technique requires a large supporting structure and is limited in its use with regard to the current speed. The sound attenuation with this system reached 5–10 dB (SPL and PK); better values were achieved with guiding the air bubbles within an isolating steel casing (see below, Section 6.7.3)

6.7.2. Hydro sound dampers

Air-filled rigid cells, called Hydro Sound Dampers (HSDs) can be installed around stationary noise source. These function using a similar theory to bubble curtains in which the air is used to absorb sound; however, they provide more control of the shape of the curtain (and therefore the frequencies mitigated) and are also capable of functioning in higher tidal speeds (Kuhn et al. 2012, Bruns et al. 2014). HSD generally consist of many rigid, air-filled balloons that are secured to a mesh/net that can be extended from the surface to the seabed in a column around the pile. The balloons can be inflated/deflated depending on noise mitigation required and environmental conditions. Because the balloons are secured to the net structure, which is fixed in place at the top and bottom, they are capable of functioning in higher tide speeds and the direction of the tide does not change their effectiveness or require alternations to how the HSD is deployed (Bruns et al. 2014).

HSDs have been used around pile driving and measured to reduce sound by 7–13 dB SEL and 7–15 dB peak SPL (Remmers and Bellmann 2013) cited in (Verfuss et al. 2016). In another study, an HSD on its own was found to reduce the SEL by 10 dB SEL and when used in combination with a big bubble curtain the reduction was 15–23 dB SEL compared to no noise mitigation (Stein et al. 2015, Bellmann et al. 2017). A similar concept is to use a foam-filled cell, which is expected to reduce noise level by 10 dB (Stokes et al. 2010).

[18] For more information on a similar system, see also Gunderboom (2011 http://www.gunderboom.com/sas/sas_2.html).

6.7.3. Isolation casings

Isolation casings involve the use of a large steel pipe which is placed around the pile. This pipe reflects sound back inside and reduces emissions. Isolation casings for offshore use are often composed of several layers with foam or bubbles between the layers to increase the acoustic impedance (Koschinski and Lüdemann 2013). Isolation casings with only water between the pile and casing provide little sound reduction (0–2 dB SEL), however with air bubbles between the pile and casing a reduction of 21 dB SEL was observed (CALTRANS 2007). Another one of these systems, called the integrated monopile installer which again has a bubble curtain between pile and casing, has been shown to reduce SEL at 750 m from pile driving from 180 dB to 163 dB (Koschinski and Lüdemann 2013, Strieman et al. 2018).

6.7.4. Cofferdams

Cofferdams are structures built around the pile driving where the water is removed between the pile and the dam. For pile driving, the dam is often a large pipe that fits over the pile, and for coastal/harbour construction these can be series of steel plates that are rammed into the seabed and dewatered on the shore side for construction or land reclamation to take place.

Cofferdams for pile driving have been measured to reduce noise levels by 20–23 dB (Stokes et al. 2010, Thomsen 2012). Thomsen (2012) reported a reduction of 23 dB SEL which reduced the impact energy of pile driving in that case from 175 dB to 153 dB SEL at a distance of 750 m and frequencies between 100–500 Hz (cited in Koschinski and Lüdemann 2013).

6.8. Mooring Methods

Water depth and sediment characteristics are the primary constraints in determining the type of foundation for offshore developments; however, in some cases there are different methods of installing and mooring structures that can be used to reduce sound emissions. These include vibration pile driving, BLUE piling, suction and gravity bases, drilling piles, jacket foundations and floating structures (Lucke et al. 2006, Saleem 2011, van den Akker and van der Veen 2013, Koschinski and Lüdemann 2015).

6.8.1. Vibratory pile driving

A system of counter-rotating eccentric weights, powered by hydraulic motors, is used in vibratory pile driving. The system is designed so that horizontal vibrations cancel out, while vertical vibrations are transmitted into the pile and drive it into the ground. In terms of the peak sound pressure levels this technique is 15–20 dB lower than that of impact pile driving (Koschinski and Lüdemann 2013). The acoustic energy (reported in SEL) emitted by vibratory pile driving, however, is likely to be close to the SEL emitted by impact pile driving. Most of the sound emitted by vibratory pile driving is centred in the low-frequency range but higher frequency harmonics can also be detected (Koschinski and Lüdemann 2013). In a study comparing the occurrence of harbour porpoises between years with and without pile driving during the construction of a harbour in Scotland (Graham et al. 2017), the animals had only a slightly lower probability of occurrence during vibration pile driving (measured SEL of 128.9 dB re 1 $\mu Pa^2 \cdot s$) and no significant difference was found compared to impact pile driving (measured SEL of 133.4 dB re 1 $\mu Pa^2 \cdot s$).

Vibratory pile driving is sometimes used in combination with impact pile driving to reduce the sound emissions and duration of pile driving. Due to sediment conditions, it may not be possible to get a pile to the required depth by vibratory pile driving alone. In other cases, vibratory pile driving is generally used first to get the pile as deep into the seabed as possible and impact pile driving finishes it off. This allows a reduction in the number of blows required by impact pile driving to get the pile to the desired distance and therefore the sound exposure level for the animals (Koschinski and Lüdemann 2013).

6.8.2. Gravity bases

Gravity bases are relatively quiet to install as they only require putting a large block of concrete on the seabed (sometimes seabed preparation is required prior to installation to ensure vertical siting of foundation). No impulsive hammering of the foundation is required, just lowering it to the seabed and filling it with sand/concrete or placing boulders over the plate of the foundation, depending on the design (Koschinski and Lüdemann 2013). The primary noise from the installation of a gravity base will be ship noise from the vessels used to manoeuvre it into position. This will generally include a large barge to carry several foundations and a large crane or sometimes the foundations float and can be towed into place by tugs then lowered to the seabed. However, these types of foundations become less suitable in deeper water because of the cost associated with building the large foundation (Oh et al. 2018).

6.8.3. Suction caisson

Suction caissons (also called bucket foundations) do not require pile driving; instead the foundation, shaped like an upside-down bucket, is placed on the seabed and usually sinks some distance due to its own weight, then sediment and water are sucked out from underneath the foundation, securing it to the seabed. Again, the primary noise from this mooring method will be generated by vessels.

6.8.4. Drilling piles

When piles are drilled into the seabed, the drill can either be at the surface with a rotating shaft which reaches the bottom of the pile, or the drill can be at the base of the pile and drilling underneath it. Drilling piles into the seabed can use both the steel piles required for use with impact or vibratory pile driving as well as concrete piles. Noise from drilling of piles will generally be similar to the noise emitted during drilling for O&G exploration and production discussed previously in Sections 3.2.2.2 and 5.1.

6.8.5. Tripod/jacket foundations

As opposed to the traditional monopile foundation which is hammered or vibrated into the seabed, tripod and jacket foundations take advantage of multiple smaller piles which do not need to penetrate as far into the seabed. Because the piles are smaller, the structure as a whole can be lighter than a monopile and is also suitable for installation in deeper waters (Oh et al. 2018). Because of the reduced pile driving depth and time required, the sound produced during installation is also reduced.

6.8.6. BLUE piling

BLUE piling is a technique which uses a water mass, instead of a steel ram, to drive the pile. Energy for driving the pile is created with a gas combustion that accelerates a large column of water inside the combustion chamber. This method is proposed to provide a quieter blow because water decelerates slower than steel. Moreover, there is more energy in the blow which makes it more effective at driving the pile into the seabed (TNO 2016, Strieman et al. 2018). This technique is still in development and has only been used on demonstration-scale projects.

6.8.7. Floating structures

There are many different designs of floating structures that have been developed for O&G and wind farms. Suitable for deep waters, floating structures generally consist of a submersible or semi-submersible structure and rely on anchors which are secured to the seabed. Vessels for installation and the method of anchoring the foundations are the primary sources of noise from this foundation type. Methods of securing the anchors to the seabed can be impact pile driving or any of the other mooring methods mentioned previously (Koschinski and Lüdemann 2013), therefore the noise emitted can vary quite substantially.

6.9. Monitoring Programmes

Common methods of studying cetaceans include visual and acoustic surveys, tagging, genetic sampling and photo Identification (ID). Unlike large whales, harbour porpoises need to be caught before a tag can be fixed to their body, greatly increasing stress on the animal. Genetic studies of harbour porpoises have been carried out, however, these generally use DNA from stranded or by-caught individuals (Rosel et al. 1999, Andersen et al. 2001, Fontaine et al. 2007). Harbour porpoises are difficult to identify using photo ID because they are small, fast and shy with few identifying markings (Diederichs et al. 2008).

Extensive genetic studies have been undertaken of both Hector's and Maui's dolphins, revealing the existence of several genetically distinct, regional sub-populations as well as the Māui subspecies ((Baker et al. 2002; (Pichler 2001), (Pichler 2002), (Hamner et al. 2012a)). Both genetic and photo ID studies are currently used to assess population abundance, survival rates, site fidelity and home range in these species (e.g., Bräger et al. 2002, Rayment et al. 2009a, Hamner et al. 2012b, Oremus et al. 2012).

Visual surveys (both aerial and ship-based) are regularly used to assess porpoise distribution and abundance (Laake et al. 1997, Hammond et al. 2002, Jewell et al. 2012, Scheidat et al. 2012). Harbour porpoises and Hector's/Māui dolphins are also ideally suited for acoustic surveys because they have identifiable acoustic signals which are very short in duration, have unique frequency characteristics and they produce sound nearly continuously (Akamatsu et al. 2007b, Rayment et al. 2009b, Kyhn et al. 2012).

Visual surveys are restricted in the times that they can be performed, requiring good weather (usually sea state 2 or less) and daylight (Hammond et al. 2002). Acoustic surveys, on the other hand, are not light dependent or as weather-dependent as visual surveys, and fixed acoustic devices can collect data for months at a time.

Methods used commonly for assessing the distribution or abundance of marine mammal species are introduced below.

6.9.1. Visual surveys

Visual surveys are used regularly to assess presence/absence of species or to estimate abundance, and standard protocols have been developed (Buckland et al. 2001, Hammond et al. 2002, Buckland et al. 2004, Hammond et al. 2013). Visual surveys for cetaceans can be performed from ships, airplanes, from offshore installations, or from land usually on coastal cliffs (Hammond et al. 2002, Hammond et al. 2013, Jones et al. 2014). It is common to survey areas using either parallel survey lines or a zig-zag survey design (Buckland et al. 2001, Brookes et al. 2013, Hammond et al. 2017).

A requirement of visual surveys is obviously that the animal must be seen; therefore, such surveys can only be performed during good sighting conditions. For harbour porpoises, detections often decline with a sea state greater than Beaufort 2 (Hammond et al. 2002), so surveys can only be performed reliably when the ocean is very calm. In addition, cloud cover, fog, glare, rain, etc. can all impact visual detections.

Distance sampling is the statistical framework that has been developed to analyse various types of visual (or in some cases acoustic) sampling data. Line transect sampling is one of the three main types of distance sampling, the other two being strip and point transect sampling (Buckland et al. 2001). In a line transect survey, the observer travels along a survey line and records the distance to each detected object of interest, in this case, a Hector's/Māui dolphin. In strip transects, the observer must count every object along a transect within a set strip width, and in point transects the observer stands in a single location and records the distance to every observed object (Buckland et al. 2001).

Distance sampling makes three assumptions: 1) objects on the transect are always detected (see below for a discussion of this), 2) objects are detected before any responsive movement (which can influence the survey method used) and 3) distances or angles are measured accurately (Buckland et al. 2001).

Line transect surveys for cetaceans are commonly performed using either ships or aircraft (Brookes et al. 2013, Williamson et al. 2016, Hammond et al. 2017). Assumption 2 can be violated during ship-based surveys because shy species (such as harbour porpoises) can avoid the survey vessel before they are detected which reduces their predicted density. Conversely, some species may be attracted to the survey vessel (e.g., dolphins that bow-ride), and potentially Hector's dolphins (which may be attracted to vessels) which inflates the density estimate for that species (Buckland et al. 2004). One way to avoid this problem is to use an aerial survey platform, which is less likely to disturb the animals.

Extensive aerial surveys on Hector's dolphins (abundance results on which the TMP is based) have been undertaken in New Zealand using methods which were specifically designed or modified to be more appropriate for this species (MacKenzie and Clement 2016). The data allowed for an estimate for the total Hector's population around the South Island (excl. sounds and harbours) of 14,849 (CV: 11%, 95% CI: 11,923–18,492).

6.9.2. Digital visual surveys

In aerial digital visual surveys, the observer is replaced by either a digital video or digital still camera which records the sea surface underneath the aircraft. Digital video surveys perform strip transect sampling with the camera recording a continuous strip underneath the survey aircraft. In digital still surveys the camera can either take still photos in rapid succession to be stitched together afterward into a continuous strip or take photos in a systematic or random grid.

Digital visual surveys have been used successfully for cetaceans (e.g., Hobbs et al. 2000, Williamson et al. 2016). Digital surveys have several potential benefits over visual surveys. Object detection is not a function of its distance from the track line, cameras do not suffer from fatigue, and a permanent record is created which can be checked for quality at a later date (Buckland et al. 2012). Surveys can also be performed from a higher altitude, which can minimise responsive movement of the survey species (Hammond et al. 2013), and allow complex habitats such as offshore wind farms to be surveyed randomly (Buckland et al. 2012); however, when calculating abundance, an estimate of availability is required to account for the proportion of animals missed (Buckland et al. 2004). Visual surveys typically employ mark-recapture approaches to estimate availability by using double platform surveys or by circling back over the survey route after a sample of sightings (Hiby and Lovell 1998) (MacKenzie and Clement 2016). Availability has been estimated for harbour porpoises in visual surveys (Hammond et al. 2013); however, the relatively narrow track width used in digital surveys constrains the design of similar experiments that could be used to estimate availability. An initial estimate has been made by comparing results from visual and digital surveys performed over the same area (Williamson et al. 2016), but requires further confirmation. This currently prevents converting estimates of relative density into absolute density for digital surveys.

6.9.3. Passive acoustic monitoring

Many species of cetaceans communicate vocally and odontocetes have evolved to use echolocation for communication, navigation, prey detection and predator avoidance. Therefore, passive acoustic monitoring is frequently used to investigate distribution and abundance trends in cetaceans (Carstensen et al. 2006, Madsen et al. 2006b, Marques et al. 2009, Bailey et al. 2010a, Kyhn et al. 2012, Mouy et al. 2013, Kowarski et al. 2015, Frouin-Mouy et al. 2017, Kowarski et al. 2018, Miksis et al. 2018). Acoustic surveys can either use fixed acoustic devices or survey vessels with towed arrays. Acoustic surveys are less susceptible to poor weather conditions than visual observations and they function equally well during the night. While ship-based surveys (both visual and acoustic) are of limited temporal scale (Diederichs et al. 2008, Marques et al. 2013), autonomous systems do not experience similar limitations.

Advantages can include the ability to detect calling marine mammals day and night in all weather conditions over long periods. High quality recorders and moorings can detect mammals at much greater distances than visual surveys allow, potentially up to 500 km for whales using low frequency sounds, such as blue whales in waters around New Zealand. Visual surveys are the alternative to acoustic studies. Although vessel and aerial visual surveys precisely localise mammals and are used to estimate marine mammal abundance, they are limited to daytime hours in good conditions and can only detect mammals at the surface. Implementing continuous visual coverage over long periods is very expensive due to high equipment and personnel costs. The disadvantages of acoustic methods generally are that only calling mammals are detected, and it is difficult to precisely estimate their abundance. Intraspecific acoustic behaviour can be highly variable and is influenced by location, season and activity (e.g. foraging versus travelling). Long-term acoustic studies minimise the time and logistic constraints otherwise required for on-site studies.

Long-term autonomous acoustic monitoring also provides data not easily obtained with other methods. Ideally, high-specification recorders with features such as wide acoustic bandwidth, low-noise floors, large memory capacity, accurate clocks are used to achieve best results. It is essential to capture the full acoustic bandwidth of the marine fauna of interest, including broadband clicks, high-frequency whistles, and low-frequency moans and growls to be detected, as well as coinciding anthropogenic and other biological and non-biological natural sounds to be characterised. The value of collecting ambient noise data cannot be understated. The results from continuous acoustic monitoring can be easily correlated with results from other surveys, such as visual marine mammal surveys and water quality surveys conducted in the same area.

Recent advances in technology have enabled multi-sensor moorings to be deployed as part of ecosystem observatories (https://adeon.unh.edu/). These record marine fauna vocalisations on multiple hydrophones to allow directional analysis, and also capture data on the ecosystems around the moorings. Acoustic recorders are also being installed on mobile autonomous platforms, with optimisation to increase performance constantly occurring (Klinck et al. 2012, Baumgartner et al. 2013, Küsel et al. 2017, Moloney et al. 2018).

While fixed acoustic surveys provide longitudinal datasets which can be compared to dynamic habitat variables and are not as weather-dependent as visual surveys, they have their own set of drawbacks when converting detections to density. The study animal must vocalise within the range of the detector. Harbour porpoises vocalise nearly continuously (Akamatsu et al. 2007a); therefore, this is generally not considered to be an issue for studies of that species, but can be more of an issue when surveying for other species with extended periods of silence. The vocalisation rate of individuals must be known or estimated, rates of false-negatives and positives must be identified, it is impossible to differentiate between individuals based on echolocation clicks, and the parameters for the detection function must be estimated (Kyhn et al. 2012, Caillat et al. 2013, Marques et al. 2013). In some cases it is possible to compare density estimates created using results from alternative methods (such as visual surveys) to acoustic detections (Williamson et al. 2016).

The porpoise detectors (PODs) made by Chelonia Ltd. UK are a common tool used for studying occurrence and behaviour of Hector’s/Māui dolphin (MacKenzie and Clement 2016) and harbour porpoise (Rayment et al. 2009b, 2009c, Williamson et al. 2016, Williamson et al. 2017), and have also been used extensively for other species such as bottlenose and Heaviside’s dolphins and beluga (Bailey et al. 2010a, Leeney et al. 2011, Castellote et al. 2013). They are currently being used on a DOC, NIWA, MPI, and University of Auckland study on Māui dolphin (https://www.niwa.co.nz/news/scientists-eavesdrop-on-endangered-dolphins).

C-PODs consist of a hydrophone, processor and timing system which identify cetacean clicks in a range of 20-160 kHz at a resolution of 5 µs (Chelonia Ltd. 2014). The maximum reported range that a C-POD can detect a harbour porpoise is 566 m; however the range generally reported in practice is usually 200-300 m (Tougaard et al. 2006, Nuuttila et al. 2018). However, the performance of a C-POD is difficult to validate due to the absence of a continuous recording functionality. Studies which have investigated validating the performance have identified that there could be serious implications for conclusions reached in effect and abundance studies if only C-PODs are used (Sarnocinska et al. 2016, Clausen et al. 2018). The authors do not recommend using C-PODs in isolation for Hector’s/Māui dolphin.

There is a wide range of autonomous recorders which can be used to record raw acoustic data, including AMARs (JASCO, http://www.jasco.com/amar-g4/) and Soundtraps (Ocean Instruments, http://www.oceaninstruments.co.nz/), both of which have been used in New Zealand (Delarue et al. 2017, McPherson et al. 2017a, Putland et al. 2017, Giorli et al. 2018, Mensinger et al. 2018). Both are capable of recording Hector’s/Māui dolphin echolocation clicks and the ambient environment.

The AMAR is arguably one of the most capable acoustic recorders available for commercial purchase, and is now up to Generation 4, with the ability to record with a low noise floor of -150 dB re FS (Sampling Frequency) on four 24-bit channels at 512 ksps, adaptable battery packs and a 6700 m depth limitation. This is a significant improvement from the Generation 2 version assessed favourably in a wide reaching review (Sousa-Lima et al. 2013). The AMAR has been included in a large number of significant long-term studies, including those in Atlantic Canada (http://www.jasco.com/esrf/) and the Arctic (https://www.chukchiscience.com/), as well as the first large scale Cook Strait monitoring study (https://www.niwa.co.nz/coasts-and-oceans/research-projects/acoustic-monitoring-whales-dolphins-new-zealand-cook-strait-region)

Soundtraps have a different functionality compared to AMARs, however they are a versatile underwater sound recorder suitable for ocean deployments of various lengths. They were developed in NZ, are widely used by university researchers, being well suited to research projects (Merchant et al. 2015, Wellard R 2015, van Oosterom et al. 2016, Videsen et al. 2017). They are currently being used in conjunction with CPODs to investigate Māui dolphin presence (https://www.niwa.co.nz/coasts-and-oceans/research-projects/acoustic-monitoring-of-the-critically-endangered-maui-dolphin).

6.9.4. Tagging

Using animal-mounted tags such as cameras or acoustic recorders in combination with Global Positioning System (GPS) has potential to greatly enhance understanding of animal foraging and temporal and spatial habitats usage (Johnson et al. 2009, Chimienti et al. 2017); however, tagging is difficult to conduct on small cetaceans such as harbour porpoises and Hector's/Māui dolphins. Unlike large whales, harbour porpoises need to be captured before a tag can be fixed to its body, greatly increasing the stress on the animal (Diederichs et al. 2008). Porpoises that have been tagged have been recorded to have a decrease in breathing rate of 30% (Eskesen et al. 2009) and also exhibit increased number of rolls and time spent at the surface (Linnenschmidt et al. 2013). Tags can either use suction cups to affix to the body (DeRuiter et al. 2009, Wisniewska et al. 2012) or be attached through the dorsal fin (Sveegaard et al. 2011).

Tagging has been used previously with harbour porpoises to investigate areas with highest density, types of habitats used, foraging, and surfacing behaviour (Johnston et al. 2005, DeRuiter et al. 2009, Sveegaard et al. 2011, Wisniewska et al. 2012, Teilmann et al. 2013). Digital acoustic recording tags (DTAGs) are archival tags that record audio, pitch, roll, heading and depth and can be attached to the animal using suction cups (Johnson and Tyack 2003). These tags offer potential to study foraging porpoises because they can detect buzzes and lunges to capture prey (DeRuiter et al. 2009, Wisniewska et al. 2012); however, they have a limited duration that they can remain attached.

6.9.5. Photo ID

Harbour porpoises are generally ill-suited to photo identification studies, however in some circumstances it is possible. Photo ID studies can be performed from high vantage points looking down at porpoises in restricted areas. For example, Golden Gate Cetacean Research performs photo ID studies of harbour porpoises directly from the middle of the Golden Gate bridge in San Francisco, CA, USA, and Elliser et al. (2018) study porpoises in Burrows Pass, WA, USA.

Photo ID is easier with Hector's/Māui dolphins, and has been used successfully in several studies to estimate population size (Gormley et al. 2005, Baker et al. 2016), site fidelity (Bräger et al. 2002, Rayment et al. 2009a), survival rates (Slooten et al. 1992) and body size (Webster et al. 2010).

7. Cumulative Effects

Many stressors have now been introduced, and each can individually cause disturbance to Hector's/Māui dolphins and harbour porpoises. In combination, effects may be much larger than the cumulative sum of each individual stressor (Wright and Kyhn 2015). Multiple activities can occur and affect an animal concurrently, or effects can accrue over time from single or multiple activities or stressors. Irrespective of the temporal or spatial correlation of activities, their effects have the potential to compound and accumulate. The highest cumulative effects for top marine predators have been found to concentrate along the continental shelf where the greatest impact of anthropogenic activities occurs (Maxwell et al. 2013).

While impacts of several individual activities at sea have been investigated on Hector's dolphins and related/proxy species, few projects have researched the potential cumulative effect of multiple anthropogenic activities.

A truly comprehensive assessment of cumulative effects would have to entail a full-region, full-season storyboarding of all proposed industrial operations and a multidisciplinary approach to investigate all relevant aspects. Such efforts would be extremely costly, and, due to the complexity of the cause-effect relationships, it would be challenging to conduct such research.

To date, there is no evidence-based data (no 'magic bullet') allowing assessment of cumulative effects of marine industrial activities on Hector's/Māui dolphins. In the absence of a such data, any assessment must rely on best available scientific knowledge on the effects of individual activities or stressors, and reasonable assumptions on compounding and cumulative effects of and extrapolation from (physiologically and/or anatomically) related species.

Several industrial activities can occur in conjunction or overlap with O&G and mineral mining in New Zealand waters (see Sections 3 and 5.1.2–5.1.4), and they have the potential to result in cumulative and/or compounding effects.

Entanglement in fishing nets (incidental bycatch) in commercial and recreational fishing gear has been commonly identified as the primary threat to Hector's/Māui dolphins over the past several decades (Currey et al. 2012, Slooten and Davies 2012). A more detailed spatially explicit fisheries risk assessment undertaken to inform the 2019 update of the TMP (Roberts et al. in prep) demonstrates that current commercial fisheries effects are highly variable in space: it is likely that some local populations remain significantly impacted whereas for others the current impact is estimated to be very low. Other possible anthropogenic threats, some of which are examined in detail as part of the TMP, include tourism, coastal development (e.g., dredging, port construction, aquaculture), vessel strikes, underwater noise, bioaccumulation of contaminants, resource competition, and land-based mammalian disease transmission (e.g., toxoplasmosis, *Giardia spp.*).

The type and level of effect of any activity considered in this review will vary considerably depending on location and magnitude relative to the dolphin habitats. The areas of overlap between Hector's and/or Māui dolphin distribution and O&G activities, are mainly concentrated in southern areas within or near Maui dolphin distribution range. Currently, commercial fishing, commercial vessel traffic, and mineral mining activities are more likely to occur in/near dolphin habitats. Acoustic noise generated from seismic surveys for O&G, however, has the greatest potential spatial effect on this species (i.e., impacts over tens of kilometres) relative to other individual pressures (McPherson et al. 2018). While seismic noise is unlikely to interfere with this species' ability to detect and avoid fishing gear in the water, it might induce individual dolphins to move away from the noise source and into waters that have a greater (i.e., outside of fisheries exclusion zones) or lower (i.e., into fishing exclusion zones) fishing bycatch risk.

Vessel noise has been identified as a significant source of potential impact on a wide range of marine mammal species including Hector's and Māui dolphins. McPherson et al. (2018) modelled the sound emitted from vessel traffic[19] and seismic surveys off the West Coast North Island (WCNI) of New Zealand during a summer and winter season (2014/2015). Their publicly available study demonstrates that traffic density north of the Taranaki region is relatively low within 12 nm of the coast, while higher densities occur in the Taranaki and South Taranaki Bight regions. Fishing vessels exhibit a strong seasonal pattern of operations while most of the commercial shipping has a density that is consistent

[19] McPherson et al. (2018) analysed AIS datasets including multiple commercial, government, and recreational vessel categories in the New Zealand (NZ) Exclusive Economic Zone (EEZ).

between seasons. Sound emitted from two seismic surveys dominated the local sound field during their operation and even propagated into the WCNI Marine Mammal Sanctuary when one survey was closest to this protected area. Further work is underway off the Taranaki coast to quantify the sound levels received within DOC's west coast marine mammal sanctuary from current O&G activities (BluePlanet Marine, pers.comm) but it is unclear if this information will become publicly available; however, there is no information to date on how Māui or Hector's dolphins respond to seismic surveying noise on its own, much less on any potential compounding effects.

While the exact impact of vessel noise is unknown it may include displacement and the masking of communication. Vessel noise adds to the noise level in an area with seismic surveys, thereby accumulating any potential impact from these two sources. The challenge lies in teasing out the individual impacts of each type of sound source and then assessing any cumulative effects. This represents a significant body of scientific work but is required if any progress is to be made on cumulative impacts.

An additional aspect of the combination of seismic survey activity in areas of high commercial or recreational traffic is the potential increase in vessel collision risk. While Hector's dolphins can be boat-positive (Dawson et al. 2000), Māui dolphins appear to be less so (R. Constantine pers. comm). Given the slow speed of seismic vessels collision risk can be considered negligible, potentially with the exception of young calves within more inshore waters (Stone and Yoshinaga 2000) which may have a slightly higher vulnerability. Overall, vessel strike is likely to represent a variable but overall low risk to these dolphins, although any increases in vessel traffic in areas with dolphins may lead to a potential cumulative increase in risk.

Existing O&G production rigs and pipelines typically have 500 m vessel (incl. fisheries) exclusion zones around them, which essentially act as marine reserves and fish aggregation structures (Todd et al. 2016a). Consequently, these offshore installations may provide a short-term food resource for Hector's or Māui dolphins found further offshore, and outside of their typical home ranges. Hector's dolphins from the west coast of the South Island have at least on two occasions crossed Cook Strait waters and are now confirmed living among Māui dolphins along the North Island's west coast (Hamner et al. 2014). DOC has also received public sightings of Hector's/Māui dolphins around platforms in the South Taranaki Bight, however, none have yet been substantiated with confirmed photographs or DNA evidence. If this species does take advantage of these platforms for temporary food resources, a potential adverse effect may be the risk of bioaccumulation of O&G related contaminants up the food chain, an interaction that has not yet been investigated, although any discharges are now highly regulated under discharge consents issues under the EEZ Act.

The 'weakest link' (i.e., the most sensitive aspect) between disturbance and population-level consequences in a simulation study based on a long-term dataset on killer and humpback (*Megaptera novaeangliae*) whales by Williams et al. (2016) was considered to be prey availability. According to their study, a reduction in prey availability of as little as 10% could cause the killer whale population to decrease by an amount equal to their potential biological removal. This demonstrates the fragility of ecosystems–if animals cannot eat, they cannot survive; therefore, any anthropogenic activities that a) disturb prey, b) cause animals to shift their distributions to poor foraging grounds, or c) interfere with an animal's ability to forage can have significant consequences for the population.

If multiple developments (e.g., O&G, wind farms, seismic surveys, sand mining, fisheries) were to occur in a localised area simultaneously, then impacts would likely be much greater than if each occurred individually. Timing and spatial arrangement of developments must be considered during the planning and construction phases, and appropriate mitigation measures must be developed to reduce the effect on Hector's/Māui dolphins on an individual and population level.

Two modelling frameworks have been developed to predict the consequences of disturbance from offshore renewable energy developments on a population level. These include the Interim Population Consequences of Disturbance, iPCOD (Donovan et al. 2016) and Disturbance Effects of Noise on the Harbour Porpoise Population in the North Sea, DEPONS (van Beest et al. 2015). Both models simulate population dynamics; however, DEPONS yields more realistic predictions of short-term effects of disturbance, while iPCOD runs faster and is therefore easier to account for in a wider range of management scenarios (Nabe-Nielsen and Harwood 2016). Using similar methodologies and expanding them to include other sources of disturbance and to be applicable for other species would aid in estimating the cumulative effects of disturbance.

8. Discussion and Conclusions

Discussing and concluding on potential impacts of O&G and mineral activities on Hector's/Māui dolphins is hampered by the overarching lack of knowledge about their sensitivity to the relevant stressors. Although harbour porpoise is considered a good proxy for understanding possible adverse effects on Hector's/Māui dolphin, such comparisons are still only approximations. Accordingly, in this Section we often refer to knowledge gaps and make recommendations for future research which are also collectively listed at the end of this Section.

The Taranaki Basin is currently the only O&G producing basin in New Zealand, with no production wells being drilled beyond the Taranaki shelf edge. Exploration drilling in deeper parts of the EEZ, however, revealed petroleum systems in other parts of New Zealand's EEZ with considerable potential for further discoveries. The New Zealand government decided to not issue any new permits for offshore exploration of O&G resources. Current exploration permits will be honoured for coastal and offshore areas off the North and South Islands.

A number of other activities are linked intrinsically with O&G and mineral activities such as pile driving, drilling, and associated vessel traffic. All these activities emit numerous chemical and physical pollutants (including noise) that have potential to affect Hector's/Māui dolphins, directly or indirectly. A key aspect for assessing risk exposure and potential impact, is determining Hector's/Māui dolphin distributional overlap with zones where these activities occur. Out of the two approaches currently considered in this report, the HMD proxy area and the TMP assessment area, the HMD proxy area is used here.

Assessing effects of industrial noise exposure on Hector's/Māui dolphins requires knowledge of animals' auditory sensitivity; however, there are no direct audiometric data available for this species. Consequently, indirect information such as their acoustic vocalisations, anatomy of their hearing apparatus, and auditory information from related/proxy species provide valuable insights. Hector's/Māui dolphins share similar characteristics with harbour porpoise in that both have comparable high-frequency vocalisations, prey-preferences, and other biological, anatomical, physiological, and ecological similarities. Both species are also faced with similar anthropogenic threats, rendering the harbour porpoise a justifiable proxy for elucidating some of these aspects to inform the assessment.

There are limited published data relating to effects of O&G and mineral activities on the New Zealand marine ecosystem (Boschen 2016, Elvines et al. In draft-a, Elvines et al. In draft-b). Moreover, much of the available marine mammal information and impact assessment advice is based primarily on marine mammal distribution information (e.g. sighting, breeding, feeding-spatial information) and expert knowledge (i.e., qualitative observation), rather than site-specific empirical observations. Consequently, gaps in information make determining best-management practices and marine consent decisions challenging, and typically require a high level of industry-related legislative management and mitigation practices (MacDiarmid et al. 2011, Lamarche and Clark 2013, Clark et al. 2017).

While incidental bycatch has been identified as the main threat for Hector's/Māui dolphins previously, O&G and mineral activities produce a different suite of stressors and emissions which have potential to negatively impact animals. Sound emitted by seismic surveys and associated vessel-based activities could potentially impact Hector's/Māui dolphins negatively both directly, and indirectly through prey-related effects. Offshore pile driving, exploration drilling, and decommissioning of offshore infrastructure at end of operational lifetimes have potential to affect animals through noise, indirectly or through habitat degradation and the release of toxins and remobilisation of contaminants, especially from resuspended oil-based mud (OBM) drilling plumes, following decommissioning jacket removal. The main effects to be expected from vessel operation are noise and potential chemical/fuel spillage contamination, though risks are low.

In addition to intensity of any one or combination of emissions, the type, frequency, magnitude, and potential likelihood of overlap with Hector's/Māui dolphins' habitat will ultimately determine severity of any potential effect(s). Effects can be wide-ranging, from the extreme (such as death due to collision with a vessel), to masking of important sounds (including communication signals, echolocation, sounds associated with finding prey or avoiding predators, and human threats such as shipping), alterations in behaviour (including displacement from feeding/breeding/migration habitat), hearing loss (temporary or permanent), chronic stress, and indirect effects, including displacement of prey species. Large scale seismic surveys or dredging campaigns for example, have potential to influence many animals over extended ranges and periods. While the direct influence of such an activity may be comparatively small, the overall cumulative effect could potentially be more substantial from an ecological point of view, i.e., acute effects that animals may be able to tolerate turn into chronic effects that may exceed the compensatory capacity of the dolphins.

No single real-time monitoring technology or method can detect all animals in all conditions and environments with 100% certainty. Visual (MMO) or acoustic (PAMO) methods are established methods but limited in their range and/or effectiveness (see Section 6.9). If the final conservation plan for Hector's, and especially Māui dolphins warrants protecting them from all intense sound exposure, including any behavioural effects, then stand-off distances (buffer zones) should be defined for all industrial activities with the potential to cause unwanted negative effects for these dolphins. These buffer zones would account for the fact that sound propagates well under water and depending on its source level, frequency spectrum and local sound propagation conditions, can be detected over considerable distances and may exceed noise exposure criteria even at large distance from the source (i.e., far beyond the range of real-term monitoring methods which are usually limited to less than 5 km). Buffer zones would have to be calculated (predicted based on sound propagation modelling and/or monitoring) for all industry-related activities that emit intense noise; they could be implemented permanently or over sensitive periods such as the breeding season. The purpose of these zones would be to prevent sounds above noise exposure criteria thresholds generated from such activities from entering areas of concern, in particular sanctuaries. This would equate to setting a maximum noise exposure threshold (for onset of PTS, TTS, behavioural disturbance or otherwise) at the boundary of all sanctuaries for this species. Depending on the regulatory paradigm of the TMP, i.e. which level of protection and thresholds are chosen as noise exposure criteria, such stand-off distances around areas of concern provide the only means for ensuring the highest level of protection from auditory injury and from behavioural disturbance for these animals.

Existing monitoring and mitigation techniques already provide a level of protection for the dolphins and emerging technologies are likely improving efficiency of these efforts. Such measures as well as temporary closures may be easier to implement as a management option and find acceptance (and use) by noise-emitting industries. Ultimately, it is a regulatory decision to define the noise exposure criteria for onset of behavioural and physical effects (based on best available scientific knowledge) that set limits to O&G and mineral mining activities as well as other industries. This will determine if sanctuaries are to become prohibitive areas in terms of excessive noise exposure or to what degree and duration a contamination is deemed acceptable. Noise exposure criteria can only be effective if enforced through a suitable set of mitigation, i.e. based on sound propagation modelling prior to surveys and acoustically monitored and validated through autonomous recorders deployed in the sanctuary or dolphin distribution area. Alternatively, the same effect can be achieved through implementation of pre-set buffer-zones that are large enough to account for the highest noise levels.

Defining the correct noise exposure criteria requires a good scientific understanding of the dolphins' auditory sensitivity. Based on acoustic characteristics of their echolocation signals, as well as anatomical similarities to harbour porpoises, it is justifiable classifying Hector's/Māui dolphins as HF cetaceans. Susceptibility to noise-induced effects on the auditory system (TTS/PTS) of marine mammals is mostly driven by anatomical and physiological characteristics. In the absence of species-specific information for Hector's/Māui dolphins, it seems also justified to infer potential effects of underwater sound on the hearing (e.g. TTS/PTS) of Hector's/Māui dolphins from relevant information on harbour porpoises.

The most appropriate noise exposure threshold level to protect them from TTS would be the NMFS (2018) HF-weighted TTS noise exposure criterion of 140 dB re 1 $\mu Pa^2 \cdot s$ SEL. To prevent PTS, the relevant threshold would be a NMFS (2018) HF-weighted 155 dB $\mu Pa^2 \cdot s$ SEL for impulsive sounds and a NMFS (2018) HF-weighted 173 dB $\mu Pa^2 \cdot s$ SEL for continuous sounds. To date, the noise exposure criteria suggested by Wood et al. (2012, see Table 9) seem to provide the most appropriate approach to regulating the behavioural effects of noise on marine mammals. There is, however, insufficient information to decide about classifying Hector's/Māui dolphins as sensitive species (following Wood et al.'s distinction between sensitive and other cetacean species) with regard to their behavioural reactions to sound. Defining best practices for industrial activities in New Zealand waters can also be informed by works such as Nowacek et al. (2013), Nowacek and Southall (2016), and Southall et al. (2016).

The modelling study by McPherson et al. (2018) showed that sound emitted from seismic surveys was likely to enter the North Island sanctuary, but only over a limited period and at reduced sound levels. However, this depends upon the location of the survey – the study only considered two seismic surveys conducted in the 2014-2015 year, the TGS Northwest Frontier Multiclient 2-D Marine Seismic Survey (MSS) (4400 in^3 array) and the Todd Energy Trestles 3-D MSS (3460 in^3 array). The modelling results are representative of the year from July 2014 through June 2015. While comparisons can be made to other periods of time, the possible location of vessels and marine seismic surveys should be considered.

Unless animals would leave their normal habitat (i.e., swim beyond the 100 m depth contour) and stay close to an active seismic vessel, effects such as TTS or more severe effects are not likely. This highlights the important roles the sanctuaries play for the conservation of Hector’s/Māui dolphins. As long as seismic surveys are planned and operated outside the sanctuaries, with a buffer to account for the long-range transmission of sound underwater, the risk for physical effects could potentially be minimised. Consequently, the optimal mitigation method for any of these activities is to avoid the sanctuaries (with a buffer range), or at least to avoid sensitive periods. Sound emissions differ between each planned seismic operation, which makes it imperative to model the sound propagation for such campaigns to inform the risk assessment and delineation of buffer zones for this activity (unless a worst-case scenario is used to delineate the buffer zone). Following existing legislative industry-specific monitoring and mitigation scheme(s) provides the most basic level of protection for the dolphins and methods should be revised and improved based on proven new technologies.

The same overall reasoning also applies for potential noise-induced effects of mineral exploration and mining. Sound emitted from dredging activities associated with mining for minerals is broadband, with most energy below 1 kHz. In general, sound levels are too low to expect animals to suffer physical harm, but auditory masking is likely to occur. If conducted near or in a sanctuary/distribution area, dredging has clear potential to cause behavioural reactions due to the sounds emitted and the presence of the vessel(s). Entrainment, habitat degradation, noise, contaminant remobilisation, suspended sediments, and sedimentation can affect benthic, epibenthic, and infaunal communities, which may impact marine mammals indirectly through changes to prey. Impacts can be reduced by implementing environmental windows on dredging activity, which can be tailored to account for the marine mammal breeding period in addition to critical times at spawning and nursery grounds of fish and benthic species of concern. Risk assessments carried out prior to dredging would have to consider that large-scale repeated alterations of the sediment over a larger area have potential to affect the entire food web, right up to marine mammals.

Vessel echosounders and geophysical survey techniques emit sounds at high frequencies (10s to 100s kHz) at high sound levels. They are of very short duration and have strong directionality. Most signals overlap in terms of their frequency range with the expected range of (best) hearing of Hector’s/Māui dolphins. Based on the source level, these sounds could be expected to cause auditory impairment such as TTS. The acoustic energy contained in each signal, however, is relatively low due to their short duration which reduces the risk of causing severe auditory damage. Due to the directionality of the signals it is very unlikely that animals will be directly exposed to vessel echosounder signals. The signals emitted from side-scan and multibeam echosounder have the widest aperture of all geophysical survey techniques and pose the highest risk for Hector’s/Māui dolphins. Under the assumption that Hector’s dolphins are more attracted to vessels, they might be at slightly higher risk of being exposed than Māui dolphins who seem to avoid vessels. Both species, however, will likely be able to detect the signals at distances and received levels high enough to elicit behavioural avoidance responses.

Offshore pile driving is another source of intense acoustic impulses. Depending on scale of operation, substrate, and number of piles, noise emissions can contribute substantially to the soundscape over wide ranges. Pile driving impulses have potential to cause auditory impairment (such as TTS) in Hector’s/Māui dolphins if an animal is close to the operation. While this is unlikely, the risk of cumulative noise-induced effects is aggravated by the repetitive and impulsive nature of these signals. The effect ranges (for onset of TTS, e.g.) for pile driving activities are smaller in general compared to seismic airgun surveys. Accordingly, mitigation methods such as safety zones around the operation controlled by visual observation (MMO) complemented by PAMO, use of acoustic deterrent devices and soft start procedures have greater potential to substantially reduce the risk for this type of activity. Evasive behavioural reactions, shown to occur in harbour porpoises over wide ranges (>10 km), cannot be ruled out for Hector’s/Māui dolphins but sufficient species-specific information is lacking. Depending on the regulatory decisions in terms of noise exposure limits, pile driving activities may have to be avoided completely within the sanctuaries and distribution areas; a stand-off distance representing an exclusion zone would ensure that activities outside the areas of concern have no undesired effect within the areas.

Drilling and vessel noise are also sources of continuous, broadband sound. Their source levels are lower compared to the seismic airgun surveys or pile driving and have a lower potential for causing physical auditory effects in Hector’s/Māui dolphins. While drilling represents a relatively rare stationary operation, rig and platform-associated vessel movements are ubiquitous, covering wide areas of the distribution area of Hector’s/Māui dolphins. Moreover, each manned offshore installation is associated with a permanent safety boat, which patrols the mitigation zone, so long-term, low level, vessel noise can contribute to background noise levels. Both subspecies can alter their behaviour but with different vectors–Hector’s dolphins have been reported being attracted to vessels while Māui dolphins seem to avoid them. It is unclear over what ranges these responses can be elicited and how severe they are for the animals. As for the other sound sources, there is insufficient information to assess this complex issue for Hector’s/Māui dolphins. Offshore drilling and dredging have been shown to cause changes to benthic communities which has – depending on scale and intensity of the activity – the potential to influence the entire food web and, with regard to Hector’s/Māui dolphins, change availability and species composition of prey. Yet, effects on benthic communities have been shown to be locally restricted (100s metres) in New Zealand for drilling, which indicates that trophic consequences for highly mobile predators such as the dolphins will be locally restricted and the overall severity is likely low.

Underwater explosions are the most powerful man-made sound sources in the ocean and pose a great risk for causing auditory injury or impairment to Hector’s/Māui dolphins. The occurrence of underwater explosions, though unreported, is likely to be low in New Zealand compared to, e.g., European waters. Underwater explosions should be avoided in or near the sanctuaries for the dolphins. If no alternative to explosions can be used at locations near the distribution of Hector’s/Māui dolphins, the full suite of mitigation and monitoring measures including sufficient stand-off distances should be imperative to be used, similar to other noise-intense activities.

With regard to behavioural reactions to any industrial activities considered in this report, the situation is more complex compared to auditory effects; behavioural reactions are highly species-specific and can vary strongly between individuals and different contexts–a young, inquisitive animal may (or may not) be more prone to exploring the source of a novel stimulus than a mother with her dependent calf. Inferring any information on the severity of behavioural reactions from harbour porpoises seems less plausible. At best, behavioural information from this species can inform the potential scale of reactions for Hector’s/Maui dolphins. Due to the scarcity of comprehensive information on behavioural reactions of Hector’s/Māui dolphins to underwater sound it is impossible to assess the risk for behavioural disruption of important behaviours and potential habitat loss. The animals (especially Māui dolphins) seem to be philopatric (i.e., they tend to return to or remain near their home range), as the range of their core distribution is limited; long-term avoidance of critical habitats, such as documented for harbour porpoises in inner Danish waters, is therefore unlikely. This should not diminish the fact that exposure to sounds from any of the activities discussed in this report can disrupt behaviour and have significant fitness implications; however, without designated, well-controlled noise exposure experiments, it is unfeasible to conclude on the avoidance effects of such activities.

To assess risk in terms of behavioural reactions and potential habitat loss, it is essential to gather dedicated information on the behavioural responsiveness of Hector’s/Māui dolphins to underwater sound. Controlled and replicated exposure experiments would provide the most valuable insights in this context. Playback experiments conducted in captive situations on harbour porpoises may inform the risk assessment, but results should not be extrapolated to Hector’s/Māui dolphins. In essence, behavioural reactions to underwater sound are a major knowledge gap and investigating this aspect requires immediate attention to reliably inform any conservation efforts such as the revised TMP. Alternatively, in the absence of appropriate information a precautionary approach should be used to prevent any undesired behavioural effects.

Empirical studies on harbour porpoises from European waters show that mitigation methods exist that have capacity to be effective in reducing the potential effects at least of stationary operations related to O&G and mineral mining activities. These could be used in New Zealand waters, if tailored to specific requirements–from a biological side (i.e., regarding the biology of Hector’s/Māui dolphins) or industrial side (i.e., accounting for activity type and location).

Concerning the influence of non-acoustic emissions from associated activities, the main obstacle is the relative lack of scientifically-robust information. Ecology of the marine ecosystem is highly complex, and it is difficult to link cause-effect relationships to a single factor. Bioaccumulation of toxins resulting from industrial activities resuspended from disturbed sediment (e.g. drilling muds) or penetrating the marine sediment or contaminated discharges can, individually or interactively, lead to conditions such as systemic suppression of immune function in marine fauna. Long-term field monitoring programmes on effects from produced water around O&G production platforms, and drilling plumes from exploration drilling rigs, however, have not revealed elevated levels of contaminants in fish tissues except in resident animals close to discharge points. This suggests that with regard to the Hector's/Māui dolphins, as long as highly contaminated discharges are avoided, the risk for food chain transmission of contaminants via phytoplankton and zooplankton is slight, and any catastrophic effects on Hector's/Māui dolphins are unlikely.

Cumulative effects are another major knowledge gap in this assessment. It is accepted widely that each of the stressors described can impact animals on their own, and that their influence can be aggravated through cumulative exposures; determining interactions qualitatively and quantifying impact on any part of the food web, not just Hector's/Māui dolphins, is extremely challenging and any conclusion would have to be treated with great caution. Modelling frameworks such as iPCOD are useful in conceptualising the scientific and regulatory approaches taken; however, sufficient data have been collected for only a few model species and stressors (e.g., effect of sound on northern elephant seals). In the current context, it remains unfeasible to assess them for Hector's/Māui dolphins at all.

Overall, the current assessment is restricted strongly in its potential to conclude on the type or scale of effects by the lack of relevant species-specific information. Attempts to populate knowledge gaps with information from harbour porpoises as a well-studied proxy has provided some insights into the severity and likelihood of effects. It is, however, inherently limited in its declarative strength.

Gaps in knowledge

Knowledge gaps identified in this literature review are likely to overlap with those previously identified in the TMP; most are not specific to activities considered in this report, but more generic. The main insufficiencies in knowledge (which have been elucidated in the report) are:

- Behavioural reactions to underwater sound;
- Noise-induced physiological effects (incl. hearing sensitivity);
- Impact from other pollutants (i.e., non-acoustic);
- Collision risk; and,
- Cumulative effects.

Recommendations for future work

All the following points are recommendations for future work:

- Long-term noise monitoring in selected habitats within the home range of Hector's/Māui dolphins: This information would provide relevant information for more detailed noise modelling. Vessel Automated Identifier System (AIS) data and other data sources on vessel movements and industrial activities could be integrated allowing quantification and, in some case, identification of types of vessels;
- Measurement of hearing sensitivity: No data exist on the hearing sensitivity of Hector's/Māui dolphins, frequency of best hearing, and overall frequency range of hearing. Conducting such measurements on live-stranded animals is unrealistic as no rehabilitation facilities exist in New Zealand which could hold dolphins in captivity and the priority in case of a live-strandings of a Hector's/ Māui dolphin will always be to return the animal back in the water as quickly as possible. Instead, as a better proxy than the harbour porpoise, the hearing sensitivity of phylogenetically more closely related species such as Commerson's dolphins can be tested to complement existing information on hearing sensitivity in high-frequency cetaceans;
- Auditory masking: This is linked directly to the previous point (i.e., measuring auditory sensitivity of Hector's/Māui dolphins) and could potentially reveal influence of vessel noise and other sound sources on the perception of important acoustic stimuli for these animals;
- Behavioural Response Study (BRS): Such studies would provide valuable insight in the reactions of Hector's/Māui dolphins to different types of underwater sound. In a carefully controlled and replicated setting, animals could be exposed to playbacks of sound or original sound source emissions and their reactions could be monitored closely;

- Satellite telemetry: While difficult to conduct, satellite tags have been reduced in size and enormous progress has been made to enhance their technical capabilities. The biggest challenge would be to deploy a tag for a limited period (by means of suction cups). If done in conjunction with a BRS, the information could provide invaluable insight into severity and onset levels for behavioural reactions of Hector's/Māui dolphins.

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Appendix A. Permitting and Licencing in New Zealand

Figure A-1 is a diagram from the New Zealand's Ministry for Environment website– (http://www.mfe.govt.nz/sites/default/files/media/who-does-what-in-offshore-waters.pdf) explaining the permitting/licencing stages for O&G exploration and production and which government agencies are involved.

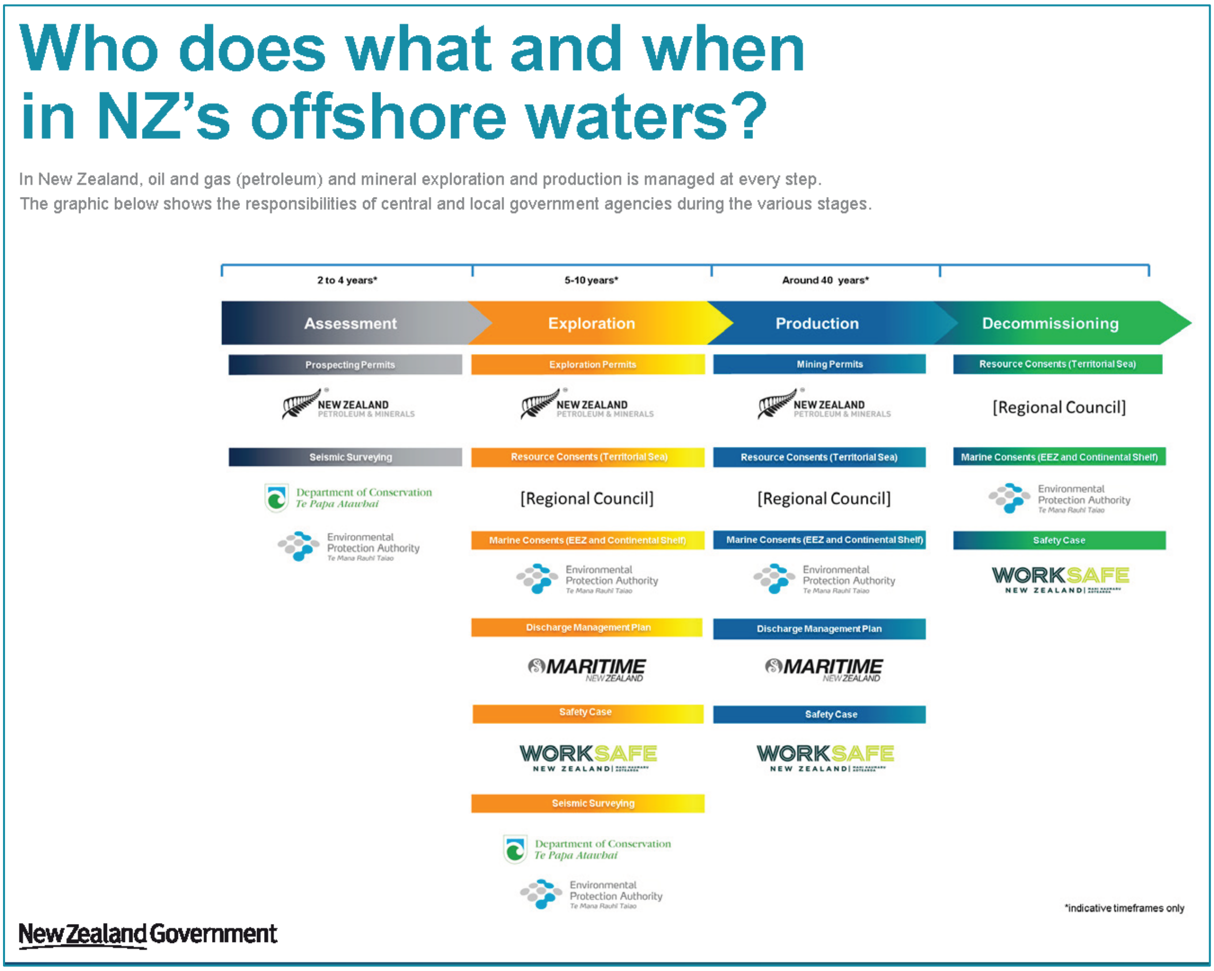

Figure A-1. Flowchart showing the permitting and licencing stages for oil and gas exploration and production in New Zealand and which government agencies are responsible.

Appendix B. Seismic Surveys within New Zealand's EEZ

The seismic survey activity in waters within the EEZ of New Zealand is shown per decade for the period from 1960–2014 in Figures B-1 to B-6 for 2-D seismic surveys and for the period from 1987–2015 in Figures B-7 to B-10 for 3-D seismic surveys.

B.1. Two-dimensional (2-D) Seismic Surveys

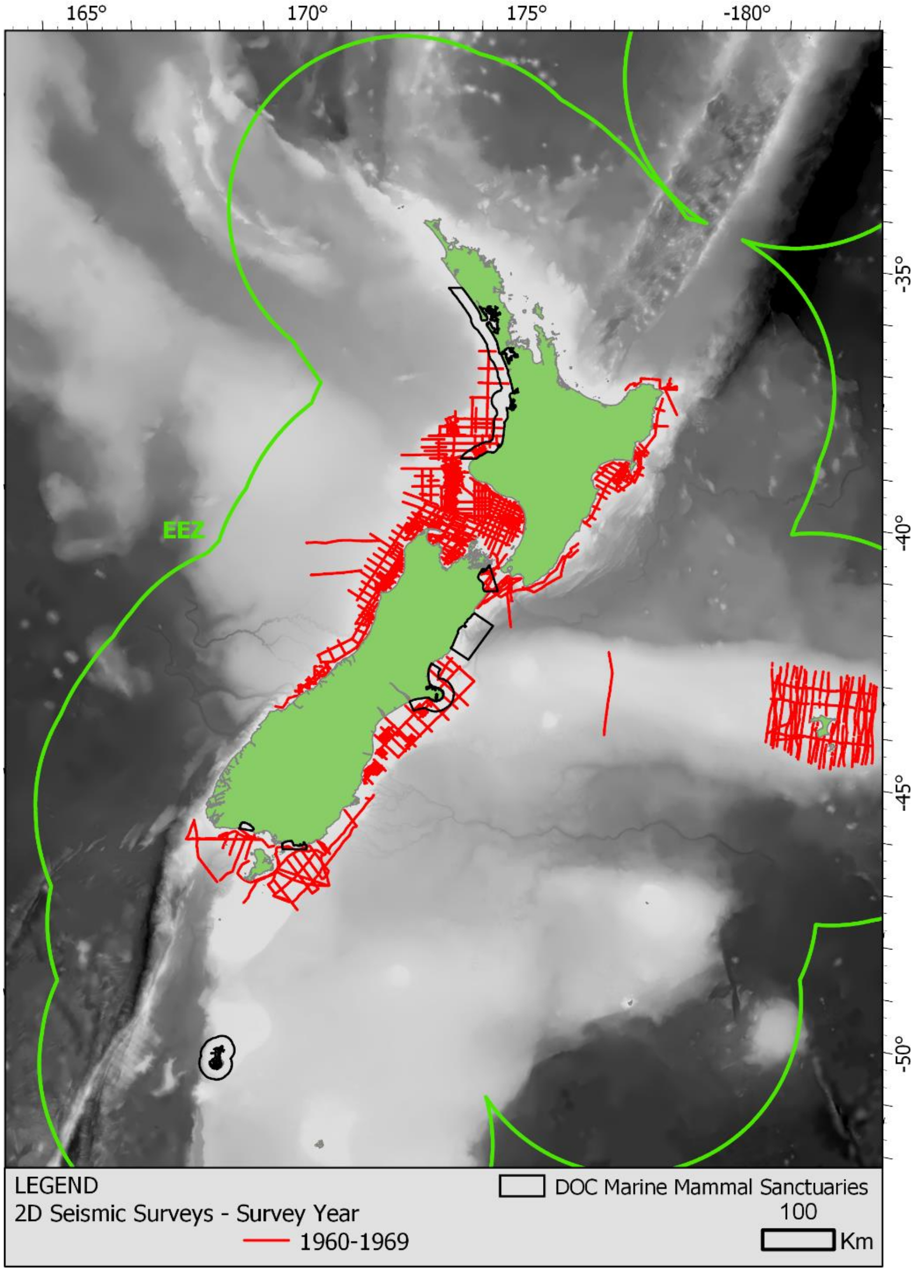

Figure B-1. Two-dimensional (2-D) seismic survey activity within New Zealand's Exclusive Economic Zone from 1960–1969. Information downloaded from New Zealand Petroleum and Minerals (NZPAM) webmaps, November 2018. The boundaries of the various Department of Conservation (DOC) marine mammal sanctuaries are outlined in black, noting that these sanctuaries have been gazetted at different time periods beginning in 1984.

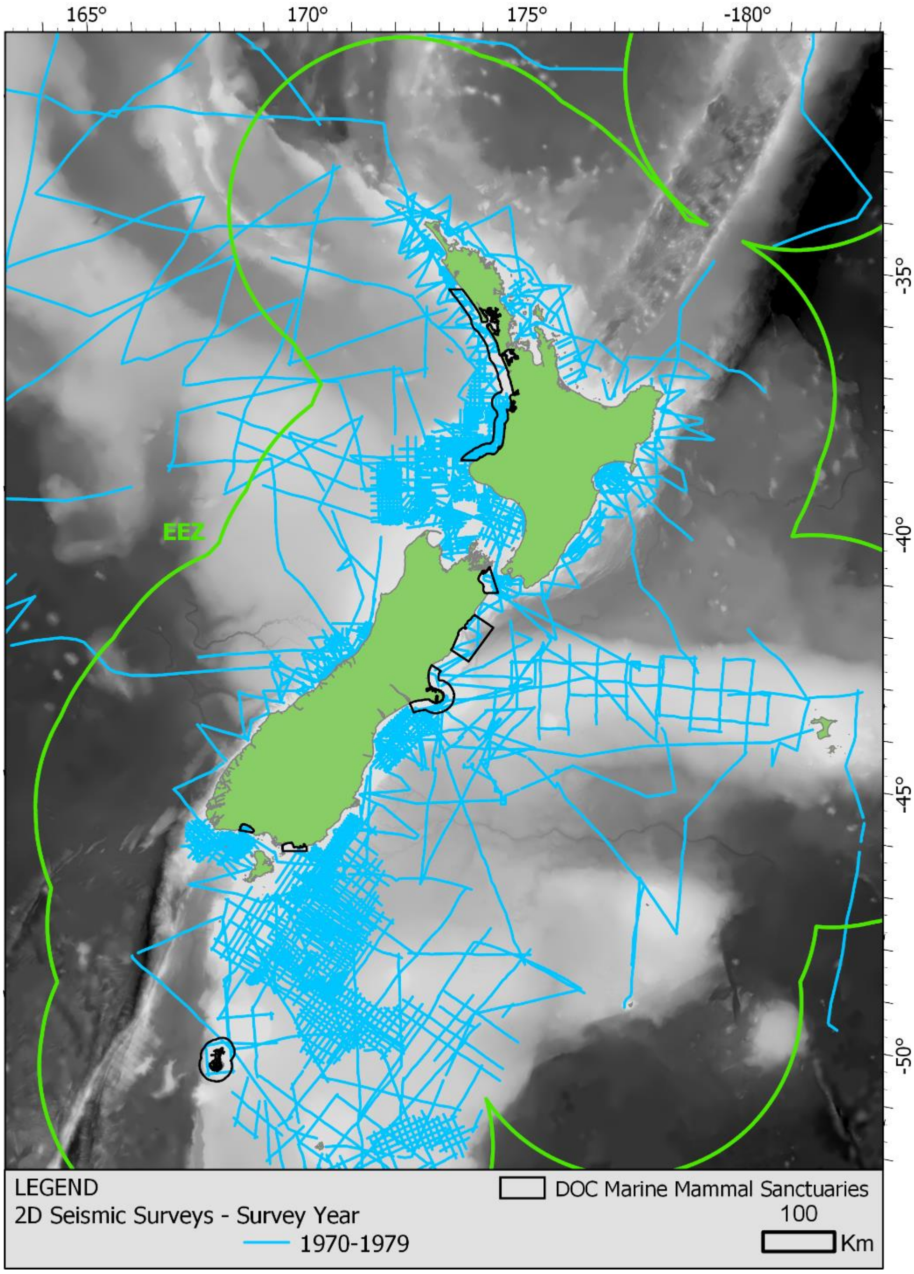

Figure B-2. Two-dimensional (2-D) seismic survey activity within New Zealand's Exclusive Economic Zone from 1970–1979. Information downloaded from New Zealand Petroleum and Minerals (NZPAM) webmaps, November 2018. The boundaries of the various Department of Conservation (DOC) marine mammal sanctuaries are outlined in black, noting that these sanctuaries have been gazetted at different time periods beginning in 1984.

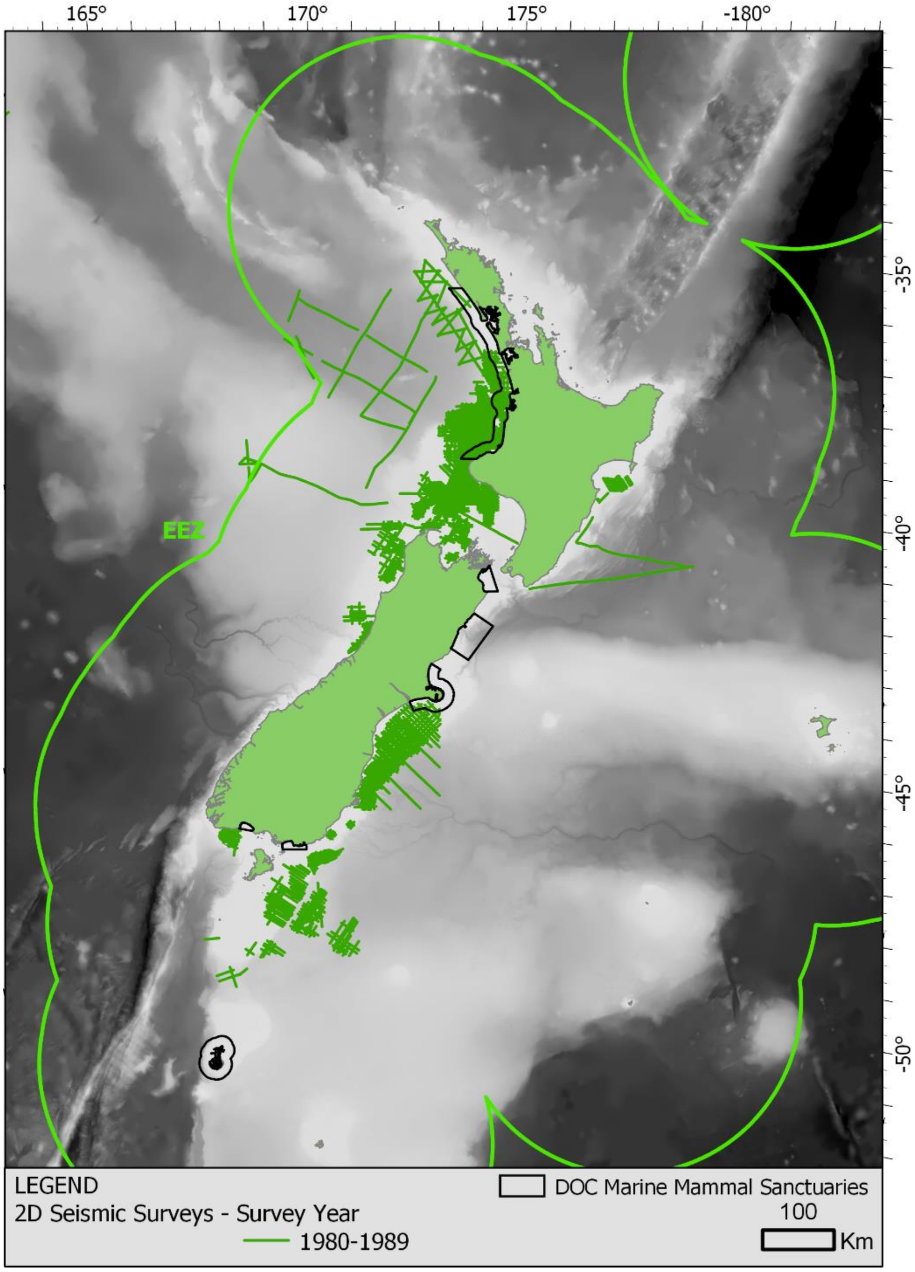

Figure B-3. Two-dimensional (2-D) seismic survey activity within New Zealand's Exclusive Economic Zone from 1980–1989. Information downloaded from New Zealand Petroleum and Minerals (NZPAM) webmaps, November 2018. The boundaries of the various Department of Conservation (DOC) marine mammal sanctuaries are outlined in black, noting that these sanctuaries have been gazetted at different time periods beginning in 1984.

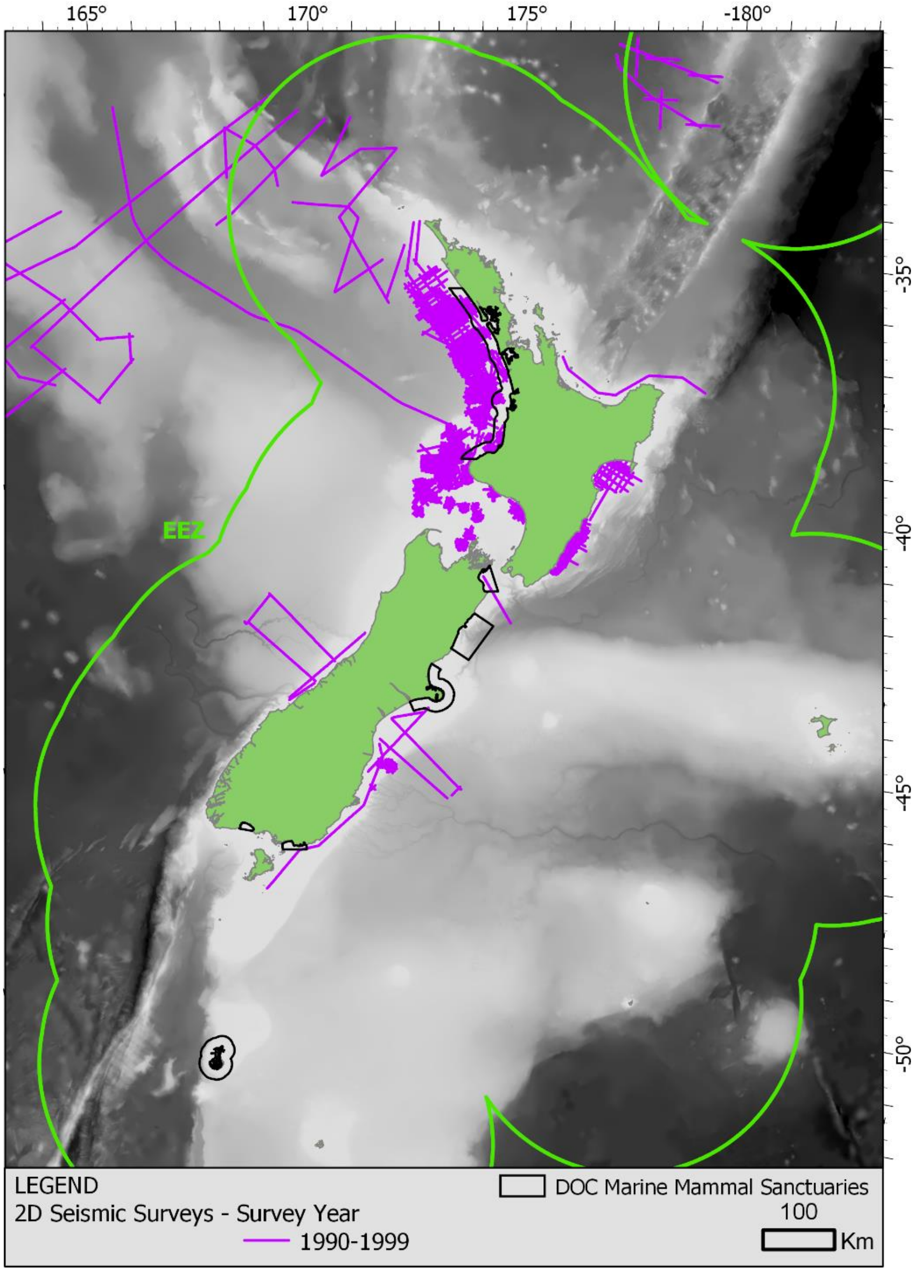

Figure B-4. Two-dimensional (2-D) seismic survey activity within New Zealand's Exclusive Economic Zone from 1990–1999. Information downloaded from New Zealand Petroleum and Minerals (NZPAM) webmaps, November 2018. The boundaries of the various Department of Conservation (DOC) marine mammal sanctuaries are outlined in black, noting that these sanctuaries have been gazetted at different time periods beginning in 1984.

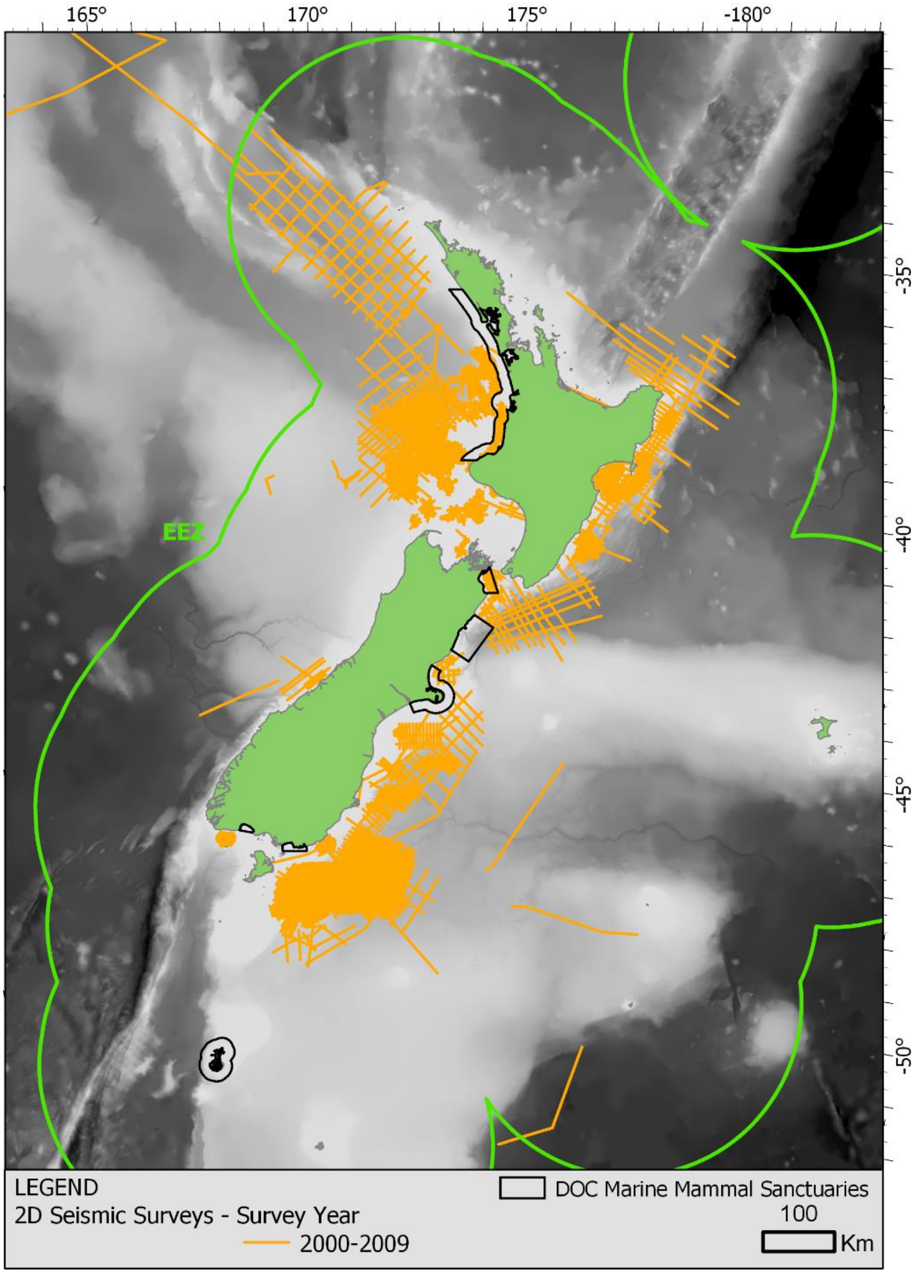

Figure B-5. Two-dimensional (2-D) seismic survey activity within New Zealand's Exclusive Economic Zone from 2000–2009. Information downloaded from New Zealand Petroleum and Minerals (NZPAM) webmaps, November 2018. The boundaries of the various Department of Conservation (DOC) marine mammal sanctuaries are outlined in black, noting that these sanctuaries have been gazetted at different time periods beginning in 1984.

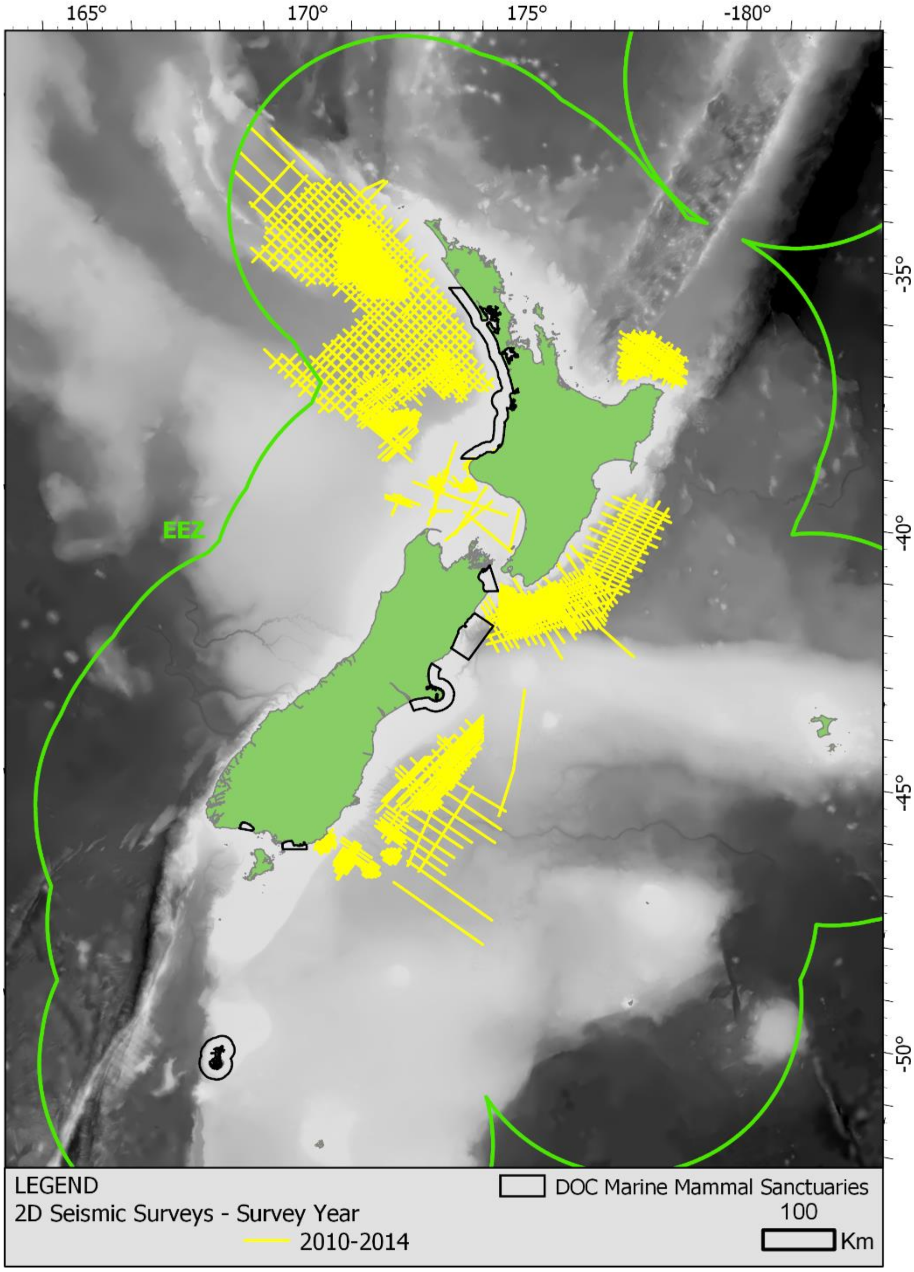

Figure B-6. Two-dimensional (2-D) seismic survey activity within New Zealand's Exclusive Economic Zone from 2010–2014. Information downloaded from New Zealand Petroleum and Minerals (NZPAM) webmaps, November 2018. The boundaries of the various Department of Conservation (DOC) marine mammal sanctuaries are outlined in black, noting that these sanctuaries have been gazetted at different time periods beginning in 1984.

B.2. Three-dimensional (3-D) Seismic Surveys

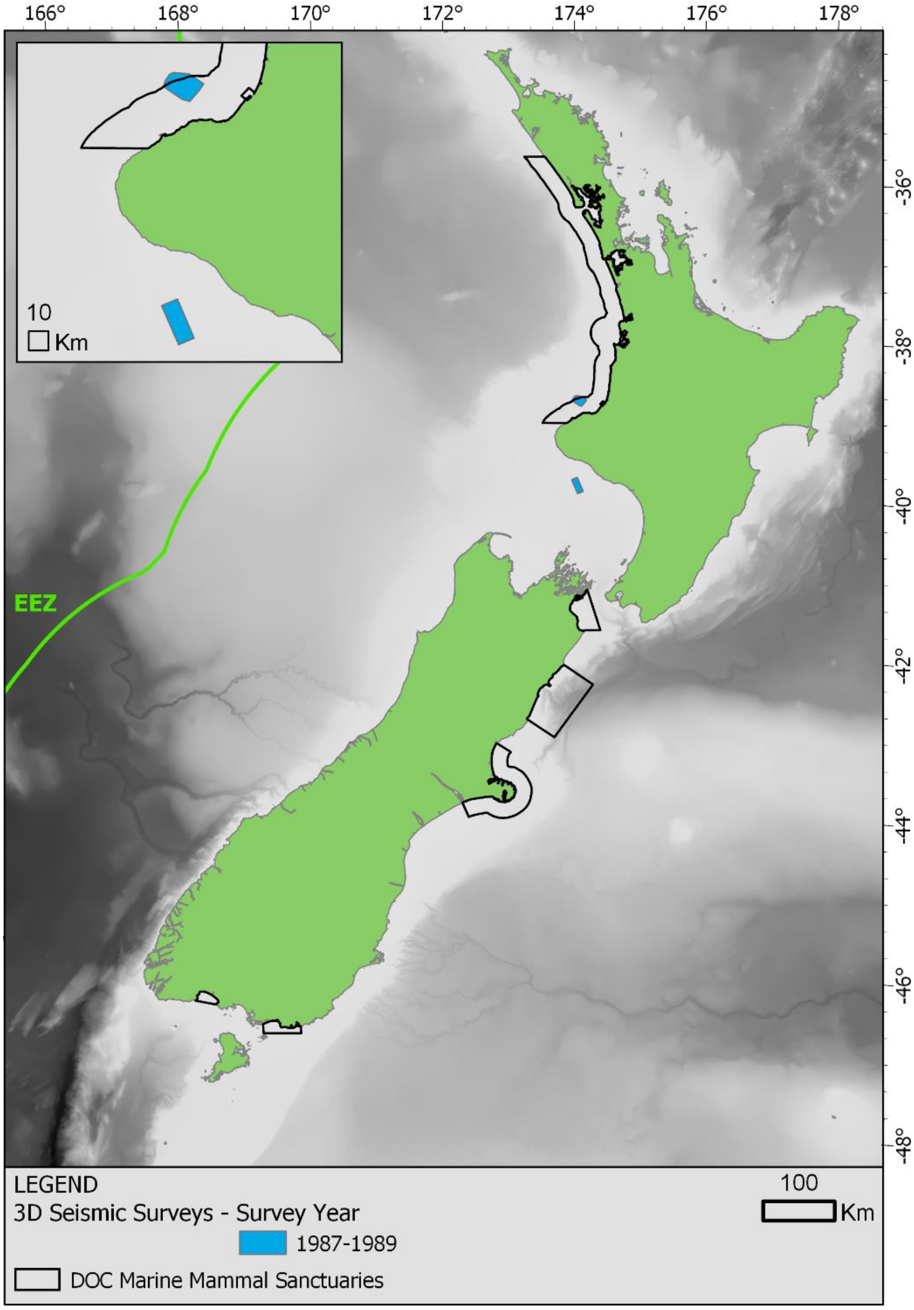

Figure B-7. Operational areas for three-dimensional (3-D) seismic survey activity within New Zealand's Exclusive Economic Zone from 1987–1989. Information downloaded from New Zealand Petroleum and Minerals (NZPAM) webmaps, November 2018. The boundaries of the various Department of Conservation (DOC) marine mammal sanctuaries are outlined in black, noting that these sanctuaries have been gazetted at different time periods beginning in 1984.

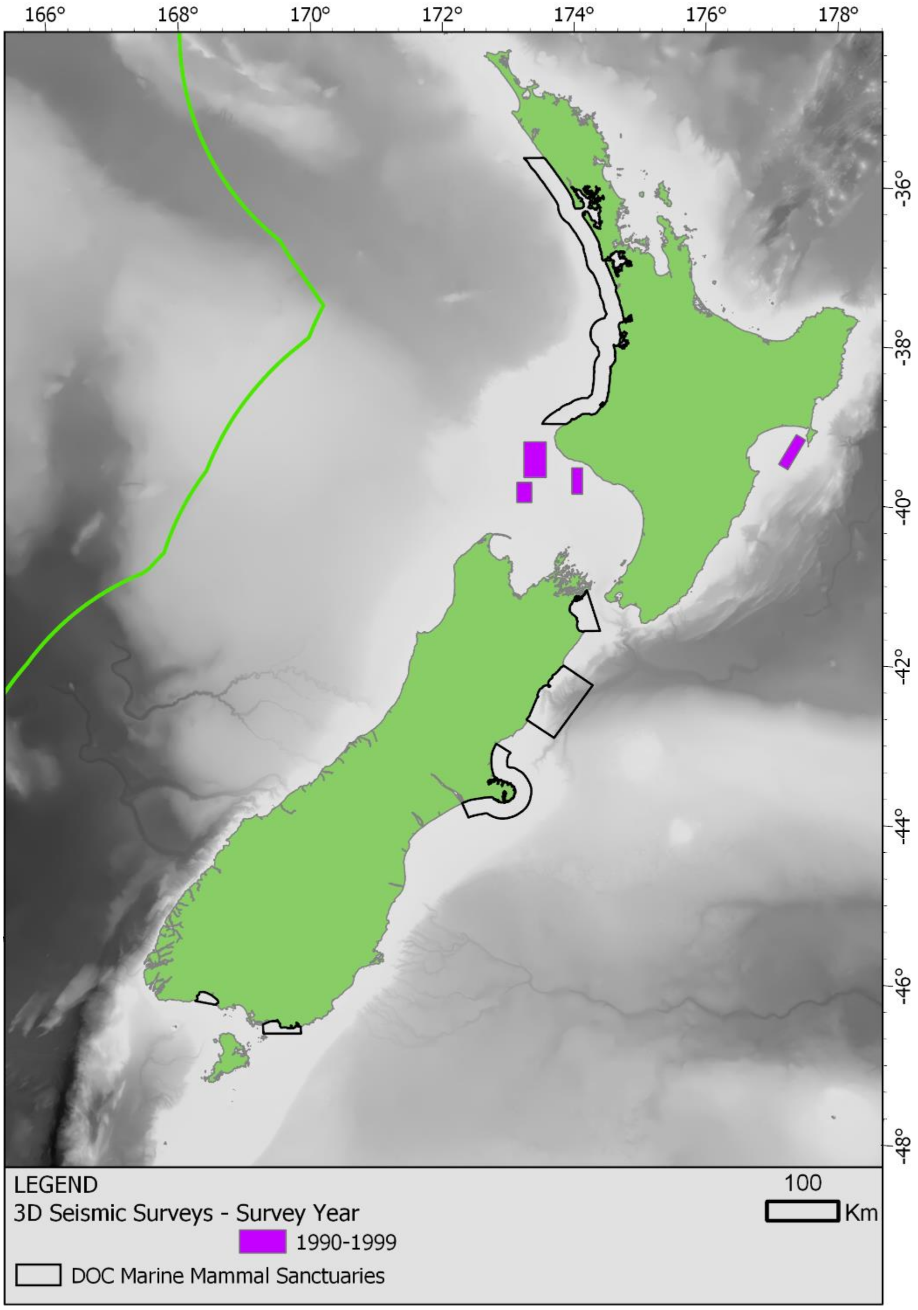

Figure B-8. Operational areas for three-dimensional (3-D) seismic survey activity within New Zealand's Exclusive Economic Zone from 1990–1999. Information downloaded from New Zealand Petroleum and Minerals (NZPAM) webmaps, November 2018. The boundaries of the various Department of Conservation (DOC) marine mammal sanctuaries are outlined in black, noting that these sanctuaries have been gazetted at different time periods beginning in 1984.

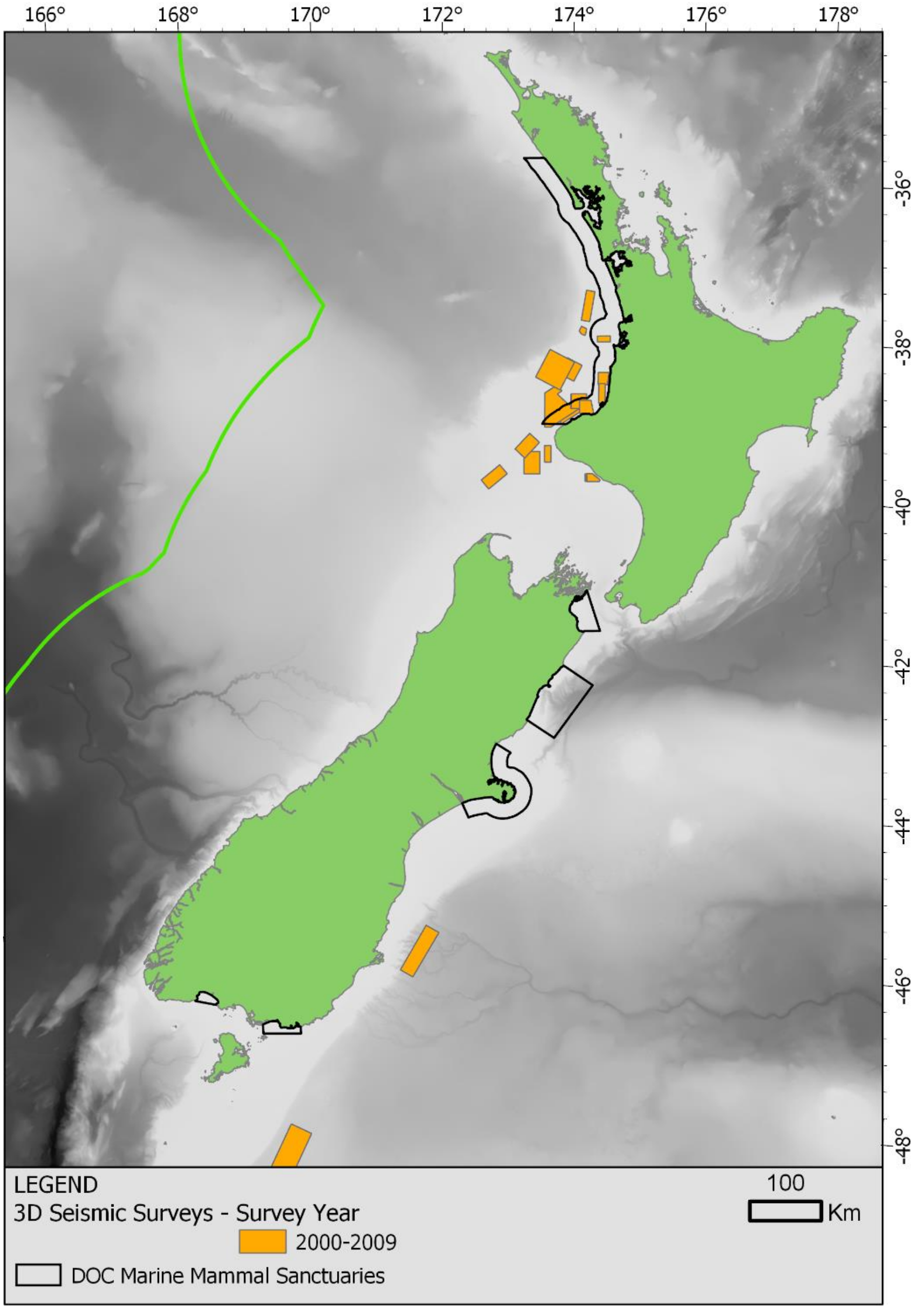

Figure B-9. Operational areas for three-dimensional (3-D) seismic survey activity within New Zealand's Exclusive Economic Zone from 2000–2009. Information downloaded from New Zealand Petroleum and Minerals (NZPAM) webmaps, November 2018. The boundaries of the various Department of Conservation (DOC) marine mammal sanctuaries are outlined in black, noting that these sanctuaries have been gazetted at different time periods beginning in 1984.

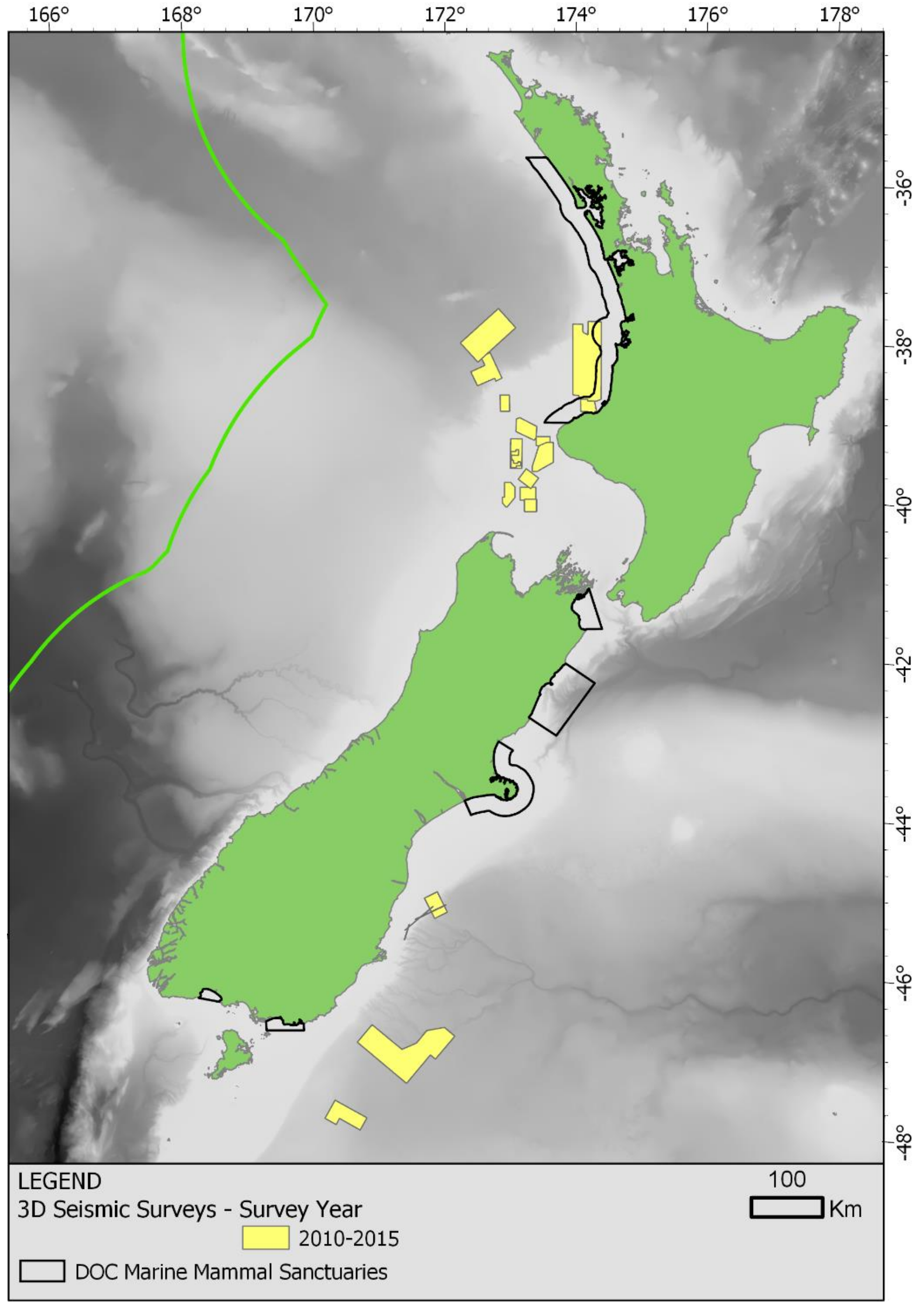

Figure B-10. Operational areas for three-dimensional (3-D) seismic survey activity within New Zealand's Exclusive Economic Zone from 2010–2015. Information downloaded from New Zealand Petroleum and Minerals (NZPAM) webmaps, November 2018. The boundaries of the various Department of Conservation (DOC) marine mammal sanctuaries are outlined in black, noting that these sanctuaries have been gazetted at different time periods beginning in 1984.

Appendix C. Underwater Acoustics

The following is an excerpt taken from a report by Ketten (2014a, 2014b) for Chatham Rock Phosphate Limited.

Physical Constants and Physiological Measures Sound Measurements in Air vs in Water

In analyzing marine mammal hearing, it is important to consider how the physical aspects of sound in air vs. water affect acoustic cues. Hearing is simply the detection of sound. "Sound" is the propagation of a mechanical disturbance through a medium. In elastic media like air and water, that disturbance takes the form of acoustic waves. Basic measures of sound are frequency, speed, wavelength, and intensity. Frequency, measured in cycles/sec or Hertz (Hz), is defined as:

$$f = c/\lambda \tag{1}$$

where c = the speed of sound (m/sec) and λ is the wavelength (m/cycle). The speed of sound is directly related to the density of the medium. Because water is denser than air, sound in water travels faster and with less attenuation than sound in air. Sound speed in moist surface air is approximately 340 m/sec. Sound speed in sea water averages 1530 m/sec but will vary with any factor affecting density. The principal physical factors affecting density in sea water are salinity, temperature, and pressure. For each 1% increase in salinity, speed increases 1.5 m/sec.; for each 1°C decrease in temperature, 4 m/sec; and for each 100 m depth, 1.8 m/sec (Ingmanson and Wallace 1973). Because these factors act synergistically, any ocean region can have a highly variable sound profile that may change both seasonally and regionally. For practical purposes, in water sound speed is 4.5 times faster and, thus at each frequency, the wavelength is 4.5 times greater, than in air.

How do these physical differences affect hearing? Mammalian ears are primarily sound intensity detectors. Intensity, like frequency, depends on sound speed and, in turn, on density. Sound intensity (I) is the acoustic power (P) impinging on a surface perpendicular to the direction of sound propagation, or power/unit area (I=P/a). In general terms, power is force times velocity (P=Fv). Pressure is force/unit area (p=F/a). Therefore, intensity can be rewritten as the product of sound pressure (p) and vibration velocity (v):

$$I = P/a = Fv/a = pv \tag{2}$$

For a traveling spherical wave, the velocity component becomes particle velocity (u), which can be defined in terms of effective sound pressure (p) the speed of sound in that medium (c), and the density of the medium (ρ):

$$u\ (x,t) = p/\rho c \tag{3}$$

We can then redefine intensity (2) for an instantaneous sound pressure for an outward traveling plane wave in terms of pressure, sound speed, and density (3):

$$I = pv = p\ (p/\rho c) = p2/\rho c \tag{4}$$

The product ρc is the characteristic impedance of the medium. Recalling that for air c=340 m/sec and for sea water c=1530 m/sec; for air, ρ=0.0013 g/cc; for sea water, ρ=1.03 g/cc, the following calculations using the intensity-pressure-impedance relation expressed in (4) show how physical properties of water vs. air influence intensity and acoustic pressure values:

$$I_{air} = p^2/(340\text{m/sec})(0.0013\text{ g/cc}) = p^2/(0.442\text{ g-m/sec-cc})$$

$$I_{water} = p^2/(1530\text{m/sec})(1.03\text{ g/cc}) = p^2/(1575\text{ g-m/sec-cc})$$

To examine the sensory implications of these equations, consider a hypothetical mammal, that hears equally well in water and in air. For this to be true, an animal with an intensity based ear would require the same acoustic power/unit area in water as in air to have an equal sound percept, or ($I_{air} = I_{water}$):

$$I_{air} = p_{air}^2/(0.442\text{ g-m/sec-cc}) = p_{water}^2/(1575.\text{g-m/sec-cc}) = I_{water}$$

$$p_{air}^2(3565.4) = p_{water}^2 \tag{5}$$

$$p_{air}(59.7) = p_{water}$$

This implies the sound pressure in water must be ~60 times that required in air to produce the same intensity and therefore the same sensation in the ear.

For technological reasons, received intensity, which is measured in watts/m^2, is difficult to determine. Consequently, we capitalize on the fact that intensity is related to the mean square pressure of the sound wave over time (4) and use an indirect measure, effective sound pressure level (SPL), to describe hearing thresholds (see Au 1993 for discussion). Sound pressure levels are conventionally expressed in decibels (dB), defined as:

$$\text{dB SPL} = 10 \log (p_m^2/p_r^2) \quad (6)$$
$$= 20 \log (p_m/p_r)$$

where p_m is the pressure measured and p_r is an arbitrary reference pressure. Currently, two standardised reference pressures are used. For air-borne sound measures, the reference is dB SPL or dB re 20 µPa, derived from human hearing. For underwater sound measures, the reference pressure is dB re 1 µPa.

Notice that decibels are a logarithmic scale based on a ratio driven by reference pressure. In the earlier hypothetical example, with identical reference pressures, the animal needed a sound level ~35.5 dB greater in water than in air (from equation 5, 10 log 3565.4) to hear equally well. However, if conventional references for measuring levels in air vs. water are used, the differences in reference pressure must be considered as well. This means to produce an equivalent sensation in water, the underwater sound pressure level in water needs to be 35.5 dB + 20 (log 20) dB greater than the airborne value. That is, a sound level of 61.5 dB re 1 µPa in water is equivalent to 0 dB re 20 µPa in air. To a truly amphibious eared mammal, they would sound the same because the intensities are equivalent. Thus, expressed underwater sound intensities are numerically ~61.5 dB greater to be comparable to intensity values in air

It is important to remember that these equations describe idealized comparison of air and water borne sound. In comparing data from different species, particularly in comparing terrestrial and marine mammal hearing data, experimental condition differences are extremely important. We have no underwater equivalent of anechoic chambers, often results are obtained from few individuals, and test conditions are highly variable.

The energy level of a sound decreases as a function of the distance between source and receiver. This loss, termed attenuation or transmission loss, is due in part to absorption and scattering of energy by the medium (e.g., water) as well as by objects in the sound path. If the water is uniform in temperature and salinity, sound from an omnidirectional or point source will spread spherically, i.e., uniformly in all directions. In reality, sound spread or transmission properties are typically more complex than simple spherical spreading. If the environment has components of different densities, which could be objects, animals, particulate aggregates, or even water masses layering, sound energy may be reflected or absorbed, . This is well demonstrated for Chatham Rise by Fig. 7 of Appendix B (McPherson et al. 2014a, McPherson et al. 2014b). Lastly, because attenuation also depends on the size relationship of the objects and wavelengths propagated, higher frequencies, which have shorter wavelengths, attenuate faster than low frequencies.

A final caveat is that multiple metrics are employed to characterize the complex sound elements that an ear may detect.

Appendix D. Vessel Classification

Vessel classification according to vessel category information embedded in the Automatic Identification System logs (taken from McPherson et al. 2018).

Table D-1. Summary of vessel classification.

Category	Length overall (m)	Vessel type
High-speed craft	0–50	Clipper; High Speed Craft; High-Speed Craft
Container	0–1000	Cargo/Containership; Container Ship
Fishing	0–1000	Factory Trawler; Fish Carrier; Fish Factory; Fishing; Fishing Vessel; Trawler
Government/ Research	0–1000	Buoy-Laying Vessel; Fishery Patrol Vessel; Fishery Research Vessel; Law Enforce; Patrol Vessel; Replenishment Vessel; Research/Survey Vessel; Fire Fighting Vessel; SAR; Law Enforcement Vessel; Law Enforcement Vessel; Research Vessel; Search and Rescue Vessel; Fisheries Protection
Bulker	0–1000	Bulk Carrier; Cargo; Cargo - Hazard A (Major); General Cargo; LPG Tanker; Rail/Vehicles Carrier; Reefer; Ro-Ro/Container Carrier; Self Discharging Bulk Carrier; Timber Carrier; Wood Chips Carrier; Heavy Lift Vessel; Cement Carrier; General Ship; Not Available or No Ship (Default); Heavy Load Carrier; Livestock Carrier; Vessel-Reserved For Future Use; Refrigerated Ship
Naval	0–1000	Naval; Naval Auxiliary; Engaged in Military Operations; Logistics Naval Vessel; Military Ops
Other	0–1000	Anti-Pollution; Cable Layer; Dive Vessel; Drill Ship; High Speed Craft; Hopper Dredger; Local Vessel; Other; Pilot Vessel; Port Tender; Reserved; Tender; Unspecified; Wing In Grnd; Anti-Pollution Vessel; Aton; Buoy; Dive Boat; Other Ship; Other Type Of Ship-All Ships Of This Type; Other Vessel; Pilot; Pilot Vessel; Service Ship; Vessel Engaged In Diving Operations; Workboat; Landing Craft; Icebreaker; Harbour Patrol; Unknown
Cruise	100–1000	Passenger; Passengers Ship; Cruise; Cruise Ship; Domestic Passenger; Passenger Ro-Ro Ship; Passenger Ship; Passenger-All Ships Of This Type; Passenger-No Additional Information; Passenger-Reserved For Future Use; High-Speed-Craft
Passenger 100 m	0–100	Passenger; Passengers Ship; Cruise; Cruise Ship; Domestic Passenger; Passenger Ro Ro Ship; Passenger Ship; Passenger-All Ships Of This Type; Passenger-No Additional Information; Passenger-Reserved For Future Use; High-Speed-Craft
Recreational	0–1000	Pleasure Craft; Yacht; Recreational; Sailing; Wig
Tanker	0–1000	Crude Oil Tanker; Tanker; Oil Products Tanker; Oil/Chemical Tanker; Bitumen Tanker; Chemical Oil Products Tanker; Chemical Tanker; LPG Tanker; Molasses Tanker; Fruit Juice Tanker; Oil and Chemical Tanker; Tankship
Tug and Support Vessels	0–1000	Anchor Handling Vessel; Dredger; Hopper Dredger; Multi-Purpose Offshore Vessel; Offshore Support Vessel; Offshore Tug Supply Ship; Offshore Vessel; Offshore Supply Ship; Pusher Tug; Towing Vessel; Tug; Pollution Control Vessel; Vessel engaged in dredging or underwater operations; Towing
Vehicle Carrier	0–1000	Vehicle Carrier; Ro-Ro Cargo
FPSO (DP)	NA	Floating production storage and offloading (FPSO) platform during dynamic positioning (DP)
Jackup platform	NA	Oil or gas production facility using jackup legs for support