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An analysis of marine anthropogenic noise in New Zealand: sources, policies, and implications for cetaceans.

A thesis presented in partial fulfilment of the requirements for the degree of Master of Philosophy in Science

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Abstract

In recent decades, anthropogenic noise has become recognised as a major pollutant worldwide and the study of its impacts has increased due to the potential for adverse consequences on wildlife. For marine environments, where sound is transmitted very efficiently through water, underwater noise has increased, mainly, at low and medium frequencies. Of all marine organisms, cetaceans may be the most affected, as they depend primarily on sound to communicate, navigate and find food. Accordingly, the general aims of this thesis are to identify the types of anthropogenic noise facing New Zealand's cetaceans, the potential impacts, review current legislation, and to propose improvements to enhance current mitigation measures of impacts.

My systematic review showed that 90% of the information about impacts of noise pollution on cetacean comes from peer-review journals and, although available from 1975, studies of marine noise pollution substantially increased after 1997. In addition, I identified the limited information on this topic in important areas such as Latin America, Africa and Southeast Asia, as well as regions in the Arctic and Southern Ocean. I also found that most effort has been focused on the impact of vessels, and bottlenose dolphin and harbour porpoise are, by far, the most studied species, showing a disparity in research coverage of both sources of noise and species. For New Zealand, there is a striking lack of knowledge of the range of sources of noise on cetaceans (excluding vessels). The information I compiled on New Zealand's cetacean distributions showed that three main groups are well represented: baleen whales, delphinids and beaked whales. Nonetheless, the information available for these species varies greatly. While there are some species very well studied, for others New Zealand species, the available information is scarce, as in the case of beaked whale.

Current mitigation measures can only be effective if comprehensive data are used to inform them. For example, planning surveys at different spatiotemporal scales are crucial to increase the effectiveness of mitigation measures. In particular, spatial modelling techniques can support mitigation measures by helping managers to identify areas of conflicts between marine mammal conservation and the development of activities such as dredging, drilling and seismic surveys. I used opportunistic sighting data collected from different platforms, and several environmental variables biologically important for cetaceans and/or their prey, to create maps of habitat suitability for seven species of cetaceans in New Zealand. These maps were created using maximun entropy modelling (MaxEnt), a model system that does not require absence data and performs well with small sample size. Models validations were done using the Receiver Operating Characteristic curve (ROC) and the Area Under the Curve (AUC) values. The models for all seven species had excellent discriminatory power (AUC > 0.9). The environmental variables depth and sediment had the most explanatory power for the distribution of these species. Comparisons of the areas of current and designated areas for exploration activities with the marine mammal distributions generated using MaxEnt show significant and wide-ranging conflicts. Of particular concern is the designated area for exploration in the northern part of the North Island, this area overlaps with the distribution of the highly endangered Maui's dolphin, and will add new pressures on this already diminished population. Expanding noise related research in this region (as elsewhere) will help stakeholders to support future decisions for planning when human activities enter into conflict with cetaceans.

Finally, the development of effective laws that adequately regulate the anthropogenic noise impacts on marine mammals has been a task that has taken many years to advance. To assess the effectiveness of New Zealand's legislation to mitigate impacts from seismic surveys and whale-watching activities, I described and compared methods prescribed by international associations. Strengths of The Code of New Zealand are that it presents a set of comprehensive guidelines with specific mention of biologically important aspects such as mother/calve pair priority. Nonetheless, improvements could be made regarding the enforcement of these guidelines. In addition, I suggest that New Zealand's whale-watching guidelines, could be improved through the inclusion and implementation of an Impact Assessment, the creation of separate guidelines to protect specific species and/or areas and, as with seismic activities, ongoing enforcement of guidelines.

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Glossary[1]

- **Attenuation:** Decrease of sound pressure levels/acoustic energy.

- **Audiogram:** Graph showing the absolute auditory threshold versus frequency

- **Auditory threshold (hearing threshold):** Minimum sound level that can be perceived by an animal in the absence of background noise.

- **Bandwidth:** Range of frequencies of a given sound.

- **Critical band:** Frequency band within which ambient/background noise has strong effects on detection of a sound at a particular frequency.

- **Critical ratio:** Is the difference in level between a tone at the threshold of aural detection and the spectrum level of masking noise at the same frequency (Cato et al., 2004)[2].

- **Decibel (dB):** Unit of sound level measured by comparing a sound pressure (P) to a reference pressure (1μPa for underwater sound reference and 20 μPa in air). Decibels are on a logarithmic scale (usually sound level (dB) = 20 log(P/Pref)) (Lusseau, 2008)[3].

- **Duty cycle:** Percent of a time a given event occurs. A 1 s long tone with silent intervals of 1 s has a duty cycle of 50%.

- **Evoked potential:** Electrical signal that is emitted in the nervous system in response to a stimulus such as a sound (Lusseau 2008)[3].

- **Masking:** Obscuring of sounds of interest by interfering sounds at similar frequencies.

[1] Glossary after Thomsen, F., Lüdemann, K., Kafemann, R., & Piper, W. (2006). Effects of offshore wind farm noise on marine mammals and fish. *Biola, Hamburg, Germany on behalf of COWRIE Ltd*, 62.

[2] Cato, D. H., McCauley, R. D., & Noad, M. (2004, November). Potential effects of noise from human activities on marine animals. In *Annual Conference of the Australian Acoustical Society* (pp. 369-374).

[3] Lusseau, D. (2008). Understanding the impacts of noise on marine mammals. In J. Higham & M. Lück (Eds.), *Marine wildlife and tourism management* (pp. 206-218). UK.

- **Octave band:** Interval between two discrete frequencies having a frequency ratio of two.

- **One-third-octave-band:** Interval of 1/3 of an octave. Three adjacent 1/3 octave bands span one octave.

- **Peak-to-peak (p-p):** Is the difference of pressure between the maximum positive pressure and the maximum negative pressure in a sound wave.

- **Permanent threshold shift (PTS):** A permanent elevation of the hearing threshold due to physical damage to the sensory hair cells of the ear.

- **Propagation loss (transmission loss):** Loss of sound power with increasing distance.

- **Pulse:** A transient sound having a finite duration.

- **Source level (SL):** Acoustic pressure at a standard reference distance of 1 m. Unit in dB re 1 μPa at 1 m (sometimes given as: @ 1m).

- **Sound pressure level (SPL):** Expression of the sound pressure in decibel (dB).

- **Temporary threshold shift (TTS):** Temporal and reversible elevation of the auditory threshold.

Chapter One

Introduction

1.1. Noise as a source of pollution

The world is full of noise affecting both humans and animals, but little is known about the role and influence of noise for biological processes at different scales (Farina, 2014). In humans, it has been demonstrated that exposure to certain sources of noise can induce hearing impairment, hypertension and ischemic heart disease, anger, sleep disturbance, and decreased academic performance (Passchier-Vermeer & Passchier, 2000). In animals, research into the effects of noise as a source of pollution is growing; currently anthropogenic noise is recognised as a major worldwide pollutant, and at times can be considered as important as chemical substances as a source of contamination and environmental damage (Francis, Ortega & Cruz 2009; Bruintjes & Radford, 2013; Morley, Jones & Radford, 2013; Farina, 2014).

Within the last century, since the industrial revolution, human activities have generated new patterns of noise that may have significant and adverse effects on acoustic communication in several taxa (Lengagne, 2008). Human generated noise is capable of moving long distances through terrestrial and marine ecosystems and affects any animal capable of hearing (Slabbekoorn et al., 2010). Noise can be defined as an unintentional or unwanted sound, possibly disagreeable or noxious (Würsig & Richardson, 2008), and can be classified as background noise (e.g. wind, storms, animal choruses, etc.) or anthropogenic noise (human-made noise). In terrestrial ecosystems, the major sources of anthropogenic noise are roads, urban development and transportation networks (Barber, Crooks & Fristrup, 2010). While in marine ecosystems, commercial shipping has become the major source of noise, as well as vessels, extraction activities and military-related activities (Popper, 2003; Firestone & Jarvis, 2007; Weilgart, 2007).

In recent years, there has been an increasing interest in understanding the impacts of noise on wildlife. Some evidence suggests that noise might cause diverse effects at different levels. At the cellular level, noise may cause DNA damage, affecting neural, developmental, immunological and physiological function (Kight & Swaddle, 2011). At ecological levels, it has been argued that noise might have negative impacts on communities through species interactions (Francis, Ortega & Cruz, 2009; Francis & Barber, 2013). In addition, noise can influence animal behaviour through the interference of sound perception; an effect called masking. Masking prevents the detection of important sounds as interspecific communication, detection of prey and predators, defence of territories or attraction of mates (Warren, Katti, Ermann & Brazel, 2006; Barber, Crooks & Fristrup, 2010; Francis & Barber, 2013) (Table 1.1).

Table 1.1. Example of impacts of noise on different taxa at different organisational levels.

Level	Species	Impact	Source of noise	Reference
Cellular	*Homo sapiens*	Vibroacoustic Disease (VAD)	Infrasound and low frequency noise (0-500 Hz)	Alves-Pereira et al., 2006
	Cyprinus carpio, Gobio gobio and *Perca fluviatilis*	Increasing cortisol secretion	Ship noise	Wysocki et al., 2006
Individual	*Siala sialis*	Reduction in productivity and brood size	Environmental noise	Kight et al., 2012
	Balaenoptera musculus	Different responses	Mid-frequency sonar	Goldbogen et al., 2013
Population	*Taeniopygia guttata*	Decreasing females' preference for pair-bonded males	Environmental noise	Swaddle & Page, 2007
Community	*Tursiops truncatus*	Increasing whistle	Watercraft	Buckstaff, 2004
Ecosystem	*Myotis myotis*	Decrease foraging efficiency	Traffic noise	Siemers & Schaub, 2011

1.2. Noise in terrestrial ecosystems

Increasing anthropogenic noise (in time, space and amplitude) represents an evolutionary novelty by increasing acoustic interference, which would be a force that could potentially influence the evolution of many species (Slabbekoorn & Ripmeester, 2008; Laiolo, 2010). Although, animals have developed different mechanisms to deal with natural background noise, the constant increase in the anthropogenic noise could represent significant challenges for animal communication systems (Lengagne, 2008).

In terrestrial urban ecosystems, the main source of anthropogenic noise is traffic. Traffic imposes serious threats to animals, which are not only exposed to a constant source of noise, but also increasing the impacts of habitat fragmentation, chemical pollution and mortality from collision (Farina, 2014). Although, sometimes it is not clear whether noise affects populations or communities of animals, some studies have shown that noise significantly alters terrestrial animal behaviours (Francis & Barber, 2013). Among all the terrestrial taxa, birds have been the most extensively studied. Some studies suggest that noise can negatively influence bird populations and communities, thus traffic noise can interfere with both the detection of heterospecific predators and the detection of other individuals from the same species, thereby interrupting species interactions (Slabbekoorn & Ripmeester, 2008; Francis et al., 2009; Barber et al., 2010).

Francis et al., (2009) demonstrated that noise can reduce nesting species richness and lead to changes in avian communities. Their evidence suggests that acoustic masking may be a major mechanism by which birds avoid breeding in noisy areas. Lengagne (2008) found that traffic noise pollution can provoke a decrease in male calling in the frog species *Hyla arborea*. Decreasing in male calling directly effects fitness of these species, inasmuch as, the reproductive success is proportional to calling effort (Lengagne, 2008). Kight, Saha, & Swaddle (2012) found that eastern bluebirds (*Sialia sialis*) experience decreased productivity when nesting in areas with elevated noise levels (Kight et al., 2012), suggesting that short-term adjustments in the acoustic signals can result in evolutionary traps as these new behaviours may be maladaptive (Francis & Barber, 2013), what can generate a long-term threat to the persistence of a population.

1.3. Noise in aquatic ecosystems

In the same way that terrestrial noise pollution has increased, anthropogenic noise pollution occurring underwater also has increased, mainly, at low and medium frequencies (Hildebrand, 2005). Unlike air, sound is transmitted very efficiently through water (Firestone & Jarvis 2007). However, when sounds propagate from water into the air, the acoustic intensity decreases 30 dB, because of the resistance of the water (Hildebrand, 2005). Sound propagation on aquatic ecosystems can vary depending on physical characteristics such as depth, temperature, salinity, and surface and bottom conditions. At higher temperatures, salinity and pressure, sounds will travel faster (Firestone & Jarvis 2007). Similar to terrestrial ecosystems, detrimental effects of noise in several aquatic animals, such as fish and marine mammals have been reported (Popper, 2003; Lusseau, 2005; Würsig & Richardson, 2008; Bruintjes & Radford, 2013). Experiments carried out with fish, have shown that noise can affect important behaviours, such as nest digging and defence against predators and social interactions (Bruintjes & Radford, 2013).

Marine mammals may be the most affected aquatic animals, since they depend mainly on sound to communicate, navigate and find food (Richardson, Greene, Jr., Malme & Thomson, 1995, 1995, Würsig & Richardson, 2008). In this group, researchers have identified a range of effects produced by anthropogenic noise (Würsig & Richardson, 2008). The impacts can vary from undetectable to severe, depending on the characteristics of the sound and the species concerned. Such effects include tolerance and habituation to certain noise, changes in behaviour, avoidance reactions, masking, hearing impairment, physiological effects and stress (Richardson et al., 1995; Hildebrand, 2005; Weilgart, 2007a, b; Würsig & Richardson, 2008).

Marine mammals can sometimes *tolerate* certain sounds, to stay in a preferred area, such as feeding grounds, even when the sounds are strong enough to cause an obvious reaction in other individuals of the same species involved in other activities (Würsig & Richardson, 2008). On the other hand, *habituation* refers to the loss of responsiveness to noise over time (Richardson et al., 1995; Hildebrand, 2005). Habituation to noisy places, as in the case of tolerance, can signify that certain areas are important for vital activities despite the noise present there (Hildebrand, 2005). Generally, animals should be exposed to a continuous or repeated stimulus not accompanied by any sign of danger to become habituated (Richardson et al., 1995).

Marine mammals have been observed *changing their behaviour* in presence of different human-made noise sources, such seismic surveys, ships and airguns (Weilgart, 2007b). The responses are diverse, and include disruption of resting, feeding and social behaviours in pinnipeds; changes in swimming speed, respiration rate, reductions in foraging efficiency and displacement from the area in cetaceans (Richardson et al., 1995; Weilgart, 2007b). For example, Florida manatees (*Trichechus manatus* *latirostris*) change their behaviour in response to both anthropogenic and background noise. Manatees with calves avoid the seagrass bed areas in the presence of high-level noise (Miksis-Olds & Wagner, 2011). Anthropogenic noise can be emitted at the same frequency and intensity as signals emitted by cetaceans, making important animal signals undetectable (Simmonds, Dolman, & Weilgart, 2004). This masking, reduces the range in which important signals can be heard and the signal's quality information (Weilgart, 2007b). Important signals include echolocation for finding prey, cues from conspecifics, groups' cohesion, navigation aid, and calls between mothers and calves (Simmonds et al., 2004).

Hearing loss in cetaceans can be induced by the exposure to high-intensity sounds. Noise can induce temporary (temporary threshold shift -TTS-) or permanent (permanent threshold shift -PTS-) consequences (Hildebrand, 2005; Weilgart, 2007a). *Hearing impairment* reduces forage efficiency, increases vulnerability to predators and affects social cohesion (Hildebrand, 2005). In mammals, it has been demonstrated that noise has indirect and direct *physiological effects*, and these effects can vary from subtle disturbances to the death of the animals (Hildebrand, 2005). Physiological effects can be divided in two categories: lethal blast injuries and sub-lethal acoustic trauma (Ketten, 1993). Lethal effects occur when animals die immediately or are seriously debilitated by an intense source of noise. Sub-lethal acoustic trauma occurs when sound levels exceed the ear's tolerance, e.g. as a result of high levels of shipping noise (Ketten, 1993).

1.4. Sound characteristics

Sound is a mechanical wave motion propagating in an elastic medium, such as air or water. When there are fluctuations in fluid pressure the sound is produced (Richardson, et al., 1995). Sound has three aspects that can be distinguished: first, there must be a source for a sound; second, the energy resulting is transferred in form of longitudinal sound waves; and third, the sound is detected by the ear or a device (e.g. microphone, hydrophone) (Giancoli, 2000). One characteristic of the sound is its speed. The speed of sound is defined as the distance travelled per unit of time by a sound wave propagating through an elastic medium (Simmonds et al., 2004). The speed of sound depends on the elasticity and density of the medium. In air at 0°C and 1 atmosphere (atm), sound travels at a speed of 331 m/s (Giancoli, 2000). Thus, in the water, it travels about 4.3 times faster; about 1,484 m/s. Sound waves are also characterised by their frequency, defined as the rate of oscillation or vibration, measured in cycles per second or hertz (Richardson, et al. 1995). Another characteristic is the wavelength that is the distance travelled by a wave in one oscillation. The amplitude is defined as the distance at which a vibrating particle is displaced from the other; it is measured in decibels (dB) (Figure 1) (Richardson, et al. 1995). When there is a change in the frequency, taking as a reference the human hearing threshold, high-frequency (ultrasonic, above 20 kHz) or low frequency (infrasonic, under 20 Hz) sounds are generated. Thus, animals such as dolphins, bats and dogs can detect ultrasonic frequencies, while whales, elephants and pigeons can detect infrasonic frequencies (Richardson, et al. 1995).

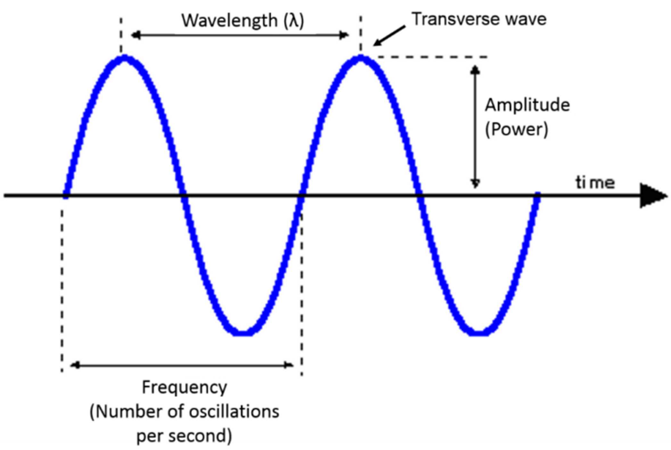

Figure 1.1. Graph of a horizontal wave showing amplitude, wavelength and frequency over time (t). Modified from http://www.ssc.education.ed.ac.uk/bsl/physics/wavelength.html.

Another characteristic is the sound intensity, which is defined as "the energy transported by a wave per unit time across a unit area perpendicular to the energy flow" (Giancoli, 2000). Sound intensity is an important characteristic to describe a specific sound; hence, it is important to measure it. Sound intensity can be measured as follows:

$$Sound\ intensity\ (dB) = 10log\left[\frac{I}{I_0}\right]$$

Where I_0 is the reference intensity, and I is the intensity of the signal. Humans translate sound intensity logarithmically, hence acousticians use a logarithmic scale to measure relative sound intensity and denote the scale in decibels (dB) (Parsons, 2013). The dB value should be followed by the notation *re*, which denotes the reference value and

$1\mu Pa$ (1 micropascal), the standard reference value for sound in water (e.g. 140 dB re:$1\mu Pa$) (Parsons, 2013). Finally, other important sound characteristics are pitch and loudness. Pitch refers to whether the sound is high- or low-frequency. Loudness is related to the intensity in the sound wave, defined as the energy transported by a wave per unit time crossing unit area (Giancoli, 2000).

1.5. Sound production in cetaceans

Cetaceans are able to produce both high frequency and low frequency sounds (Wartzok & Ketten 1992), but the mechanisms underlying the production of these sounds are poorly understood, particularly in baleen whales. Some of the mechanisms explaining the sound in cetaceans are described below.

1.5.1. Baleen whales

Studies on the anatomy of baleen whale sound production are limited. Reidenberg and Laitman (2007) studied the internal anatomy of the larynx in 34 baleen whales specimens. The researchers found that baleen whales have a U-fold structure homologous to the vocal folds in other mammals. They argue that despite some differences in positioning of the structure with respect to other mammals, the U-fold structure might have similar function in airflow regulation and pneumatic sound generation. Researchers concluded that baleen whales rely on their larynx to produce sounds, and that the mechanisms of sound production in baleen whales are as follows: the generation of the fundamental frequencies is made through U-fold vibration, sound quality is modified by larynx muscles contractions and, finally, the vibration of the laryngeal sac wall produces a sound transduction which passes to the ventral throat pleat by pulsation reaching the water (Reidenberg & Laitman, 2007) (Figure 1.3).

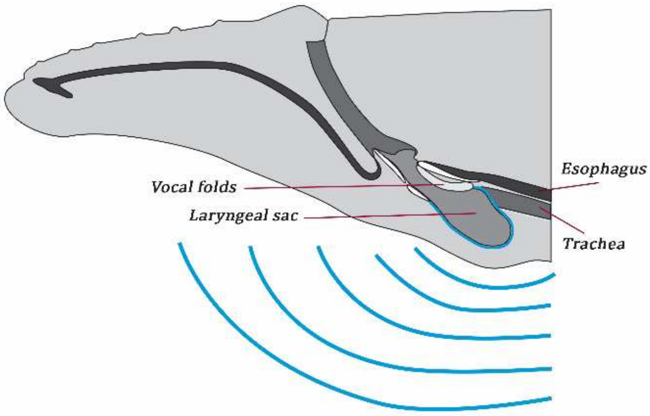

Figure 1.2. Diagram of the sound production structures in baleen whales. Modified from Reidenberg & Laitman, 2007.

1.5.2. Toothed-whales

Unlike baleen whales, toothed-whales produce sounds through nasal air sacs located below of the blowhole (Berta et al., 2006; Frankel, 2009). This structure is responsible, at least, for the production of whistle and echolocation clicks (Berta et al., 2006). This sound system comprises a structure called the monkey lips/dorsal bursae (MLDB) complex that is formed by two lipid filled sacs known as bursae, one anterior and the other posterior, in which the phonic lips (or “monkey lips”) are inserted. In addition, the bursal cartilage and the blowhole ligament form part of this system. All components are suspended by muscles and air spaces (Cranford et al., 1996; Berta et al., 2006). The sound is produced when the air passes through the phonic lips, which produce a vibration of the MLDB complex. The opening and closing of the phonic lips determine the click repetition rate (Cranford et al., 1996), and the air used in this process either can return to the nasal passage or be released into the water (Frankel, 2009). The vibration produced by the MLDB complex is focussed and directed into the water with the help of the melon, a fatty structure at the anterior of the skull (Berta et al., 2006; Frankel, 2009) (Figure 1.4).

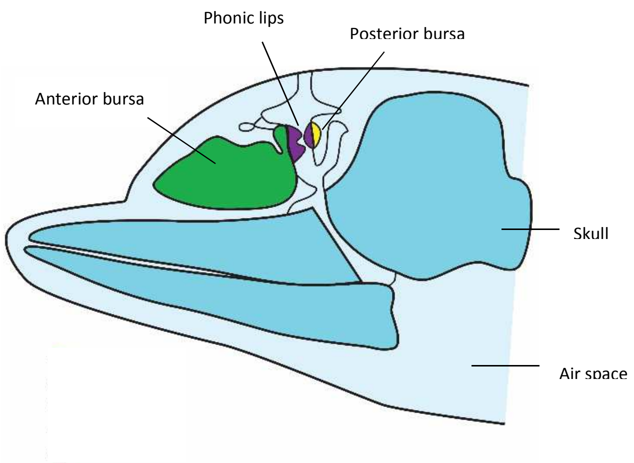

Figure 1.3. Diagram of the MLDB complex and sound production structures in dolphins. Modified from Cranford, 1999.

1.6. Type of sounds in cetaceans

Baleen whales are capable of producing different types of sounds classified as moans, simple and complex calls and complex ‘songs’ (Wartzok & Ketten 1992). It has been suggested that these vocalisations are used mainly for communication, mate attraction, aggression, distress and feeding (Reidenberg & Laitman, 2007). Moans are sounds low in frequency, generally below 200 Hz and between 0.4 and 40 s in duration. Simple calls are narrow band sounds with a peak frequency below1 kHz. In contrast, complex calls are characterised by broadband pulsating amplitude and/or frequency modulation and finally, baleen whales are able to produce complex “songs” which are series of sounds that are repeated continuously (Wartzok & Ketten, 1992; Darling, 2009).

In comparison, toothed-whales are able to produce three types of sounds: clicks, whistles and pulsed sounds. It has been suggested that clicks are used mainly for echolocation, while pulsed sounds and whistles are used for communication (Cranford 2000; Frankel, 2009). Pulsed sounds and whistles are produced in the nasal region (Cranford, 2000), while clicks are broadband sounds with frequencies between 10 and 200 kHz (Wartzok & Ketten 1992). A click’s structure can vary in duration, waveform type and frequency between different groups of odontocetes (Frankel, 2009).

Whistles are a type of vocalisation with a narrow band frequency modulated sound with a harmonic structure. The frequencies of these vocalisations are between 4 and 16 kHz, and their duration is less than 1 s (Wartzok & Ketten 1992; Berta et al., 2006). Almost all odontocetes can produce this type of sound, except for dolphins in the genus *Cephalorhynchus*, *Kogia*, *Neophocoena*, *Phocoena*, *Phocoenoides* and *Physter (*Au and Hastings 2009; Frankel, 2009). Within this category, signature whistles, i.e. whistles with individualised contours have been described (Frankel, 2009). This type of whistles can provide individual recognition of a specific dolphin, and it has been suggested that they help to maintain group cohesion (Frankel, 2009). Finally, pulsed sounds are sounds with short duration and constant frequency, which occur quickly and consecutively (Wartzok & Ketten 1992; Frankel, 2009). Within this category are broadband pulses known as burst-pulses, most of their energy is in the low frequencies and they are likely used for communication between group members (Frankel, 2009).

1.7. Thesis outline

In recent decades, the study of the impact of marine noise pollution has become a significant area of research due to the increasing magnitude of the issue and its adverse consequences for cetaceans and other marine animals. Among the sources of anthropogenic noise affecting marine environments, noise from vessels and seismic surveys are those of greatest interest to New Zealand. For vessels, whale-watching activities pose a big threat for marine mammals, and taking into account that ecotourism is a significant industry in the country, assessing the potential effects of vessel noise is crucial. Likewise, seismic activities have augmented due to the increasing interest of New Zealand in the extraction of mineral resources. The fact that both industries are very important in the national panorama necessitates the evaluation of existing mitigation measures and the proposal of new tools to support them. This information is needed to propose more efficient measures of protection for cetaceans in New Zealand since many of these species are under high threat, for example Maui's and Hector's dolphins.

1.8. Thesis structure and aims

This thesis is composed of seven chapters, including an introductory and a concluding chapter. A description of each chapter and objectives are shown below:

Chapter one: this introductory chapter presents an overview of sound and its effects on wildlife in both terrestrial and aquatic environments. In addition, it presents and defines terminology used in studies that involve sound.

Chapter two: this chapter presents the sources of natural and anthropogenic noise that are potentially detrimental for marine fauna. The aim of this chapter is to contextualise and characterise the sources of noise that can be found in aquatic ecosystems.

Chapter three: this chapter presents a systematic review of current knowledge of the impacts of noise pollution on cetaceans worldwide. The aim of this chapter is to identify current gaps in the knowledge about this topic.

Chapter four: this chapter is a compilation of the available information about the distribution of cetaceans around the world and in New Zealand. The aim of this chapter is to summarise the distribution of marine mammals and use this information to understand areas of human wildlife conflict (chapter five).

Chapter five: this chapter proposes the use of species distribution models, MaxEnt in this case, for planning activities that produce high levels of noise, such extraction activities. Taking seven species as models for this analysis, the aims of this chapter were to generate models of potential distribution of selected threatened marine mammals in New Zealand. In addition, based on the maps obtained, use them as a tool for planning and decision making of activities undertaken offshore, such as drilling, dredging and seismic surveys, to minimise the impact of anthropogenic noise on marine mammals.

Chapter six: this chapter presents different guidelines and legislations from different regions around the world for comparison with New Zealand’s legislation with the aim of finding areas where legislation could be improved.

Chapter seven: this chapter summarises the main findings in the previous chapters from a management and conservation perspective.

Chapter two

Sources of noise in the ocean

2.1. Introduction

In the oceans, there are multiple sources of noise differing from each other by characteristics such as frequency, amplitude, duration, rise time, duty cycle and repetition rate (Weilgart, 2007). Noise in the ocean is the result of both ambient and anthropogenic sources. Ambient noise (background noise) in the ocean can come from many sources; including natural and man-made noise (distant shipping). Natural sources of noise can include those from physical and natural processes such as earthquakes, tectonic plates, wind and waves and vocalisations of different marine species (Hildebrand, 2009).

Natural sources of noise include both physical and biological processes, while anthropogenic sources may include aircraft, boats and ships, explosions, oil and gas drilling, seismic exploration, sonar, acoustic deterrents, harassment devices and marine wind farms. Anthropogenic noise sources have increased dramatically in recent decades as a major background noise in the ocean, essentially, in many coastal areas near urban centres. Many of these sources are also concentrated in busy routes at sea, and include areas such as continental shelves and coastal waters areas of biological importance and habitat for many marine species (Hildebrand, 2009).

This chapter presents the sources of natural and anthropogenic noise that have been studied as potentially detrimental for marine fauna. The aim of this chapter is to contextualise and characterise the sources of noise that can be found in aquatic ecosystems.

2.2. Biological sources of noise in the ocean

In the oceans, marine mammals can be the main contributors to biological background noise, as well as other species such as fish and shrimp (Richardson et al., 1995). These noises can be produced in a range between ~ 12 Hz to over 100,000 Hz, and also can be almost absent or dominant over certain frequency ranges. When biological noise is dominant in a particular frequency band, it can interfere with detection of other sounds at those frequencies (Richardson et al., 1995). In the case of marine mammals, these can contribute to the ambient noise by 20-25 dB at specific locations and specific periods of the year. For example, colonies of snapping shrimp can produce sounds that range from few kilohertz to above 100 kHz (National Research Council, 2003).

Marine mammals produce vocalisations covering a wide range of frequencies, from <10 Hz to >200 kHz (National Research Council, 2003) (Table 2.1). For example, blue whales (*Balaenoptera musculus*) and fin whales (*B. physalus*) produce low-frequency moans, between 16 and 25 Hz, with a source level around 155 – 188 dB re 1 μPa at 1 m (Cumming and Thompson, 1971; Au, 2000; Kuperman, 2013). On the other hand, fish can produce pulsed signals below 1 kHz. Although, the overall contribution of fish to the total noise has not been quantified, it has been suggested that the major contribution comes from animals that form choruses. These choruses can increase the ambient noise level by 20 dB or more in the 50-Hz to 5-kHz band over sustained periods of time (National Research Council, 2003).

Table 2.1. Source levels and frequency for some sounds generated by marine species.

Source		Source level (underwater dB at 1 m)	Frequency	Reference
Sperm whale clicks (*Physeter macrocephalus*)		Up to 223-236	12-15 kHz	Goold & Jones, 1995 Mohl, et al., 2000; 2003
Bottlenose dolphin whistles (*Tursiops truncatus*)		125-173	4-20 kHz	Janik, 2000; Jensen, et al., 2012; Leatherwood & Reeves, 2012; Kuperman, 2013
Fin whale (*Balaenoptera physalus*)	Moans	155 – 186	Dominant 20 Hz	Au, 2000; Kuperman, 2013.
	Calls	189±4	15-28 Hz	Širović, et al., 2007
Blue whale (*Balaenoptera musculus*)	Moans	188	Dominant 16-25 Hz	Cummings & Thompson, 1971 Au, 2000
	Calls	189±3	25-29 Hz	Širović, et al., 2007
Gray whale (*Eschrichtius*	Moans	126-152	20-300 Hz	Cummings & Thompson, 1971 Au, 2000
	Blow sounds	-	15-175 Hz	

robustus)	bubble-type signals	112	15-305 Hz	
	Knock sounds	116	350 Hz	
	Songs	144-189	Up to 24 kHz	
Humpback whale (*Megaptera novaeangliae*)	Fluke and Flipper Slap	183-192	0.03-8 kHz	Au, et al., 2001 Au, et al., 2006 Samaran, et al., 2012
Snapping Shrimp (Family Alpheidae)		183-189 (peak-to-peak)	-	Samaran, et al., 2012

2.3. Anthropogenic sound

Noise can be introduced directly on the ocean or can be a sub-product of other activities, such as shipping (Hildebrand, 2005). Different sources of noise can contribute in different bands. For example, ship propellers, explosives and seismic sources are the main contributors in the lowest bands between 1-10 Hz. In mid-bands, between 10-100 Hz, the main contributors are shipping, explosives, seismic surveying sources, construction and industrial activities, and naval surveillance sonar. Finally, at higher bands (1-10 kHz), the main contributors are nearby ships, seismic air-guns, underwater communication, naval tactical sonars and depth sounders (National Research Council, 2003).

2.3.1. Vessels/boats and ships

The noise produced by vessels has become globally important because it is considered a major pollutant and a threat to aquatic animals (Abrahamsen, 2012). Noise from vessels contribute to the ambient noise (background noise) of the marine environment primarily at frequencies below 100 Hz, and it has been estimated that over the last five decades this noise has increased 15 dB in the deep ocean (Pine, 2014). The contribution of vessels to ambient noise is not equally distributed around the globe, being higher in the shipping lanes and the northern hemisphere (Hatch et al., 2008). In general, the noise contribution by vessels may vary depending on certain characteristics of the vessels such as size, speed and mode of operation. Noise levels are higher in large vessels, and this increase as their speed increase (Richardson, et al., 1995). These low frequencies overlap with the frequencies used by baleen whales for different vital activities such as communication (Simmonds et al., 2004).

Vessels can be divided into two major groups, recreational and commercial vessels.

- Commercial vessels are primarily used for either carrying cargo or passengers. They can be found in a variety of sizes from 6 m to 415 m. In this category are placed the tankers, supertankers, containers, bulk carriers, ferries and cruise ships[4]. Some examples of the impacts of these types of vessels are shown in Table 2.2.

Table 2.2. Example of studies addressing the responses of cetaceans to commercial vessels.

Type of commercial vessel	Species	Impact	Reference
Large vessels (ultrasonic components)	Cuvier's beaked whale	change in the foraging and diving behaviour	Aguilar-Soto et al., 2006
Ship (low-frequency noise)	Right whale	Stress	Rolland et al., 2012
Maritime traffic	Bottlenose dolphin	call rates decreased	Luís et al., 2014
Ferry	Beluga whale	Reduction in calling rate; increase call repetition, etc.	Lesage et al., 1999
Commercial ships	North Pacific blue whale	Changes in calls	McKenna, 2012

- Recreational vessels are those used for leisure, such as fishing, navigation, small watercraft or whale-watching boats. Small boat's engine generates noise around 1-5 kHz (mid-frequency) at moderate source levels (150 to 180 dB re 1 μPa at 1 m) (Erbe, 2002). These high frequencies have the potential to perturb small cetaceans (Simmonds et al., 2004). Table 2.3 shows some examples of the impact of recreational vessels on cetaceans.

[4] http://www.ics-shipping.org/shipping-facts/shipping-and-world-trade/different-types-of-ship-in-the-world-merchant-fleet

Table 2.3. Example of studies addressing the responses of cetaceans to touristic vessels.

Type of recreational vessel	Species	Impact	Reference
Boats	Bottlenose dolphins	Seasonal displacement	Rako et al., 2013
Boat traffic	Orca	Longer call duration	Foote et al., 2004
Whale-watching boats	Indo-Pacific bottlenose dolphins	Altered dolphins' behavioural states and activity budgets	Steckenreute et al., 2012
Whale-watching boats	Sperm whale	Change in swimming patterns	Ritcher et al., 2006
Vessel generated noise	Blainville's beaked whales	Change in foraging patterns	Pirotta et al., 2012

2.3.2. Seismic exploration

Seismic surveys consist in the generation of regular pulses of sounds through devices (general airguns) attached to a vessel. These airguns release a volume of air at high pressure (about 2000 psi), which expands violently, contracts and re-expand again, creating a sound wave (Richardson et al., 1995; McCauley et al., 2000). This sound wave travels to the seabed and is reflected back. The sound is picked up by hydrophone arrays allowing form a profile of the rock strata of the seafloor (McCauley et al., 2000). Seismic surveys are important contributors to low-frequency sound in the oceans, and one of the most intense noises, producing short duration sounds (Richardson et al., 1995). The noise varies depending on the different characteristics of the devices such as design, capacity, air pressure, etc., but in general, they can reach broadband impulses with source levels between 216 and 232 dB re 1 μPa at 1 m (Richardson et al., 1995). On the other hand, for arrays of air guns the sources level can reach 230 - 255 dB re 1 μPa at 1 m (Richardson et al., 1995, Hildebrand, 2005; Marine Mammals Commission, 2007; Nowacek et al., 2007).

There are two types of marine seismic surveys, either two-dimensional (2D) or three-dimensional (3D). 2D surveys are made using a single hydrophone array, and produce two-dimensional cross sections of the strata. While 3D surveys use several hydrophones and airgun arrays, creating 3D images of the strata (Marine Mammals Commission, 2007). Three-dimensional seismic surveys are used in several fields, such as oil, gas and mining industries, by academic and government groups, environmental consulting, among others (National Research Council, 2003). McCauley et al. (2000) studied the responses of Australian marine animals to air gun signals. They found that migrating humpback whales showed some degree of avoidance to 3D seismic survey vessels passing at distances around 4 km. They also found that pods of humpback whales containing cows showed an avoidance response to these vessels at distances as far as 7-12 km. Authors established sighting rates of whales within 3 km when air guns were not being used, suggesting there is a localised avoidance of the operating vessels (McCauley et al., 2000).

Blackwell et al. (2013) studied the effects of airguns sounds on the calling rates of migrating bowhead whale (*Balaena mysticetus*) in the Alaskan Beaufort Sea. They compared Call Localization Rates (CLRs) between two sites designated *near* and *far*, in three different seismic activity periods, *before, during* and *after*. Researchers found that at sites close to the airguns, at median received levels between 116–129 dB re 1 μPa (10–450 Hz), whales' calls rate diminished. On the other hand, at distant places, at median received levels between 99–108 dB re 1 μPa, the vocalisation did not change. The researchers argue that this change in the vocalisation rate could be due to a cessation of callings when they are close to the airguns in operation (Blackwell et al., 2013). The call localization rates dropped from 10.2 calls/h before the beginning of the operation of the airguns, to 1.5 call/h during and after airgun use.

Di Iorio & Clark (2010) investigated changes in the vocal behaviour of blue whales (*Balaenoptera musculus*) during a seismic survey using a 'sparker' in the St. Lawrence Estuary, Alaska. They found that the whales increased their calls in days when the seismic survey was operating compared to days where there was not operation. According to the authors, these findings suggest that the animals increased their calls in order to make sure that their signal was successfully received by other individuals (Di Iorio & Clark, 2010).

2.3.4. SONAR (Sound Navigation And Ranging)

SONAR can be divided into low-frequency (<1 kHz), mid-frequency (between 1 and 10 kHz), and high-frequency (>10 kHz) (National Research Council, 2003). There are several types of sonar such as commercial, military, mapping, research and hydroacoustic sonars. Commercial sonar is used mainly for detection, localization and classification of different objects. This type of sonar produce sounds at low source levels, but the contribution of these sonars to underwater noise can be quite large because of the large number of vessels, both civilian and commercial, that are equipped with those systems (Hildebrand, 2009). Mapping sonars are used to obtain information about seafloor bathymetry. The sonar used for this purpose are mid-frequency (12 kHz) for deep-water systems and high-frequency (70 to 100 kHz) for shallow water systems. Hydroacoustic sonars are employed to detect organisms in the water column, using mid- and high frequencies between 20 and 1000 kHz (Hildebrand, 2009).

Military sonars can produce source levels about 210 dB re 1 μPa at 1 m, and they range from low frequency (1000 Hz), mid-frequency (1–10 kHz) to high frequency (10 kHz) (Nowacek et al., 2007). There are two types: passive and active sonars. Passive sonars are used to listen and receive sounds. On the other hand, active sonar is used to detect objects and use echoes of produced sounds, which might be noticed by marine mammals (Nowacek et al., 2007). Miller et al. (2000) performed experiments using playbacks of low-frequency active sonar (LFA) in humpback whales (*Megaptera novaeangliae*). Researchers recorded the sing of focal humpback whales after, during and before exposure to LFA. They recorded at least two complete songs before transmitting ten 42-s LFA signals at 6 minutes intervals. They found that the singing behaviour of male humpback whales was 29% longer when they are exposed to LFA. According to researchers this change in the vocal behaviour of male humpback whales was temporal and a mean to compensate the interference of the LFA (Miller et al., 2000).

In another experiment, Kuningas et al. (2013) performed a study within a fjord basin in northern Norway to assess the potential displacement of orca in relation to naval activities and prey abundance. The researchers used anti-submarine warfare ships that operate in the 6–8 kHz band at source levels ranging from 215 to 227 dB re 1 μPa at 1 m, in addition to controlled sonar exposure experiments (CEEs) (Kuningas et al., 2013). The researchers found that numbers of orcas dropped next days of the exercises. According to the authors, these results suggest that the naval exercises triggered the orcas to leave the area, although the main factor affecting the presence of orcas in the fjord area is the presence of their main prey. However, low abundance prey in conjunction with sonar activity in the fjords could displace the remaining orcas (Kuningas et al., 2013).

2.3.5. Acoustic Deterrents Devices (ADDs) and Acoustic Harassment Devices (AHDs)

Acoustic Deterrents Devices (ADDs) or "*pingers*" and Acoustic Harassment Devices (AHDs) are mechanisms that emit regular or randomised sounds at different frequencies, producing underwater sounds in order to minimise predation of fishing farms and to intent to reduce cetacean by-catch (Richardson et al., 1995). The objective of the ADD is to alert the animals of the presence of fishing gear and, generally, is deployed on moveable or transient gear such as gillnets and set nets. Those devices use source levels between 130 and 150 dB re 1 μPa at 1 m. On the other hand, the AHDs aim to cause pain in animals exposed to these devices, and produce source levels between 185 and 195 dB re 1 μPa at 1 m. Generally, they are deployed permanently on structures such as fish pens and dams. Both devices, pingers and AHDs, use frequencies in the 5 to 160 kHz band, and generate pulses lasting from 2 to 2,000 msec (Simmonds et al., 2006; Nowacek et al., 2007). While it is true that ADDs and AHDs cause disturbance in cetaceans producing exclusion of areas (Hardy et al., 2012), from a conservation point of view, these devices can help to reduce by-catch of certain species (e.g. harbour porpoise), which may ultimately result in more benefits for a species than harm (Ministerio de Agricultura, Alimentación y Medio Ambiente, 2012).

Hardy et al. (2012) performed a study in Cornwall Coast (UK) to evaluate the response of harbour porpoise to pingers. They used four vessels that deployed nets with and without pingers. The pingers used had frequencies between 20-140 kHz (frequencies within the range audible to porpoises), and a duration of 0.4 seconds. Through passive acoustic monitoring (C-PODs), researches compiled the sounds produced by the harbour porpoises. During the study, only one porpoise was captured in one of the nets without pingers. Researchers found that the rate of recorded harbour porpoises' clicks at nets with pingers was between 35–51% of the rate at control net. There was evidence that the porpoises were excluded from the area for a period longer than 7 hours, there was no evidence of attenuation, and they consider that attenuation is not a big issue for this population.

Carretta, Barlow and Enriquez (2008) assessed pinger efficacy in beaked whales. Using 17 years of data, they found that at the beginning of the monitoring 33 beaked whales were captured in gill net in the California Current (USA). After six years of implementation of pingers on nets, there have been no entanglements reported for this group of cetaceans. However, 260 cetaceans belonging to other families were captured accidentally in the same period. The authors argued that this is possible due to beaked whales are more sensitive at the types of frequencies used by these pingers than other species.

Chapter three

Impacts of anthropogenic noise on cetaceans: a systematic review

3.1. Introduction

In recent decades, the study of the impact of noise pollution on marine mammals has been one of the major areas of interest for researchers due to the large amount of evidence showing that different sources of underwater noise can produce behavioural and/or physiological effects on marine animals (e.g. Rendell and Gordon, 1999; Scheifele et al., 2005; Gray & Van Waerebeek, 2011; Rolland et al., 2012; Cerchio et al., 2014). These disturbance effects can be minor, negative or positive effects. They can 1) Mask sounds with biological importance for the receiver, 2) Cause hearing damage through long exposures to a particular source of noise or during short exposures at higher frequencies, and 3) Cause tissue damage (Cato, et al., 2004). Behavioural responses to noise disturbances are highly variable between species and even between populations, but in general, responses depend on the context of the disturbance (Southall et al., 2007). The impacts of those behavioural perturbations on a population or on an individual will depend on how long they persist (Southall et al., 2007).

Behavioural effects of noise include avoidance of the ensonified area (Goold, 1996; Culik et al. 2001; Weir, 2008; Antunes et al. 2014); changes in the vocal behaviour such as, modification in song parameters, shorter songs, increment in whistles frequencies or decrease in echolocation clicks, etc. (Van Parijs & Corkeron, 2001; Sousa-Lima et al. 2002; Buckstaff, 2004; Foote et al. 2004; Carlström, Berggren & Tregenzab, 2009; Castellote et al. 2014); temporal displacement (Johnston, 2002; Morton & Symonds, 2002, Breandt et al 2011; Tyack et al. 2011; Rako et al. 2013); changes in activity budgets (Arcangeli et al. 2008; Christiansen et al. 2010; Lundquist, Gemmell & Würsig, 2010; Goldobogen et al. 2013); changes in abundance (Bedjer et al. 2006; Scheidat et al. 2011); changes in group formation (Bedjer et al. 1999); changes in respiratory frequency (Hastie et al. 2003; Ritcher, Dawson & Slooten, 2003; Kastelein et al. 2005, 2006); among others.

On the other hand, physiological effects include chronic stress (Rolland et al. 2012); tachycardia (Lyamin et al. 2011); temporary hearing loss (temporary threshold shifts TTS) (Mooney, Nachtigall & Vlachos, 2009; Schlundt et al. 2006; Finneran et al. 2007; Finneran & Schlundt, 2013) and mechanical trauma in ears (Ketten, Lien & Todd, 1993). In general, the severity of the consequences of an animal exposed to a noise will depend, as mentioned above, on the characteristics of the noise and duration and proximity of exposure (Southall et al. 2007; Bailey et al., 2010). Physiological effects are more difficult to test in the field, and most of the information about them comes from experimental research (e.g. Kastelein et al., 2012; Finneran et al., 2010).

In the last 20 years, several reviews have been published addressing the impacts of different aquatic/marine based human activities on cetaceans. One of the most influential reviews was by Richardson et al. (1995) where the authors exhaustively reviewed all the information available to date on the behavioural and physiological responses of marine mammals to anthropogenic noise. The authors highlighted the importance of determining if these responses are specific to the noise perceived by the animals, or more general, as marine mammals responses may often be attributed multiple signals (e.g. visual clues). In addition, the authors highlighted the importance of long-term studies and the unique ability of these data to assess impacts for particular populations. The review by Richardson et al. (1995) remains a foundation for current research. Other relevant reviews are Gordon et al. (2003) which address the impact of seismic surveys and Southall et al. (2007) who reviewed this topic and suggested 'safe' exposure criteria for marine mammals.

Currently, ecologists are adopting tools from other disciplines to develop alternatives to classic narrative reviews with the aim of more transparent and unbiased conclusions using predetermined protocols (Littell, Corcoran & Pillai, 2008). To this end, systematic reviews have been recently proposed as appropriate tools in ecology, evolution and conservation biology. A systematic review is an objective method that synthetizes and identifies the research that has been done on a certain topic, the gaps and methods used, and the hypotheses and/or species focus of studies. This type of review follows a predetermined protocol that reduces bias and increases transparency and repeatability throughout all stages (Littell, Corcoran & Pillai, 2008; Higgins & Green, 2011; Lowry et al., 2012; Lortie, 2014). Systematic reviews are commonly used in biomedical and social sciences, where defined protocols are established, but have only recently gained support in ecological disciplines (Littell et al., 2008; Lowry et al., 2010). In summary, the protocols used in systematic reviews should clearly state the question addressed, how and where the documents were searched and the exclusion/inclusion criteria used to select the final dataset (Lowry et al., 2010).

The following chapter presents a systematic review of current knowledge of the impacts of noise pollution on cetaceans. To accomplish this, the following questions were proposed: what sources of information are there on impacts of noise pollution in cetaceans? What species have been studied? Where have these studies been conducted? Which sources of noise are most commonly studied? What are the responses of cetaceans to these disturbances? What are the main knowledge gaps for this topic? Where future research efforts should be focused?

3.2. Methods

3.2.1. Literature search

A literature search was conducted using several electronic databases and different keywords. The electronic databases consulted were Web of Science, Discover and Scopus, and additionally Google Scholar was included. All these databases were available through Massey University Library. Since Google Scholar does not allow the use of Boolean words, and represents an important source of both published articles as "grey literature" (e.g. theses and technical reports), the search was performed by removing the connectors (i.e. AND) between keywords, and covering the same years as other databases. The documents (i.e. journal articles, theses and technical reports) selected during the search, should contain at least one of the selected words in either the title, abstract or keywords.

The search was made using broad terms, such as: Noise AND pollution AND marine mammal*. After this first collection of studies, the search was refined with synonyms of these words, as follows:

- Impact* AND effect* AND "anthropogenic noise" AND cetacean.
- Impact* AND "sound pollution" OR "underwater noise" OR "underwater sound" AND cetacean* AND whale* AND dolphin* AND porpoise*

- Noise AND pollution AND whale*
- Noise AND pollution AND dolphin*
- Noise AND pollution AND porpoise*

All types of studies found (i.e. peer-review journals articles, theses, conference abstracts and technical reports) were included in the preliminary database. The initial search included various keywords in other languages, but no results were obtained and the inclusion of these words was discarded. These search criteria were selected with help of the Science Librarian at Massey University. All records obtained from each database were compared manually with the records from the other databases in order to exclude replicates.

3.2.2. Inclusion and exclusion criteria

During this phase, all the documents found were subjected to an 'Inclusion' criteria process, and only the documents that fulfilled the following requirements were kept:

- Subject studies: any cetacean species (i.e. baleen whales, dolphins and porpoise).
- Intervention used: human activity causing underwater noises.
- Outcomes: changes in behavioural budgets, vocal behaviour or respiration patterns, displacement, changes in swimming patterns, any physiological effect or no response induced by different sources of anthropogenic noise.
- Comparator: the results obtained in the studies should have a control or base-information, in order to have a reference for comparing responses.

In addition, exclusion criteria were used to filter the studies:

- Reviews and conference abstracts about the topic were excluded to avoid replication.
- Documents regarding Pinnipeds, inasmuch as, these species have different sensitivity to noise pollution in the air and in land.
- Sirenids also were excluded because very few studies were found addressing this topic.
- Documents where there was no evidence of significant impacts from noise on a particular species.

After this stage, bibliographies of peer-reviewed journal articles between 2010 and 2015 were consulted in search of other studies that may have gone unnoticed earlier.

3.2.3. Data collection and analysis

After the inclusion phase, the following information was extracted and organised in a spreadsheet (MS Excel Microsoft Corporation) to create the final data set: source of study; study title; author; year of publication; abstract (if available); study area (as detailed as possible e.g. GPS location); species being studied; source of noise; type of impact; response of the organism and type of research (Table 3.1). A brief description of the data collection approach can be found in Appendix 3.1.

Table 3.1. Information collected and categories chosen to classify the studies that formed the basis for the systematic review.

Information collected	**Categories**
Source of the study	Peer-reviewed journal, thesis, technical reports.
Study area	Country, state, location, coordinates (if available) and Ocean.
Source of noise	Aircraft, pingers, sonars, any type of vessel, laboratory-based studies, industrial noise (drilling, dredging and explosions), seismic surveys and airguns, and background noise (noise that are recognised as anthropogenic but it cannot know with certainty to what source they belong).
Type of impact	Acoustical, behavioural and/or physiological.
Response	Changes in behavioural budgets, vocal behaviour or respiration patterns, displacement, any physiological effect or no response.
Type of research	Observational and/or experimental.

Regarding data analysis, all papers found were analysed in terms of research methodology and content using descriptive statistic such as percentages and bar charts. Percentages were calculated using a spreadsheet (MS Excel Microsoft Corporation), calculating the proportion of studies from the total in each category. In addition, bar charts were used to assess the frequency of studies per year, publications per journal and studies by species.

3.3. Results

3.3.1. Number of studies

Three hundred and seventy-nine peer review journals, theses, technical and reports were found addressing the impacts of noise pollution in marine mammals. After this, titles and abstracts were assessed and 30 unrelated studies were excluded. The remaining 349 studies were assessed completely (i.e. full text was reviewed) and 198 were selected after assessment of the inclusion criteria, since they met the criteria previously defined for this review (Appendix 3.1). The documents found were mainly: peer-review journal (90%, n = 179) and to lesser extent technical reports (7%, n = 14), theses (2%, n = 5) and book chapters (0.5%, n = 1).

3.3.2. Dates of the studies

The documents included range from 1975 to 2014, with a considerable increase in studies after 1997. Only one study was found in 1975 and between 1976 and 1981, no studies related to the topic were found. After 1982, averages of two studies were found each year until 1999, with an exception in 1998 when six studies were published. Since the year 2000, the number of studies found increased from 8 in that year, to 14 in 2006 and 20 in 2014. In 2005, only six studies were found and in 2010, the number of studies found halved compared to the previous year (Figure 3.2).

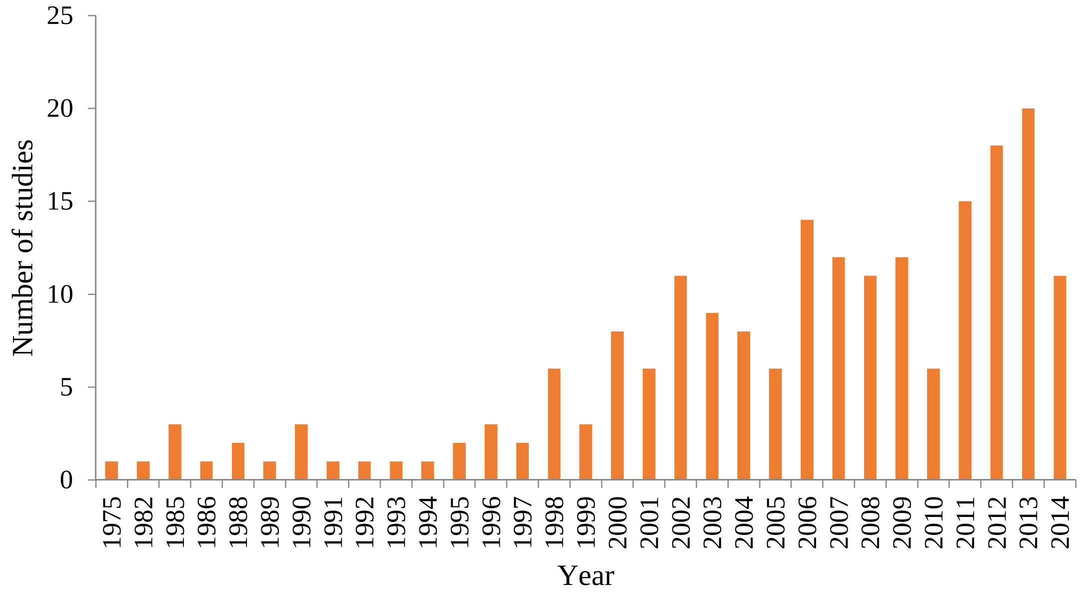

Figure 3.2. Number of studies published per year on marine acoustics impacts on cetaceans included in the systematic review. A total of 198 publications were found.

3.3.3. Peer-reviewed journals

The peer-reviewed papers on this topic were published in 49 different journals (Appendix 3.2). These journals have very broad scopes. The most important journals, in terms of number of published studies, were *The Journal of the Acoustical Society of America* (JASA) (19%, n = 34) followed by *Marine Mammal Science* (14%, n = 25). *The journal Aquatic Mammals* contributes with 6% (n = 11) of the publications, followed by *Marine Ecology Progress Series* (5%, n = 10), *Endangered Species Research* (4%, n = 8), *Biological Conservation* (4%, n = 7), and *Marine Environmental Research* (3%, n = 7) (Figure 3.3). Another 42 journals contributed less than two studies addressing the impacts of noise pollution on marine mammals per journal.

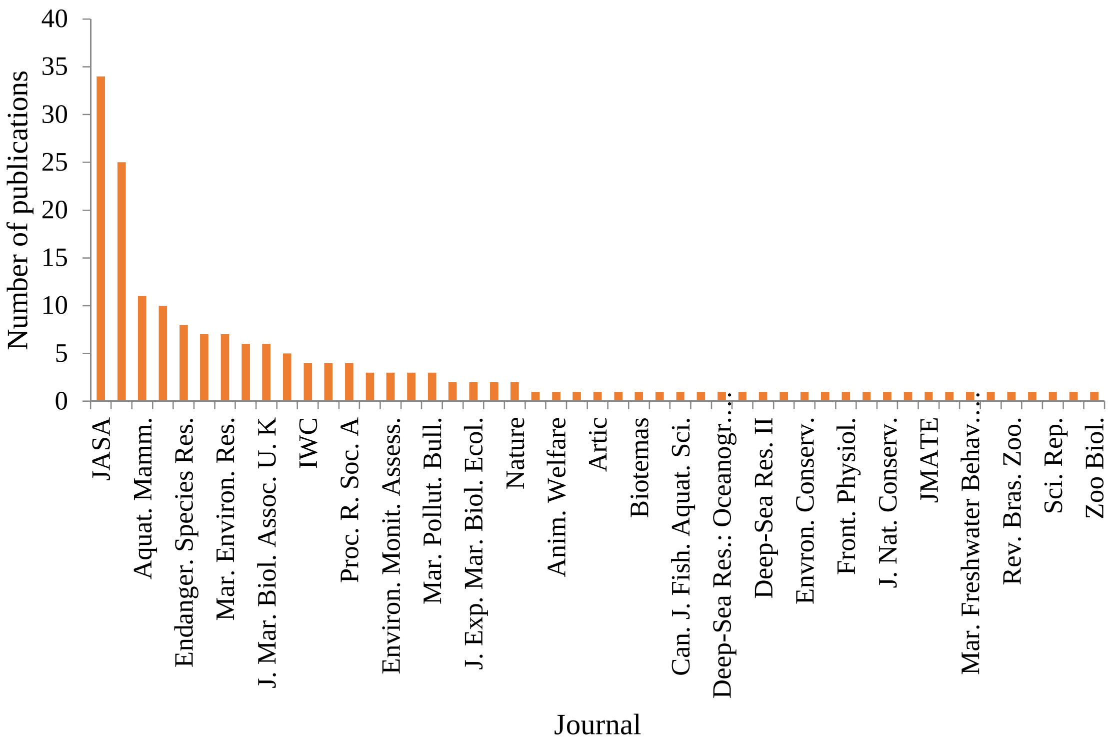

Figure 3.3. The distribution of studies published in peer-reviewed journals assessed in this review. A total of 198 publications from 49 journals were included.

3.3.4. Studied species and geographical area of research

These studies involved 37 of the 90 species of cetaceans recognised at this time. Thirty of 76 species of dolphins and porpoises were studied, while 7 out of 14 baleen whales species were the focus of these studies (Figure 3.4). Among toothed whales, bottlenose dolphins were the species most commonly studied (21%, n = 43), followed by the harbour porpoise (16%, n = 33). In addition, for the baleen group, humpback whales (10%, n = 21) were the most common studied species. Other species of toothed whales commonly studied were orca (n = 15), beluga (n = 11) and sperm whale (n = 11) (Figure 3.4). Most of the studies involved one species and only 19 studies (9%) assessed the impacts of noise in two or more species.

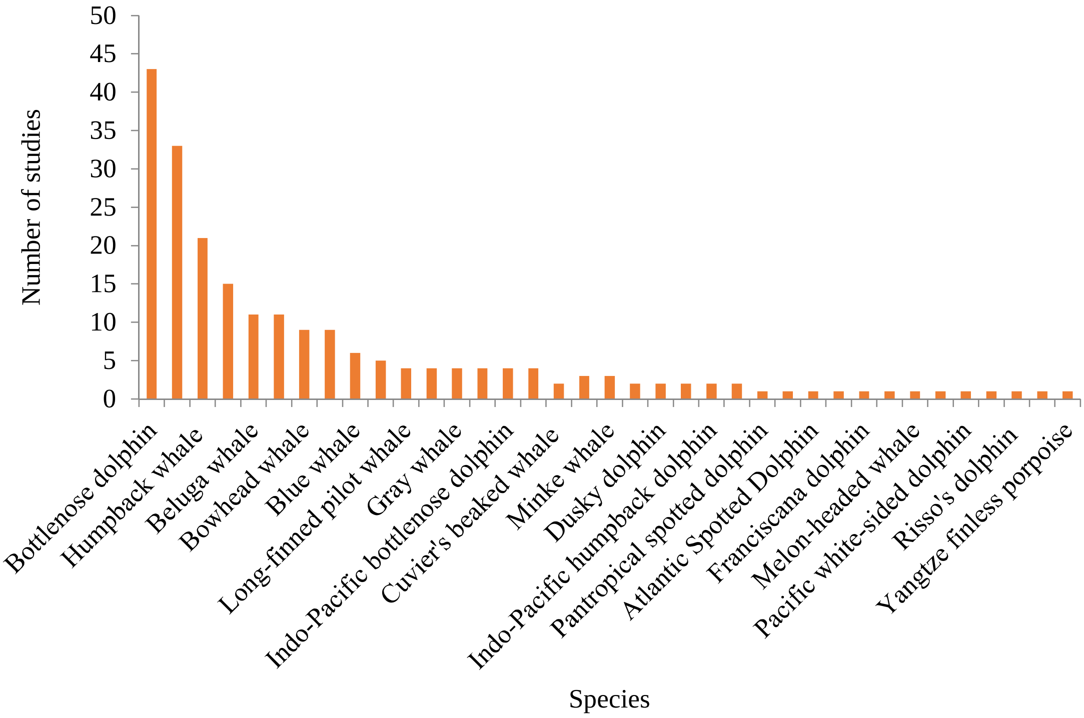

Figure 3.4. Number of studies assessing the impact of different sources of noise on cetaceans; 7/14 and 31/76 species of baleen and toothed whales have been studied, respectively.

Studies of noise impacts have been conducted in 29 countries. Almost half of the studies were conducted in the United States of America (USA; 26%; *n* = 59), and Canada (16%; *n* = 32), followed by New Zealand (8%; *n* = 16), and The Netherlands (7%; *n* = 15) (Figure 3.5). It should be noted that 14 studies were performed across territorial waters of more than one country. In contrast, for some large geographic areas such as Latin America, few studies were found, and of these, most were located in Brazil (5%, *n* = 10) and The Bahamas (*n* = 4), followed by Argentina (*n* = 3), Panama (*n* = 2), Mexico, Costa Rica and Ecuador (*n* = 1 per country, respectively).

Similarly, only six studies have been published in Africa, these were done in territorial waters of Angola (*n* = 2), Tanzania (*n* = 2), Gabon (*n* = 1) and Liberia (*n* = 1). In Europe studies were localised mainly in the North and Mediterranean Sea (North Atlantic Ocean), and the Arctic Ocean. The studies in The Netherlands came from laboratory-based studies. Only six studies were found in the Indian Ocean (Figure 3.5). These studies came from only two countries: Australia, including the Heard Islands (*n* = 4) and Tanzania (*n* = 2). Finally, no studies were found in Southeast Asia.

Figure 3.5. Map showing the location of the studies assessed in this review. Some coordinates were extracted directly from the publication; others were obtained thorough Google Maps by typing the location given in the article.

3.3.5. Sources of noise

Of the 198 studies assessed in this review, 41% (n = 84) were related to vessels, being by far the source most widely studied. Vessel studies were followed by studies involving seismic studies and airguns, which represent one third of the total. The next most frequently researched noise impacts were laboratory-based experimental studies (11%), sonar (10%), pingers (9%), and industrial activities (9%) and to a lesser extent, oceanographic investigation (research, 3%), aircrafts (2%) and background noise (1%).

3.3.6. Responses of cetaceans to anthropogenic noise

The responses of cetaceans to different sources of noise were highly variable within species and sources of noise. The responses of cetaceans were classified in several broad categories (Table 3.2). Most of the species had responses in multiple categories and few showed no response.

Table 3.2. Categories of response presented by cetaceans and the definition of those categories.

Categories of response	**Definition**
Avoidance	Movement in contrary direction to the source of noise.
Changes in behavioural budgets	Variation in time allocated to certain activities, e.g. Increasing time of diving, decreasing in foraging.
Changes in vocal behaviour	Variation in normal vocalisation, e.g. cessation of them, longer calls, Lombard effect, increase in calls amplitude.
Changes in respiration patterns	Variation in regular patterns of respiration such as, increase of breathing synchrony or respiration rates, variability in respiratory intervals.
Changes in swimming patterns	Sudden variations on swimming. E.g. increase in swimming speed, change in the direction of travel.
Displacement	Temporal or permanent abandonment of an area
No response	No apparent reaction in front of anthropogenic sources of noise.
TTS	Temporary deafness.
Others	Responses that did not fit into the above categories. E.g. Tachycardia, chronic stress, startle response, etc.

3.3.6.1. Vessels

In this study was found that the impacts of vessels on cetaceans have been widely studied around the world (84 studies on 25 species). The responses of cetaceans were highly variable and dependent on the type of boat or activity to which the study population was subjected (Table 3.3).

Table 3.3. Studies addressing the responses of cetaceans to vessels (n = 84); 41% of the total number of studies reviewed.

	Changes in:							
Species	Avoi-dance	Vocal behaviour	Behaviour budgets	Respiration patterns	Displace-ment	No response	Swimming patterns	Others
Harbour porpoise	**X**[69]							
Indo-Pacific humpback dolphin		**X**[22,55]	**X**[56,66]				**X**[56]	
Killer whales	**X**[41]	**X**[2,27,42]	**X**[23,41,43,62]	**X**[42]			**X**[41,42,46]	
Common dolphin	**X**[76]		**X**[57]					
Bottlenose dolphin	**X**[54,82,83]	**X**[3,9,28,31,35,49]	**X**[12,17,31,34,82,84,53,54,70,79,81]	**X**[37,53]	**X**[4,49]	**X**[8,81]	**X**[12,47,70,84]	**X**[15,17,35]
Indo-Pacific bottlenose dolphin			**X**[16,19,30]					
Hector's dolphin			**X**[61,72]				**X**[72]	**X**[14,72]
Guiana dolphin	**X**[75]	**X**[51]	**X**[52,70,73,74,75]	**X**[52,67]	**X**[73,74]	**X**[50]		
Sperm whale		**X**[25]	**X**[25,26,36,80]	**X**[25]		**X**[26]	**X**[80]	
Dusky dolphin			**X**[24,60]					
Risso's dolphin			**X**[66]					
Kogia spp.	**X**[48]							
Ziphiids	**X**[48]							
Blainville's beaked whale		**X**[11]						
Cuvier's beaked whale		**X**[7]	**X**[7]					
Stripe dolphin	**X**[30]							
Pantropical spotted dolphin	**X**[30]							
Spinner dolphin	**X**[30]		**X**[76]		**X**[76]			
Beluga whale		**X**[6,10,38]	**X**[59]				**X**[59]	
Humpback whale	**X**[63,64,65]		**X**[33,65,78]	**X**[58]			**X**[64,78]	**X**[45,58]
Blue whale		**X**[29]	**X**[29]					
Fin whale	**X**[1]		**X**[18]		**X**[1]		**X**[5,18]	
North Atlantic right whales						**X**[13]		**X**[5]
Minke whale			**X**[20]		**X**[8]	**X**[21]		
Bowhead whale	**X**[39]		**X**[39]		**X**[40]	**X**[39,40]		

[1]Castellote et al., 2012; [2]Foote et al., 2004; [3]Buckstaff, 2004; [4]Rako et al., 2013; [5]Rolland et al., 2012; [6]Scheifele et al., 2005; [7]Aguilar-Soto et al., 2006; [8]Anderwald et al., 2013; [9]May-Collado & Quiñones-Lebrón, 2014; [10]Erbe & Farmer, 1998; [11]Pirotta et al., 2012; [12]Nowacek et al., 2001, [13]2004; [14]Bedjer et al., 1999, [15]2006; [16]Lemon et al., 2006; [17]Arcangeli et al., 2008; [18] Jahoda et al., 2003; [19]Christiansen et al., 2010, [20]2013, [21]2014; [22]Ng & Leung, 2003; [23]Lusseau et al., 2009; [24]Lundquist et al., 2012; [25]Ritcher et al., 2003, [26]2006; [27]Holt et al., 2009; [28]Luís et al., 2014; [29]McKenna, 2011; [30]Steckenreuter et al., 2012; [31]Taubitz, 2007; [32]Au & Perryman, 1982; [33]Corkeron, 1995; [34]Constantine et al., 2004; [35]Guerra et al., 2014; [36]Gordon et al., 1992; [37]Hastie et al., 2003; [38]Lesage et al., 1999; [39]Richardson et al., 1985, [40]1986; [41]Williams et al., 2002, [42]2009, [43]2011, [44]2012; [45]Weinrich & Corbelli, 2009; [46]Williams & Ashe, 2007; [47]Janik & Thompson 1996; [48]Würsig et al., 1998; [49]La Manna et al., 2013; [50]Izidoro & Le Pendu, 2012; [51]Martins, 2010; [52]Santos et al., 2013; [53]Miller et al., 2008; [54]Papale et al., 2012; [55]Van Parijs & Corkeron, 2001; [56]Piwetz et al., 2012; [57]Stockin et al., 2008a; [58]Baker & Hermas, 1989; [59]Blane & Jaakson, 1995; [60]Dans et al., 2008; [61]Martinez, 2008; [62]Noren et

al., 2009; [63]Schaffar et al., 2013; [64]Scheidat et al., 2004; [65]Stamation et al., 2010; [66]Stensland & Berggren, 2007; [67]Tosi & Ferreira, 2009; [68]Visser et al., 2011; [69]Polacheck & Thorpe, 1990; [70]Mattson et al., 2005; [71]Carrera et al., 2008; [72]Nichols et al., 2001; [73]Pereira et al., 2007; [74]Santos et al., 2006; [75]Valle & Melo, 2006; [76]Neumann & Orams, 2006; [77]Courbis & Timmel, 2009; [78]Morete et al., 2007; [79]Underhill, 2006; [80]Magalhães et al., 2002; [81]Acevedo, 1991a; [82] Lusseau, 2003, [83]2005, [84]2006.

3.3.6.2. Seismic survey

Seismic surveys can be performed from two different perspectives: research or industrial activities. This type of noise source accounts for more than half of the total species studied and one third of the studies found for this review, which highlights its importance. Major responses included avoidance, displacement, tachycardia, and increase in the frequency of calls. ‘No response’ appeared to be the most common finding (Table 3.4).

Table 3.4. Studies addressing the responses of cetaceans to seismic surveys (n = 29); 14% of the total number of studies reviewed.

				Changes in:					
Species	Avoidance	Vocal behaviour	Behaviour budgets	Respiration patterns	Displacement	No response	Swimming patterns	TTS	Others
Harbour porpoise		**X**[27]			**X**[26]			**X**[16]	
Striped dolphin						**X**[20]			
Common dolphin	**X**[1]								
Bottlenose dolphin	**X**[5]								
Sperm whale					**X**[17]	**X**[10,11,20,25]		**X**[12]	
Atlantic spotted dolphin					**X**[17]				
Pantropical spotted dolphin	**X**[2]					**X**[20]			**X**[2]
Spinner dolphin						**X**[20]			
Rough-toothed dolphin						**X**[20]			
Short-finned pilot whale	**X**[18]	**X**[18]							
Long-finned pilot whale									**X**[25]

Bowhead whale		X[3]	X[13,14]			X[15,24,29]			
Beluga whale								X[12]	X[4]
Humpback whale	X[9]	X[23]			X[17]	X[6]			X[9]
Blue whale		X[8]							
Gray whale			X[7,19]	X[19]	X[19,22]	X[21]	X[19]		
Fin whale		X[8]			X[8]				

[1]Goold, 1996; [2]Gray & Van Waerebeek, 2011; [3]Blackwell et al., 2013; [4]Lyamin et al., 2011; [5]Goold & Fish, 1998; [6]Malme et al., 1985, [7]1988; [8]Di Iorio & Clark, 2010; [9]McCauley et al., 2003; [10]Miller et al., 2009, [11]Madsen et al., 2002; [12]Finneran et al., 2002; [13]Ljungblad et al., 1988, [14]Robertson et al., 2013; [15]Koski et al., 2008; [16]Lucke et al., 2009; [17]Weir, 2008a, [18]b; [19]Gailey et al., 2007; [20]Rankin & Evans, 1998; [21]Yazvenko et al., 2007a, [22]b; [23]Cerchio et al., 2014; [24]Fraker et al., 1985; [25]Stone & Tasker, 2006; [26]Thompson et al., 2013; [27]Pirotta et al., 2014; [28]Castellote et al; [29]Richardson et al., 1986.

3.3.6.3. Laboratory-based studies

Nonpulse sounds are mainly used in laboratory-based studies to assess levels at which animals react when they are exposed to certain pressures. Most of the studies under this category sought to assess temporary thresholds shifts (TTS), mainly in bottlenose dolphins and harbour porpoise. Responses exhibited include changes in diving behaviour, masking, and startle responses among others (Table 3.5).

Table 3.5. Studies addressing the responses of cetaceans to laboratory-based studies (n = 22); 11% of the total number of studies reviewed.

			Changes in:				
Species	Avoidance	Vocal behaviour	Behaviour budgets	Respiration patterns	Displacement	TTS	Others
Harbour porpoise	X[6,7]					X[8,11]	X[9,10,13]
False killer whale					X[5]		
Yangtze finless porpoise						X[19]	
Humpback whale			X[1, 12]		X[12]		
Beluga whale						X[16, 20]	
Bottlenose dolphin	X[22]	X [22]	X[16, 17, 22]		X[22]	X[2,3,4, 14,15,16,17, 18,21]	

[1]Frankel & Clark, 1998; [2]Finneran et al., 2005, [3]2007, [4]2010; [5]Akamatsu et al., 1993; [6]Kastelein et al., 2008a, [7]2008b, [8]2012a, [9]2012b, [10]2012c, [11]2013; [12]Dunlop et al., 2013; [13]Lucke et al., 2007; [14]Nachtigall et al., 2003, [15]2004; [16]Schlundt et al., 2000; [17]Ridgway et al., 1997; [18]Finneran & Schlundt 2010; [19]Popov et al., 2011, [20]2013; [21]Mooney et al., 2009; [22]Niu et al., 2012.

3.3.6.4. Sonar

Cetaceans' responses to sonar have been assessed in 16 different species. The most common response across species was change in vocal behaviour (Table 3.6). Other responses included avoidance, displacement, and habituation in some cases (referred as 'other' on table 3.6).

Table 3.6. Studies addressing the responses of cetaceans to sonars (n = 21); 10% of the total number of studies reviewed.

				Changes in:					
Species	Avoidance	Vocal behaviour	Behaviour budgets	Respiration patterns	Displacement	No response	Swimming patterns	TTS	Others
Harbour porpoise	**X**[21]		**X**[21]	**X**[21]			**X**[21]		
Killer whales	**X**[5,6]	**X**[5]	**X**[14]			**X**[8,14]	**X**[5,6]		
Common dolphin		**X**[17]					**X**[17]		
Bottlenose dolphin		**X**[17]						**X**[3]	**X**[16]
Sperm whale	**X**[5]	**X**[5]	**X**[14]				**X**[5]		
False killer whale		**X**[18]							
Melon-headed whale		**X**[18]							
Blainville's beaked whale	**X**[11]	**X**[9,11]	**X**[11]		**X**[11]				
Cuvier's beaked whale		**X**[19]			**X**[19]		**X**[19]		
Baird's beaked whale		**X**[20]					**X**[20]		
Pacific white-side Dolphin		**X**[17]	**X**[17]						
Pilot whale						**X**[18]			
Long-finned pilot whale	**X**[1,5]	**X**[5,15]	**X**[14]				**X**[5]		
Humpback whale		**X**[4,12,13]							
Blue whale	**X**[7]	**X**[10]	**X**[7]			**X**[2]	**X**[7]		
Fin whale						**X**[2]			

[1]Antunes et al, 2014; [2]Croll et al., 2001, [3]Mooney et al., 2009; [4]Miller et al., 2000, [5]2012, [6]2014; [7]Goldbogen et al., 2013; [8]Kuningas et al., 2013; [9]McCarthy et al., 2011; [10]Melcon et al., 2012; [11]Tyack et al., 2011; [12]Biassoni et al., 2000; [13]Fristrup et al., 2003; [14]Sivle et al., 2012; [15]Rendell & Gordon, 1999; [16]Houser et al., 2013; [17]Henderson et al., 2014; [18]DeRuiter et al., 2013a, [19]b; [20]Stimpert et al., 2014; [21]Kastelein et al., 2011

3.3.6.5. Pingers

Nineteen studies assessed the reactions of cetaceans to pingers. Since the main purpose of these devices is deterring odontocetes from fishing nets, it was expected that the most common responses would be displacement or avoidance from the ensonified areas. Nonetheless, other responses were also identified such as changes in behaviour, cessation of vocalisation, increase of respiration rate, among others (Table 3.7).

Table 3.7. Studies addressing the responses of cetaceans to pingers (n = 19); 9% of the total number of studies reviewed.

	Changes in:							
Species	Avoidance	Vocal behaviour	Behaviour budgets	Respiration patterns	Displacement	No response	Swimming patterns	Others
Harbour porpoise	**X**[6,8,9,17,19]	**X**[11]	**X**[7,10,11]	**X**[7,8,9]	**X**[2,3,10,14]		**X**[10]	**X**[11,14]
Killer whale					**X**[1]			
Striped dolphin						**X**[9]		
Hector's dolphin	**X**[4]		**X**[4]					
Bottlenose dolphin	**X**[5]		**X**[13]		**X**[13]	**X**[18]		
Sperm whale		**X**[11]						
Guiana dolphin	**X**[15]							
Franciscana dolphin					**X**[16]			

[1]Morton & Symonds, 2002; [2]Johnston, 2002; [3]Olesiuk et al., 2002; [4]Stone et al., 2000; [5]Cox et al., 2004; [6]Culik et al., 2001; [7]Kastelein et al., 2000, [8]2001, [9]2006, [10]2014; [11]Watkins & Schevill, 1975; [12]Teilmann et al, 2006; [13]Leeney et al., 2007; [14]Carlström et al., 2009; [15]Monteiro-Neto et al., 2004, [16]Bordino et al., 2002, [17]Koschinski & Culik, 1997; [18]Diaz Lopez & Mariño, 2011, [19]Laake et al., 1998.

3.3.6.6. Construction and industrial activities (drilling, dredging, wind farms and explosions) and oceanic research

Eighteen studies examined the responses of cetaceans to industrial activities. Seven species were assessed and the most common responses ranged from temporal displacement and avoidance to increasing echolocation, cessation of feeding and an increase in respiration (Table 3.8). It is worth noting that some species showed no detectable response to these sources of noise. On the other hand, unlike other sources of noise, oceanographic research focuses on the impact of this source of noise in larger areas rather than for a particular location or species. Nine species were identified reacting to these projects and the main responses are summarised in table 3.7. The most common response among the species was displacement. The category ‘others’ included variable responses such as very close or very far from the source, or very small responses to received levels (RL).

Table 3.8. Studies addressing the responses of cetaceans to construction and industrial activities (n = 18) and oceanic research (n = 6); 9% and 3% of the total number of studies reviewed, respectively.

			Changes in:				
Species	Avoidance	Vocal behaviour	Behaviour budgets	Respiration patterns	Displacement	No response	Others
Responses to industrial activities							
Harbour porpoise	**X**[4,6]	**X**[2,7,8]	**X**[2,5]	**X**[3]	**X**[1,5,9]		
Bowhead whale	**X**[13]	**X**[14]	**X**[3,14]	**X**[3,14]			
Gray whale						**X**[18]	
Humpback whale						**X**[17]	**X**[10]
Beluga whale			**X**[12]			**X**[15]	
Bottlenose dolphin			**X**[12]		**X**[16]		
Sperm whale						**X**[11]	
Responses to oceanic research							
Harbour porpoise	**X**[22]			**X**[22]			
Humpback whale		**X**[24]	**X**[20]			**X**[23]	**X**[20,21]
Blue whale				**X**[19]			**X**[19]
Beaked whales					**X**[19]		
Southern bottlenose whale					**X**[19]		
Minke whale					**X**[19]		
Sperm whale					**X**[19]		
Hourglass dolphin						**X**[19]	
Pilot whale					**X**[19]		

[1]Brandt et al., 2011;[2] Koschinski et al., 2003; [3]Kastelein et al., 2013; [4]Dähne et al., 2013; [5]Carstensen et al., 2006; [6]Sundermeyer et al., 2012; [7]Scheidat et al.,2011; [8]Teilmann & Carstensen, 2012; [9]Tougaard et al., 2006; [10]Todd et al., 1996; [11]Madsen & Mohl, 2000; [12]Finneran et al., 2000, [13]Richardson et al., 1985, [14]1990; [15]Thomas et al., 1990; [16]Pirotta et al., 2013; [17]Malme et al., 1985, [18]1988; [19]Bowles et al., 1994; [20]Frankel & Clark, 2000, [21]2002; [22]Kastelein et al., 2005; [23]Mobley Jr., 2005; [24]Risch et al., 2012.

3.3.6.7. Aircraft and background noise

Aircrafts and background noise impacts comprised the smallest number of studies assessed in this review (Figure 3.9). Responses to aircraft were studied in just four species, all in the Family Ziphiidae. In addition, only two types of aircrafts were assessed: airplanes and helicopters. Both types of aircraft elicited different responses from the animals. The most common response of these species comprised signs of disturbance at different altitudes of the aircrafts such as increases in diving behaviour and dramatic changes in other important behavioural states such as milling and resting. Other responses included longer surface times, latency of the first click and short surfacing times, immediate dives or turns, changes in behaviour state, vigorous swimming, and breaching (Table 3.9). In comparison, responses to increasing background noise were assessed in two species of baleen whales and one toothed whale. The responses included increased call amplitude (Lombard effect) and lower rates of calling (Table 3.9).

Table 3.9. Studies addressing the responses of cetaceans to aircrafts (n = 4) and background noise (n = 3); 3% of the total number of studies reviewed.

	Changes in:			
Species	Behavioural budget	Vocal behaviour	Swimming patterns	Other
Responses to aircraft				
Bowhead whale	**X**[1,2]		**X**[2]	
Beluga whale	**X**[2]		**X**[2]	
Sperm whale	**X**[3]	**X**[3]		
Kogia spp.	**X**[4]			**X**[4]
Ziphiids	**X**[4]			**X**[4]
Responses to background noise				
Killer whale		**X**[5]		
North Atlantic Right whale		**X**[6,7]		
South Atlantic Right whale		**X**[7]		

[1]Richardson et al., 1985; [2]Patenaude et al., 2002; [3]Richter et al., 2006; [4]Würsig et al., 1998. [5]Holt et al., 2011; [6]Parks et al., 2007, [7]2011.

3.3.7. Studies in New Zealand

For New Zealand in particular, 15 studies were found addressing the impacts of noise pollution on cetaceans. These studies were done in seven different locations around the country: Akaroa Harbour (*n* = 3), Doubtful Sound (*n* = 3), Hauraki Gulf (*n* = 1), Kaikoura (*n* = 4), Macon State Park (*n* = 1), Mercury Bay (*n* = 1), Milford Sound (*n* = 1) and Porpoise Bay (*n* = 1) (Figure 3.6). These studies were focused on five species of toothed whales: bottlenose dolphin (*n* = 5), Hector’s dolphin (*n* =4), sperm whale (*n* =

3), common dolphin (*n* = 2) and dusky dolphin (*n* =1) (summary in Table 3.10). One study documented the reactions of Hector's dolphin to pingers and found responses such as avoidance and change in behavioural budgets. Another study assessed the impacts of both vessels and aircraft on sperm whales and found changes in behavioural budgets and in vocal behaviour.

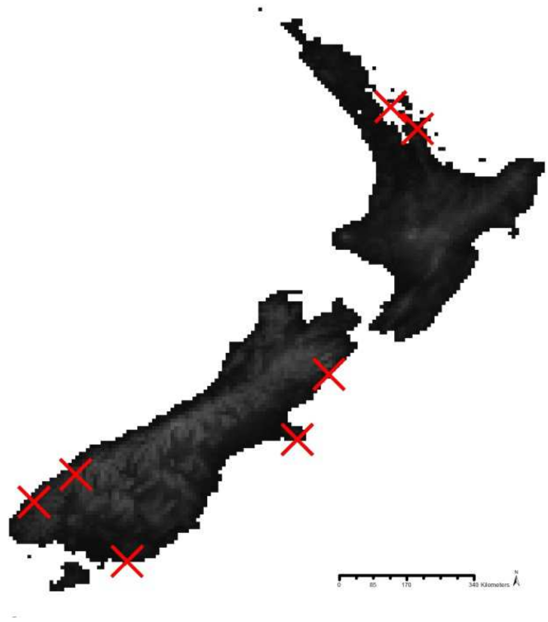

Figure 3.6. Map showing the location of the studies done in New Zealand. Some coordinates were extracted directly from the publication; others were obtained thorough Google Maps by typing the location given in the article.

Table 3.10. Cetacean species studied and the responses found to vessels in New Zealand.

			Changes in:				
Species	Avoidance	Vocal behaviour	Behaviour budgets	Respiration patterns	No response	Swimming patterns	Others
Common dolphin	**X**[15]		**X**[12]				
Sperm whale			**X**[7,11,8]	**X**[7]	**X**[8]		
Dusky dolphin			**X**[5]				
Hector's dolphin			**X**[13,14]			**X**[14]	**X**[1,14]
Bottlenose dolphin	**X**[2,3]	**X**[2,4,10]	**X**[9]			**X**[4]	**X**[10]

[1]Bedjer et al., 1999; [2]Lusseau, 2003, [3]2005, [4]2006; [5]Lundquist et al., [6]2012; [7]Ritcher et al., 2003, [8]2006; [9]Constantine et al., 2004; [10]Guerra et al., 2014; [11]Gordon et al., 1992; [12]Stockin et al., 2008a; [13]Martinez, 2008; [14]Nichols et al., 2001; [15]Neumann & Orams. 2006.

3.4. Discussion

3.4.1. What was found in the literature?

The concern about the impacts of noise pollution on cetaceans, and the creation of legislation and agreements to protect these species, has resulted in the categorisation of anthropogenic noise as a pollutant. This designation of noise as a pollutant and potential environmental issue has generated an increasing number of studies and literature concerning this topic. However, this growing body of literature has covered the range of noise sources, species affected and locations in a disproportionate way. In this review, I present a systematic overview of current information about the impacts of noise pollution on cetaceans. I describe and categorise what has been done in this field to date and I answer seven basic questions: *1) What sources of information are there regarding impacts of noise pollution in cetaceans? 2) Of all cetaceans, which species have been studied? 3) Where have these studies been conducted? 4) What are the sources of noise most commonly studied? 5) What are the major responses of cetaceans to these disturbances? 6) What are the remaining gaps in current knowledge of this topic? 7) Where can/should future research efforts be focused?*

What sources of information are there regarding impacts of noise pollution in cetaceans? It is clear from the results obtained that the main sources of information were publications from peer-reviewed journals. This source of information provided 90% of the studies assessed, followed by technical reports and theses. This makes sense, considering that publications are widely accessible, in contrast to theses and technical reports that have limited circulation. This suggests that potentially important sources of information (theses and reports) have been underestimated. The oldest study dated from 1975, and only few sporadic studies occurred in the years immediately following. It was not until 1998 that the number of studies on this topic began radically to increase.

This likely occurred because in the 1990’s acoustic pollution was recognised as a major source of threat to marine organisms by both researchers and policy makers. At this time, the topic began to be studied in more depth and the quantity of publications subsequently rose. It was also around this time that the technology needed to record and analyse acoustic environments (in particular hydrophones, computer and digital technology, and advanced spectral analysis software) become affordable and widely available (Gerhardt, 1998). At the same time, important reviews were published about this topic that highlighted the significance of this issue (e.g. Richardson et al. (1995). One of the most influential reviews was by Richardson et al. (1995), where the authors made the most complete compilation about the topic at that time. This publication is still used as point of reference for current work.

Which species have been studied? Where have these studies been conducted? The results also show that not all geographic areas and species have been studied. Only 37 of 90 species of cetaceans have been studied and the geographical range of these studies is biased towards North America. Bottlenose dolphin and harbour porpoise are the species most highly studied, accounting for 35% of all assessed studies on responses to noise. One contributing reason is that both species are more commonly used in experimental studies compared to other species. The next most commonly studied marine mammal is the humpback whale; the most studied baleen whale around the globe. Like the bottlenose dolphin, the humpback whale has a very wide distribution that makes them relatively easy to study.

It was also found that the great majority of all studies are focused in the northern hemisphere and are concentrated in two major areas: North America (USA, including Hawai'i and Canada) and around the North and Mediterranean Seas. The largest contribution of studies in the southern hemisphere comes from Australia and New Zealand. Strikingly, it was found major underrepresentation from areas such as Central and South America (particularly the Pacific coast), and Africa and Southeast Asia. One explanation these biases in some areas could be that countries in these regions, where this topic has been highly studied, have conservation plans and legislation that seek to protect marine mammals, among others things, from noise pollution, and these plans have been implemented from the 1980s.

What are the sources of noise most commonly studied? In the same way that some regions are underrepresented, it was found that studies of the sources of anthropogenic noise were also unequal. The category 'vessels' was almost three times more represented than the second most frequent category, 'seismic'. The unequal spread of studies reflects to some degree the perceived noise risk. For example, vessels are the major contributors of background noise in the sea (Richardson et al., 1995). More recently, 'seismic' noise due to global and large-scale mineral exploration is increasing considerable, for example, in the USA this industry had an annual growth of 5.3% during 2009 and 2014[5] and the number of studies reflects this risk. 'Laboratory-based' studies are more difficult to compare with environmental studies as responses to these sounds are generally conducted as lab-based experimental tests to determine detection levels and distance at which certain sounds can elicit a response.

These types of experiments are useful to determine thresholds of minimum response to a stimulus, and to lay the foundation of minimum standards for SPL (or other measurements) required as 'safety zones' for cetaceans in mitigation plans. One limitation of these studies is that they have been conducted on only the few species (e.g. bottlenose dolphin, harbour porpoise and Beluga whale) that are easily kept in captivity. Generalising to other cetaceans should therefore be done with caution and with recognition of this limitation. Sonar was almost as frequently studied as laboratory-based. The importance of sonar as a source of underwater noise pollution was recognised when several mass stranding began to be associated with neighbouring naval training and use of sonar. Today, some legislation has been implementing to control these activities (e.g. Agreement on the Conservation of Small Cetaceans in the Baltic, North East Atlantic, Irish and North Seas, ASCOBAMS).

'Pingers' can be considerate a special case of underwater noise pollution contributor; the objective of pingers is to repel Odontocetes and Pinnipeds to avoid conflicts with fishing gear and reduce cetacean mortality related to by-catch. Pinger devices use mainly mid- and high-frequency sound, and are widely used in fisheries to reduce small dolphins by-catches, thus the studies assessed only Odontocetes (the group capable of detecting and using these frequencies) (Stone, et al., 2000; Cox, Read, Solow & Tregenza, 2001; Marine Mammal Comission, 2007). It was found that the categories of noise pollutants least studied included 'industrial' (activities related to drilling, dredging, construction and the operation of wind farms and explosives), and 'research', 'aircraft' and 'background noise'. Regarding to 'industrial' noise, this may be because

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[5] http://www.ibisworld.com/industry/default.aspx?indid=1406

seismic operations, also related to these activities, has grabbed more attention due to its well know consequences for the marine fauna than the other activities (e.g. drilling, dredging, etc.). Finally, in the case of oceanic research, on the scale analysed in this review and 'aircraft' are unusual activities, and the small number of 'background noise' may be because most of these type of studies only take into account shipping, excluding combination of different sources of noise.

What are the major responses of cetaceans to these disturbances? The responses of cetaceans to different sources of noise are highly variable and depend on the type of sound, the time of exposure, sound pressure level, and in some cases the condition, age, state or behavioural state of the animal exposed (Southall et al., 2007; Bailey et al., 2010). It was found that these responses varied from undetectable to changes in vocal behaviour, behavioural budgets, avoidance and displacement. Changes in behaviour have the potential to generate detrimental consequences at individual and/or population levels (Constantine, Brunton & Todd, 2004; Nowacek & Tyack, 2008; Laiolo, 2010). In this review, it was also found that vessels could elicit highly variable responses in the studied species. For example, in bottlenose dolphins, all categories of responses to vessels selected (including no response) have been reported, from avoidance and displacement, to changes in behavioural budgets, vocal, swimming and respiration patterns. In contrast, for species such as Indo-pacific bottlenose dolphin or harbour porpoise, only changes in behavioural budgets and avoidance, respectively, have been found (See table 3.3). This also highlights the disparity in which species have been studied.

For baleen whales, studies have reported changes in behavioural, swimming and respiration patterns and avoidance in the most commonly study species, the humpback whale. The next most frequently studied baleen whales are the fin and bowhead whales, both of which have been found to show changes in behaviour, displacement and avoidance. Fin and bowhead whales were also found to exhibit very different vessel responses, changes in swimming patterns and no response, respectively. Responses to vessels need to be examined with caution as the sound produced by the vessel is not the only form of environmental disturbance it creates; the mere physical presence of vessels may already be a disturbing factor (Pirotta et al., 2015).

Marine seismic surveys are an important source of underwater noise due to these activities, generally, covering extensive areas over long periods of time (Gordon et al., 2003). It was found that seismic surveys elicited a wide variety of responses in cetaceans, although most of them are under the category ‘no response’. In this category, some biases can be identified, e.g. studies of wind farms have been assessed only for harbour porpoise. Most strikingly, there have been no studies of responses to seismic surveys in the South Pacific Ocean. ‘Laboratory-based’ are done on captive animals to determine thresholds at which an animal can exhibit TTS. Because of this, the results are able to detect very precise responses. As mentioned above, these studies are limited to few easily held species of Odontocetes, but two studies, have attempted to test these types of sounds with humpback whales in their natural environment (Frankel & Clark, 1998; Dunlop et al., 2013). Frankel & Clark (1998) found subtle responses of humpback whales to M-sequence playbacks only detected statistically, while Dunlop et al. (2013) found that the response to ‘tones’ was consistent, showing an aversion to the stimulus.

Sonar has been linked to strandings and mass mortality of cetacean worldwide (Dolman, Weir & Jasny, 2009). In this review was found that only on 16 species have been assessed the potential effects of this source of noise. Although, most of them exhibited some sort of change in their vocal behaviour, the responses are variable. In the case of beaked whales, there is a huge gap of knowledge even when has been recognised the sensitivity of these animals to this particular noise. On the other hand, although pingers have been used in Odontocetes with conservation purposes, has been suggested that they can have adverse effects such as repel them from important areas (e.g. breeding, feeding areas) (Leeney et al., 2007). Pingers have been tested only in Odoncetes, thus they are the most affected by the frequencies used by these devices.

Regarding the impacts of industrial activities, few species have been evaluated, showing diverse responses. The quantity of studies on this type of source of noise could be considered low, if taken into account the rapid growth of renewable energy projects, such as wind farms, and projects involving the search for fossil fuels. Finally, the last three categories involved few studies. Studies addressing oceanic research are the only ones that are focused in big areas not in particular species, with an exception of an experimental study found. This approach, studying the whole community, let collect more information from a bigger number of species, most of them difficult to study due to their habits. Nevertheless, nowadays the type of oceanic research grouped in this category is not been applied.

3.4.2. What happen in New Zealand?

Most of the studies found for New Zealand assessed the impacts of vessels on Odontocetes. This tendency makes sense given the importance of eco-tourism activites, a major source of income for the country. However, it is particularly interesting that there is an absence of studies of other sources of noise such as seismic surveys. Projects related to seismic activities are now widely approved across New Zealand's territorial waters, but no study was found. While it is true that all the seismic activities should have a mitigation plan, these mitigation plans may not be accomplishing their aim due to insufficient knowledge of impacts and cetacean responses (across the wide range of species found in New Zealand marine ecosystems). Clearly, New Zealand needs more studies addressing the impact of noise pollution from sources other than vessels, particularly from seismic and industrial activities. These studies should include baleen whales, particularly as distributions of many endangered populations of these animals overlap with planned and ongoing seismic activities (See Chapter 5).

3.4.3. Review limitations

This assessment of literature was based on a systematic review, a technique long used in the medical sciences and now increasing being applied to address ecological questions. The infancy of this tool in the field of ecology means that there are few standard criteria and several suggested approaches (e.g. Stewart, Pullin & Coles, 2005; Reid, Lamarque & Lortie, 2010; Lowry et al., 2012; Carmel et al., 2013). Besides the problem of standardisation of a methodology, another issue to highlight is the omission and inaccessibility of documents during the search phase. Lawry et al. (2012) point out that databases are idiosyncratic and some documents are going to be missed for no apparent reason, even if the keywords used for searches are in an omitted document. Some documents cannot be included due to the difficulty of access such as theses and technical reports. The vast majority of these documents are not for public access, and in some cases is the property of companies (e.g. technical reports). A final limiting factor for this review was that access to documents in other languages was not possible. This could be due either to an absence of information about the topic or that the searched database does not have the right to include documents in languages other than English. Alternative search engines (e.g. screen references of documents) could help to reduce these potential biases.

3.5. Conclusions

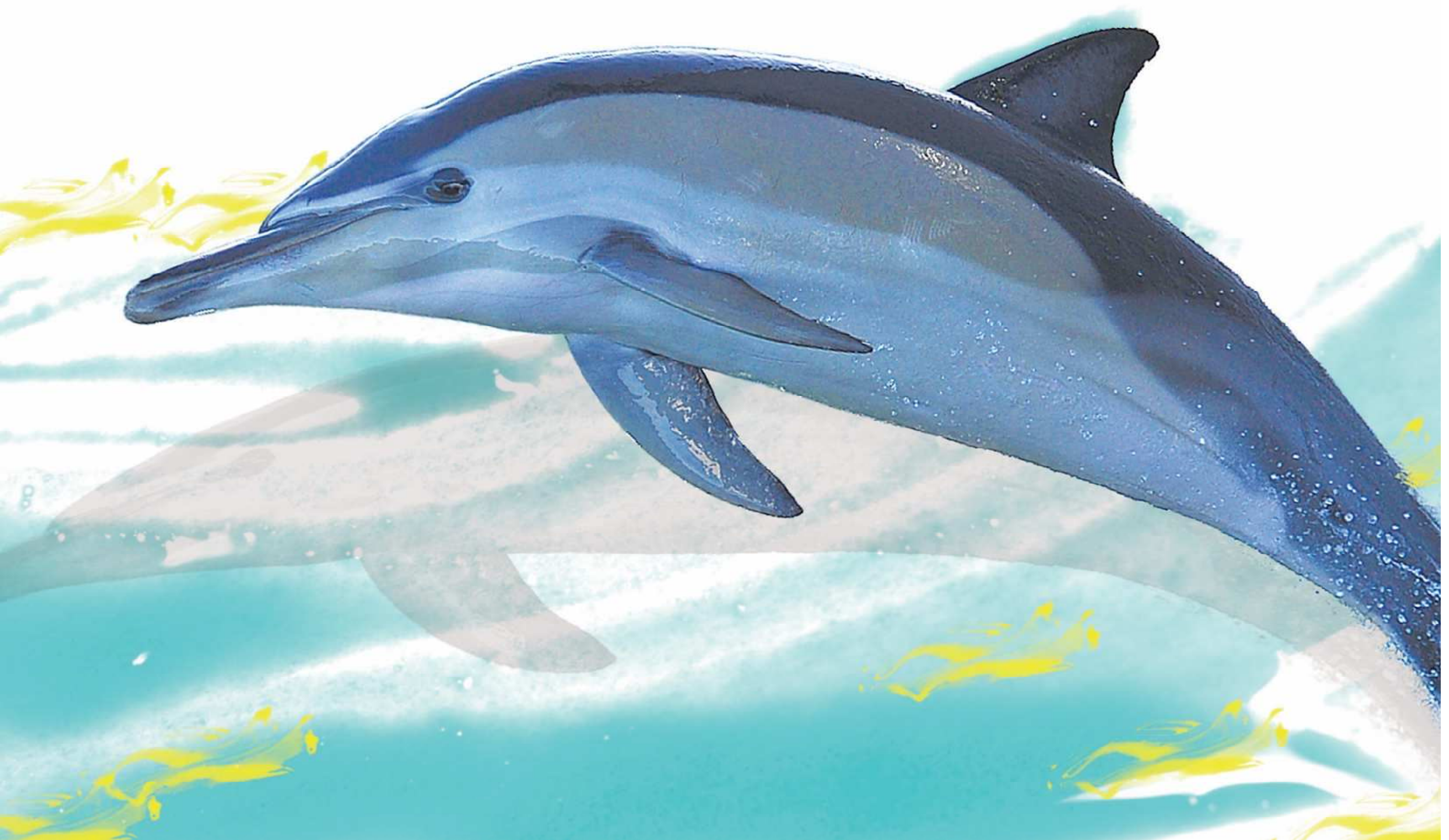
What are the remaining gaps in current knowledge of this topic? In this review, I found knowledge gaps of the impacts of noise pollution in certain regions of the word such as Latin America, Africa and Southeast Asia, as well as regions in the Arctic and Southern Ocean. I also found that most effort has been focused on the impact of vessels, potentially neglecting other important and globally increasing contributors to marine noise such as industrial activities. Furthermore, the studies have been uneven done regarding species, for example, bottlenose dolphins are commonly studied while there are other species, under some similar pressure, lacking assessment. In New Zealand, there are a completely lack of knowledge about the impacts of different source of noise on cetaceans except for vessels. Other sources of concern include seismic surveys and industrial activities, those activities are highly promoted within the country.

Where can/should future research efforts be focused? Accordingly to what I found in this review, research is needed in oceanic species that due methodological constrains, are difficult to study. Regarding sources of noise, industrial activities have been underestimated and it is notorious that these activities are growing fast around the world. In New Zealand, effort should be put on industrial activities due it is a global trend, but focussing more in coastal species such as Hector's, Maui's and bottlenose dolphin, for example. Even, more studies about the impact of vessel on other species such as southern right whale are necessary. On the other hand, although there is a Code of practice to mitigate impacts of seismic activities on marine mammals, nobody has studied the real impacts of these activities on these animals.

Finally, regarding to systematic reviews, these are a useful tool to synthesise information and they have some advantages over traditional reviews, such as results can be better analysed, evaluated and biases are greatly reduced. This systemic review embraces a broad scope in a topic that has high conservation relevance. To my knowledge, this is the first attempt to do a systematic review about the impact of noise pollution in marine mammals and I believe it can provide a useful starting point for future reviews and research in this topic.

Chapter Four

Distribution of cetaceans



4.1. Introduction

Pompa et al. (2011), propose New Zealand as one of the nine key conservation sites for marine mammals, along with the coasts of Baja California, North-eastern America, Peru, Argentina, North-western Africa, South Africa, Japan and Australia (Figure 4.1), due to its high marine mammals richness (Pompa et al., 2011). Currently, there are around 47 species of cetaceans reported for New Zealand, that include resident, migrant and vagrant species (Baker et al., 2010). This chapter aiming compiles the available information about the general distribution of cetaceans around the world and, in particular, in New Zealand. The data were obtained from different sources of information such as the IUCN webpage, peer-review journal articles and grey literature. The sigthings maps of cetaceans' distribution in New Zealand were done with data obtained from the Department of Conservation (DOC).

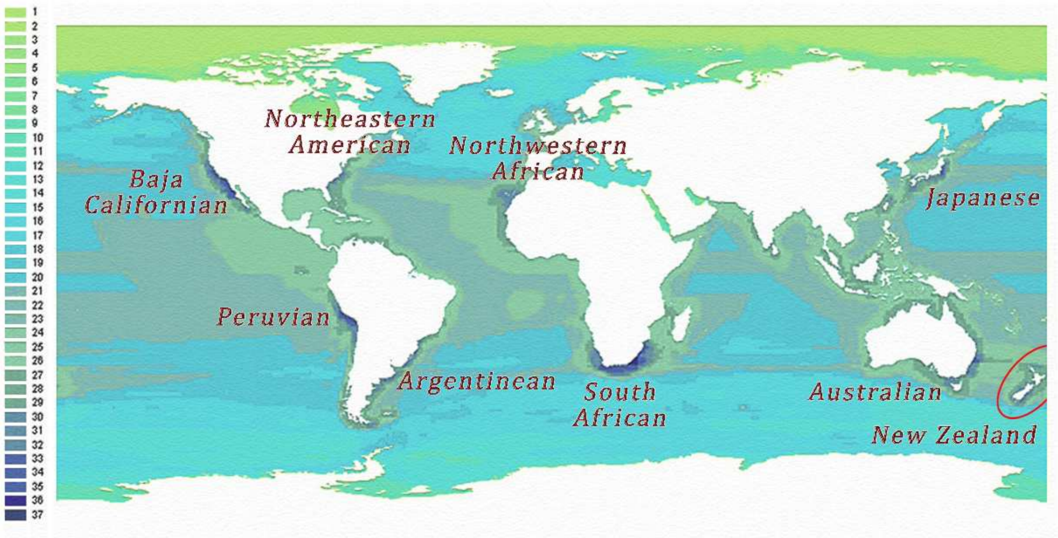


Figure 4.1. Patterns of geographic distribution and species richness of marine mammals. The number of species in each cell is shown in the column on the left. Red circle showing the location of New Zealand. Modified from Pompa et al. (2011).

4.2. Distribution of cetaceans in New Zealand

4.2.1. Baleen Whales

4.2.1.1. Family Balaenidae

4.2.1.1.1. Southern right whale (*Eubalaena australis* (Desmoulins, 1822))
IUCN Status: Least Concern (2013)
New Zealand Status: Nationally Endangered (Baker et al., 2010)

Southern right whales have a circumpolar distribution in the Southern Ocean, in waters of Argentina, Brazil, South Africa, east Africa, Australia, New Zealand and Chile. (Kenney, 2009; Reilly et al., 2013a) (Appendix 4.1; map 1). Southern right whales used to be common throughout New Zealand waters, but due to whaling activities, the population dropped dramatically at the beginning of the 20th Century (Lusseau & Slooten, 2002). Patenaude (2003) compiled the registers of southern right whales around mainland in New Zealand. According to this report, the species has been sighted along the east coast of the North Island, and the east and south coast of the South Island, generally within 200 m of shore (Patenaude, 2003).

In the North Island, southern right whales have been sighted in the Bay of Islands (Patenaude, 2003; Gaborit-Haverkort, 2012) and the East Coast/Hawke's Bay and Bay of Plenty Conservancy, which seems to be an important areas for cow/calf pairs, as well as the coastline between Napier and Mt Manganui (Patenaude, 2003). Regarding the South Island, the majority of observations were made in Stewart Island and Otago, which has shown to be preferential habitat for these whales (Patenaude, 2003).

In addition, this species has been recorded at Port Pegasus, Banks Peninsula, Marlborough Sounds and Wellington (Patenaude, 2003). During winter, southern right whales can be found primarily along the northeast coast (Port Ross) of the Auckland Islands (Patenaude, Baker and Gales, 1998), Campbell Island/Motu Ihupuku (Baker et al., 2010; Berkenbusch, Abraham & Torres, 2013), Milford Sound (Lusseau & Slooten, 2002), Chatham Rise, Fiordland, Te Waewae Bay and Wellington Harbours and Kapiti Coast (Torres, Halliday, & Sturman, 2013). In addition, it seems to be that whales are recolonising former calving sites of which had been displaced during former whaling activities, such as Auckland Islands (Rayment, Davidson, Dawson, Slooten and Webster, 2012); therefore, there have been an increase of southern right whales around mainland in New Zealand (Berkenbusch et al., 2013; Torres et al., 2013) (Figure 4.2).

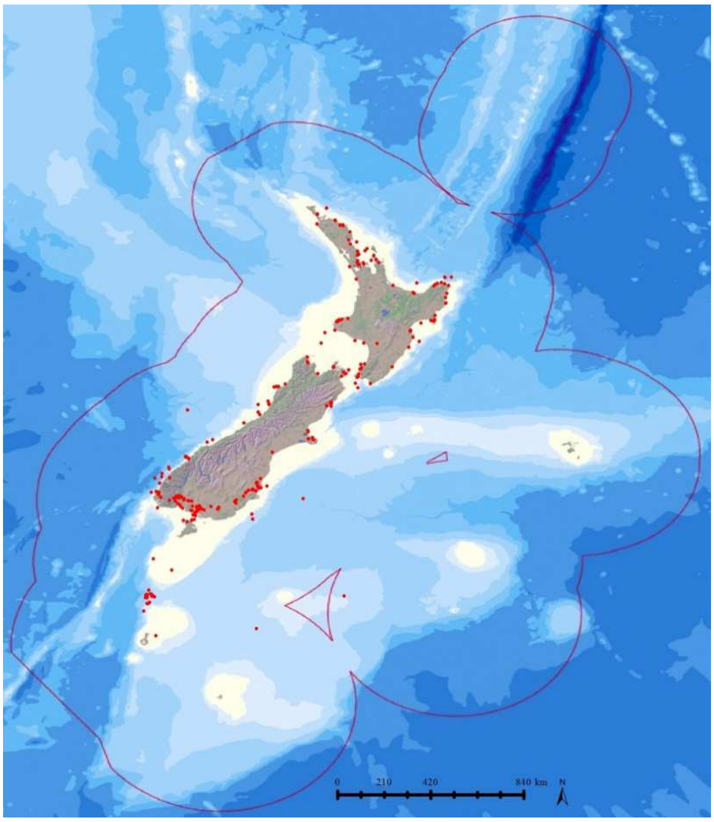


Figure 4.2. Sightings of southern right whales *Eubalaena australis* in New Zealand's Exclusive Economic Zone (EEZ). Source: Department of Conservation.

4.2.1.2. Family Balaenopteridae

4.2.1.2.1. Common minke whale (*Balaenoptera acutorostrata* Lacépède, 1804)

IUCN Status: Least Concern (2008)

New Zealand Status: Not threatened (Baker et al., 2010)

Common minke whale has a cosmopolitan distribution, and it can be found in almost all oceans, mainly in the North Atlantic and North Pacific, as well as in the southern hemisphere, although its migratory patterns are poorly known (Reilly et al., 2008a). In the North Atlantic, common minke whales, during summer, can be found around Ungava Bay and Baffin Bay (Canada), Denmark Strait, Norway and the Barents Sea;

ranging south to New Jersey (USA), Portugal and the Mediterranean Sea. During winter, they can be sighted from the Gulf of Mexico, Greater Antilles and Dominica to the Strait of Gibraltar (Rice, 1998; Reilly et al., 2008a). On the other hand, in the North Pacific, during the summer, this species is present at the Chukchi Sea south to the East China Sea; otherwise, the winter range is poorly known (Rice, 1998). In the southern hemisphere, records of this species are not reliable due to its sympatry with the Antarctic minke whale (*Balaenoptera bonaerensis*) (Reilly et al., 2008a) (Appendix 4.1; map 1).

Within the species *Balaenoptera acutorostrata* Lacépède, 1804, three sub-species have been recognised: *B. a. acutorostrata* Lacépède, 1804 (North Atlantic minke whale), *B. a. scammoni* Deméré, 1986 (North Pacific minke whale) and *B. a.* un-named subsp. (Dwarf minke whale) (Committee on Taxonomy, 2014). The latest subspecies has a circumpolar distribution and is found mainly off the South Atlantic coast of South America, off South Africa, Australia, New Zealand and New Caledonia (Rice, 1998; Reilly et al., 2008a).

In New Zealand waters, minke whales have been reported from the North Island in the Bay of Plenty (Stockin & Orams, 2009). In the South Island, the species have been reported from strandings at Golden Bay (Brabyn, 1991) and a sightings off Ferguson Island, Doubtful Sound in 1997, which was the first official record of this species in Fiordland (Lusseau & Slooten, 2002). In the literature there are references of sightings of minke whales, but due to its taxonomic uncertainty, it is not clear which species, either Antarctic (*Balaenoptera bonaerensis*) or Dwarf minke whale, was sighted. Gaborit-Haverkort (2012) reported sightings of *Balaenoptera acutorostrata/bonaerensis* in the Bay of Plenty (Gaborit-Haverkort, 2012). Other sightings of minke whales include Mercury Bay area, in the east coast of Coromandel Peninsula (Neumann, 2001) and the Great Barrier Island (Gaskin, 1968a) (Figure 4.3).

4.2.1.2.2. Bryde's whale (*Balaenoptera edeni* Anderson, 1879)

IUCN Status: Data Deficient (2008)

New Zealand Status: Nationally Critical (Baker et al., 2010)

As the taxonomy of the species is uncertain, the distribution of this species around the globe is not clearly known and different forms have been recognised based on their body length (Kato & Perrin, 2009). The large-type of Bryde's whales are distributed in all tropical and temperate waters in the Pacific, Atlantic and Indian Ocean between 40°N and 40°S (Kato & Perrin, 2009). This form, in the Pacific, has been reported in the Gulf of California, off the coasts of Peru, Ecuador, Chile and the north Island of New Zealand. In the Atlantic Ocean, this form has been reported in southern Africa in summer but migrates towards western Africa in winter (Best, 2001). In addition, they seems to be all year-around in Brazilian coasts (Zerbini, Secchi, Siciliano, & Simões-Lopes, 1997) and in the Gulf of Mexico (Mullin & Fulling, 2004) (Appendix 4.1; map 2).

In New Zealand waters, Bryde's whales seems to be mainly concentrated in the Hauraki Gulf where the species is present all year-around and it can be found mainly around the middle portion of the inner Gulf (O'Callaghan & Baker, 2002; Baker & Madon, 2007; Wiseman, Parsons, Stockin & Baker, 2011). In addition, there are reports of the species in Central Bay of Plenty (Gaborit-Haverkort, 2012), Mercury Bay area (Neumann, 2001), Great Barrier Island, where it is the most common baleen in the area (McDonald, 2006) and Bay of Islands (Stockin & Orams, 2009) (Figure 4.3).

4.2.1.2.3. Blue whale (*Balaenoptera musculus* L.)

IUCN Status: Endangered (2008)

The blue whale is a cosmopolitan species found in almost all the oceans around the world (Sears & Perrin, 2009). This species has four recognised subspecies *Balaenoptera musculus musculus* present in the northern hemisphere; *B. m. intermedia* found in antarctic waters, *B. m. indica* found in the northern Indian Ocean; *B. m. brevicauda* present in the subantarctic area of the southern Indian Ocean and south western Pacific Ocean; and finally, an un-named subspecies from Chile (Sears & Perrin, 2009; Committee on Taxonomy, 2014) (Appendix 4.1; map 2). In New Zealand waters, two sub-species have been reported *Balaenoptera musculus brevicauda* and *Balaenoptera musculus intermedia* (Baker et al., 2010) (Figure 4.3).

Pygmy blue whales stranding have been reported in the Hauraki Gulf and Henderson Bay, although the last one record is not accurate (Branch et al., 2007). Records compiled by the Department of Conservation report strandings of this particular subspecies at Rabbit Island, Tasman region; Waiinu beach, south of Waitotara, Taranaki; Wakawau Stream, south of Port Waikato and Himatangi Beach, Manawatu (Department of Conservation unpub. data). Other reports of *Balaenoptera musculus* (regardless of the subspecies), includes: Bay of Plenty (Gaborit-Haverkort, 2012), Great Barrier Island (McDonald, 2006), coastal waters off Greymouth on the west coast and southeast of Stewart Island, off Oamaru and Kaikoura on the east coast (Sears & Perrin, 2009), Chatham Rise (Torres et al., 2013) and the subantarctic region (Sears & Perrin, 2009). Apparently, this species has a wide range of distribution in New Zealand with two areas of apparent concentration in coastal waters of the North Island (Torres, 2013; Miller et al., 2013).

4.2.1.2.4. Humpback whale (*Megaptera novaeangliae* (Borowski, 1781))

IUCN Status: Least Concern (2008)
New Zealand Status: Migrant (Baker et al., 2010)

Humpback whale is a cosmopolitan species and it can be found in all oceans of the world (Clapham, 2009). Humpback whale is a migratory species moving between feeding (at mid- or high-latitude waters) and breeding grounds (in the tropics) (Dawbin, 1966). In the North Atlantic, humpback whales are found from the Gulf of Maine (USA) to Ireland, and up to the pack ice in the north; the northern extent of the humpback's range includes the Barents Sea, Greenland Sea and Davis Strait (Reilly et al., 2008e). Humpback whales' feeding grounds have been identified in the Gulf of Maine, Gulf of St. Lawrence, Newfoundland, Labrador, Greenland, Iceland, and Norway (Clapham, 2009). In the North Pacific, during the summer these whales are found from southern California¸ to the Gulf of Alaska, Bering Sea and southern Chukchi Sea, the Aleutian chain and Kamchatka, Kurile Islands, Okhotsk Sea and north-eastern Japan. In the southern hemisphere, humpback whales are found south to the ice edge. On the other hand, during the winter these whales are found in near shore breeding areas in the Atlantic, Indian and Pacific oceans (Reilly et al., 2008e) (Appendix 4.1; map 3).

In New Zealand, humpback whales are commonly sighted from May to October during their migration between the Antarctic, where their feeding grounds are located, and the tropical waters of the South Pacific during the winter where their breeding grounds are (Constantine, Russell, Gibbs, Childerhouse, & Baker, 2007; Berkenbusch et al, 2013). Sighting of humpback whales have been reported in Bay of Plenty (Gaborit-Haverkort, 2012); Great Barrier Island (McDonald, 2006), the Otago Peninsula (Hawke, 1989); Doubtful Sound and offshore from Cape Farewell, Fiordland (Webb, 1973; Lusseau & Slooten, 2002) and Chatham Rise (Torres et al., 2013). On the other hand, strandings of this species has been reported at New Plymouth (Brabyn, 1991) and Cook Strait (Childerhouse, 2006) in the North Island (Figure 4.3).

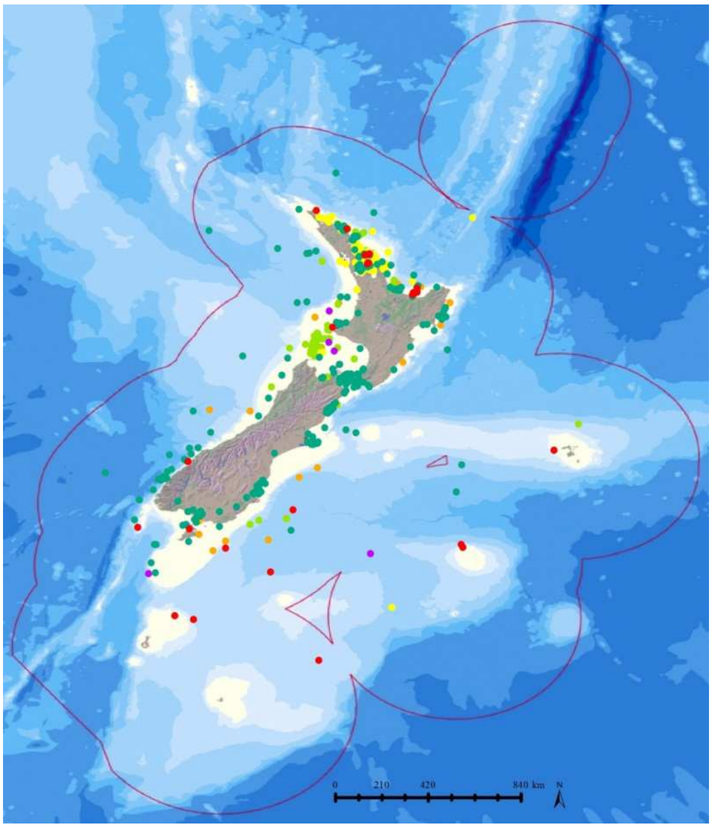


Figure 4.3. Sightings of Balaenopteridae family in New Zealand's EEZ. Minke whale (red dots), Bryde's whale (yellow dots), blue whale (green dots), fin whale (purple dots), Sei whale (orange dots) and humpback whale (turquoise dots). Source: Department of Conservation.

4.2.2. Toothed whales

4.2.2.1. Family Delphinidae

4.2.2.1.1. Hector's dolphin (*Cephalorhynchus hectori* Van Beneden, 1881)

IUCN Status: Endangered (2013)

New Zealand Status: Nationally Endangered (Baker et al., 2010)

Hector's dolphin is a species of toothed-whale endemic to New Zealand with a very restricted distribution. They are distributed along the coast of the south Island and the west coast of the North Island (Reeves et al., 2013a). In South Island, Hector's dolphins have been reported at Porpoise Bay (Bejder & Dawson, 2001); Banks Peninsula (Slooten, Dawson & Rayment, 2006; Martinez, 2010; Rayment, Dawson & Slooten, 2010; Dawson, Fletcher & Slooten, 2013); Kaikoura (Stockin and Orams, 2009), along the Otago coastline (Turek, Slooten, Dawson, Rayment & Turek, 2013), Jackson Bay area and Marlborough Sounds (Childerhouse, 2006). On the west coast of the South Island records come from Cape Foulwind, Karamea and Jackson Head (Brager & Schneider, 1998). In addition, have been seen concentrations of Hector's dolphins near river mouths, such as Ngakawau, Buller, Grey, Arahura, Haast, and Arawata Rivers, or prominent headlands, such as Dolomite Point, Point Elizabeth, and Tauperikaka Point directly southwest of Arnott Point (Brager & Schneider, 1998) (Figure 4.4).

4.2.2.1.2. Maui's dolphin (*Cephalorhynchus hectori maui* A. Baker, Smith and Pichler, 2002)

IUCN Status: Critical Endangered (2013)

New Zealand Status: Nationally Critical (Baker et al., 2010)

Cephalorhynchus hectori maui is the only recognised subspecies of the endemic Hector's dolphin (*Cephalorhynchus hectori hectori*), and is restricted to the west coast of the North Island of New Zealand (Ferreira & Roberts, 2003; Baker et al., 2010). Maui's dolphins range goes up North until Maunganui Bluff and down to south until New Plymouth (Slooten, Dawson, Rayment & Childerhouse, 2005). Maui's dolphins have been reported between Kaipara Harbour and Kawhia Harbour, but most of the sightings were made between the Manukau Harbour and Port Waikato (Ferreira and Roberts, 2003; Slooten et al., 2005) (Figure 4.4).

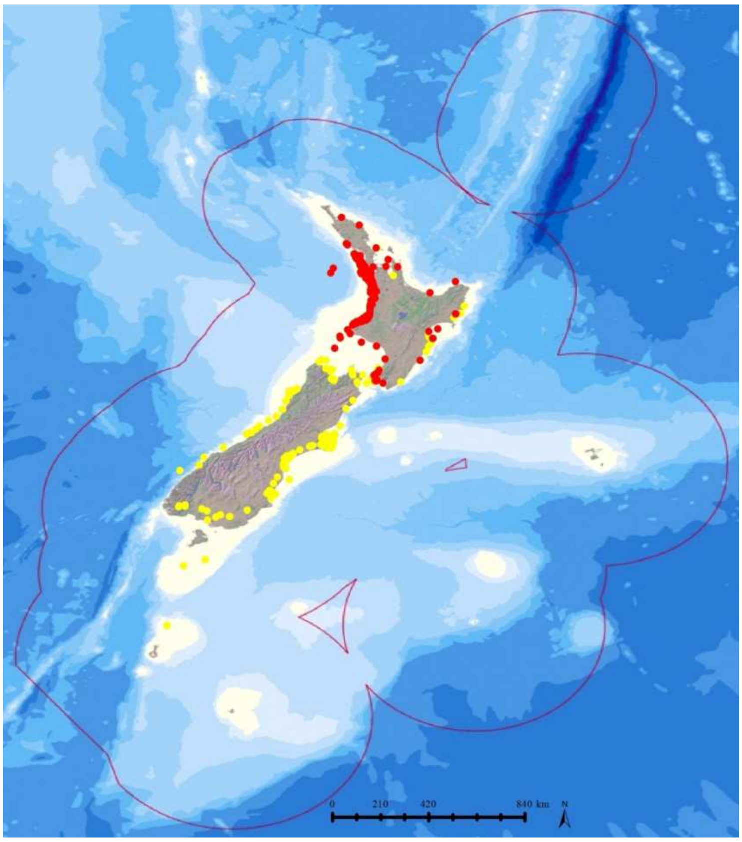


Figure 4.4. Sightings of Hector's dolphin *Cephalorhynchus hectori hectori* (yellow dots) and Maui's dolphin *Cephalorhynchus hectori maui* (red dots) in New Zealand's EEZ. Source: Department of Conservation.

4.2.2.1.3. Long-finned pilot whales (*Globicephala melas* (Traill, 1809))

IUCN Status: Data Deficient (2008)

New Zealand Status: Not threated (Baker et al., 2010)

The Genre *Globicephala* comprises two recognised species *G. melas* and *G. macrorhynchus* (Committee on Taxonomy, 2014). Long-finned pilot whales (*G. melas*) is distributed mainly in temperate waters and subpolar zones (Taylor et al., 2008). There are two different populations, one in the North Atlantic and other one in the southern hemisphere (Rice, 1998). The population in the North Atlantic can be found from western Greenland, eastern Greenland, Iceland, the Faroes and Norway, south to North Carolina, Açores, Madeira and Mauritania (Rice, 1998). In the southern hemisphere the species have been reported from southeast Brazil, South Africa, southern coast of Australia, New Zealand and Chile (Rice, 1998) and as far as he Antarctic Convergence (Taylor et al., 2008) (Appendix 4.1; map 4).

In New Zealand, Long-finned pilot whales have been reported in waters from both main islands, as well as off shore areas and subantarctic islands (Berkenbusch et al., 2013). In the North Island, there are records from the Central Bay of Plenty, where is presumed that this species is a potential offshore resident (Gaborit-Haverkort, 2012), Cook Strait region (Gaskin & Cawthorn, 1967) and the Hauraki Gulf (O'Callaghan & Baker, 2002). In the South Island, there have been reports at North Harbour, Auckland Islands (Baker, 1977), from west of Westport to north of Tasman Bay (Webb, 1973), at Dusky and Doubtful Sound in Fiordland (Lusseau & Slooten, 2002) and Chatham Rise (Torres et al., 2013) (Figure 4.5). Strandings have been report throughout the coastlines of New Zealand (Torres et al., 2013).

4.2.2.1.4. Short-finned pilot whale (*Globicephala macrorhynchus* Gray, 1846)

IUCN Status: Data Deficient (2011)

New Zealand Status: (Baker et al., 2010)

Short-finned pilot whales (*G. macrorhynchus*) have a tropical and subtropical distribution overlapping in few places with the Long-finned pilot whale (Olson, 2009). In the Atlantic, Short-finned pilot whales are distributed from the mid-coast of the United States to France (Rice, 1998; Olson, 2009). In the Pacific, this species can be found from Japan to Vancouver Islands, extending toward south until south-east Brazil, South Africa, Western Australia, Tasmania and the North Island of New Zealand (Rice, 1998) (Appendix 4.1; map 4). Sightings of this species have been made at White Island and Hauraki Gulf (Department of Conservation unpub. data).

4.2.2.1.5. Short-beaked common dolphin (*Delphinus delphis* L.)

IUCN Status: Least Concern (2008)

New Zealand Status: Not threatened (Baker et al., 2010)

Short-beaked common dolphin is a species widely distributed in warm-temperate and tropical waters worldwide; however, much of the distribution of this species is uncertain due to taxonomic problems (Rice, 1998). *Delphinus delphis* has been reported in the Atlantic, from Newfoundland to Argentina and from Norway to West Africa including the Mediterranean and the Black Seas (Rice, 1998; Perrin, 2009). In the Pacific, Short-beaked common dolphin range from southern Canada to Chile (except in Hawaii); and from central Japan to Taiwan, going to the south to New Caledonia, New Zealand, and Tasmania (Perrin, 2009) (Appedix 4.2; map 5).

In New Zealand waters, common dolphins are found in both Islands with more prevalence in the North Island (Gaskin, 1968). In the North Island, the species have been reported in the northwestern and the east coast of this Island (Neumann, 2001) and Central Bay of Plenty (Gaborit-Haverkort, 2012). In this last location, the dolphins were sighted mainly between Motiti Island, Mayor Island and Waihi on the mainland (Gaborit-Haverkort, 2012). In addition, there are reports from the Hauraki Gulf (O'Callaghan & Baker, 2002; Stockin et al., 2008b) and Mercury Bay area, east coast of Coromandel Peninsula (Neumann, 2001). Gaskin (1968) reported sightings at Hawke’s Bay, as well as large concentration of common dolphins off the Wairarapa Coast in summer and smaller schools near Wellington Harbour (Gaskin, 1968a) and Cook Strait (Bräger & Schneider, 1998) (Appendix 4.1).

The southern limit of common dolphin’s distribution seems to be near to Banks Peninsula in the South Island (Gaskin, 1968a). Reports on this Island include the Fjords (Lusseau & Slooten, 2002), around the west coast at Cape Foulwind and Jackson Head (Bräger & Schneider, 1998), off the Waiau rivermouth, Secretary Island in Doubtful and Marlborough Sounds (Webb, 1973; Lusseau & Slooten, 2002) and Chatham Rise (Torres et al., 2013) (Figure 4.5).

4.2.2.1.6. Dusky dolphin (*Lagenorhynchus obscurus* (Gray, 1828))

IUCN Status: Data Deficient (2008)

New Zealand Status: Not Threated (Baker et al., 2010)

Dusky dolphin has a patchy distribution in the southern hemisphere. They can be found in South America, from northern Peru to Cape Horn in Argentina, and from southern Patagonia, including the Falkland Islands (Rice, 1998; Van Waerebeek & Würsig, 2009). In Africa, they can be found from False Bay, South Africa to Lobito Bay, Angola in the southwestern part of the continent (Rice, 1998; Van Waerebeek & Würsig, 2009). In New Zealand, the species is found in the east coast of the island from Whitianga on North Island south to Stewart Island and is also found in Campbell, Auckland and Chatham Islands (Rice, 1998; Van Waerebeek & Würsig, 2009). In Australia, dusky dolphins are only known by few reports. They occur across southern Australia from Western Australia to Tasmania, and probably in south part of continental Australia. Finally, there are confirmed sightings near Kangaroo Island, South Australia, and off Tasmania (http://www.environment.gov.au/). In addition, some population of dusky dolphins are found around some oceanic islands such the Tristan da Cunha Archipelago in the mid-Atlantic, the Prince Edward Islands, and Crozet and Amsterdam Island in the southern Indian Ocean (Hammond et al., 2008) (Appendix 4.1; map 6).

In New Zealand waters, dusky dolphins are found mainly off the South Island and the southern portion of the North Island, although there are some reports of this species as far as Coromandel Peninsula in the North Island (Gaskin, 1968). In addition, dusky dolphins have been reported around the subantarctic Campbell and Auckland Islands, and Chatham Rise (Harlin et al., 2003; Würsig Duprey & Weir, 2007). In the North Island, the species have sighted south of East Cape (Würsig et al., 2007), at the Hawke's Bay area (Würsig et al., 2007), the Taranaki/Wanganui region and Wellington (Würsig et al. 1997).

On the other hand, in the South Island, the species have sighted in Admiralty Bay in the Marlborough Sounds (Weir, 2007), around Kaikoura area, Westport, Jackson Bay, southeastern Fiordland, Greymouth, Moeraki and Otago Harbour (Würsig et al., 2007; Stockin and Orams, 2009; Torres et al., 2013). In addition, the species has been reported at Banks Peninsula, between the Conway and Waiau Rivers, and to the north of Otago Harbour, between Kaikoura Peninsula and Haumuri Bluffs and Cloudy Bay (Cipriano, 1992; Würsig et al., 2007). Other reports confirm the presence of dusky dolphins at the Otago Peninsula (Hawke, 1989), around the fjords (Hudgins & Bachara, n.d.) and North Canterbury coast (Gaskin, 1968a), as well as, Cape Foulwind and Jackson Head (Bräger & Schneider, 1998), around Solander Island, Kahurangi Point, Greymouth, Tasman Bay (Webb, 1973) and Milford Sound (Lusseau & Slooten, 2002) (Figure 4.5).

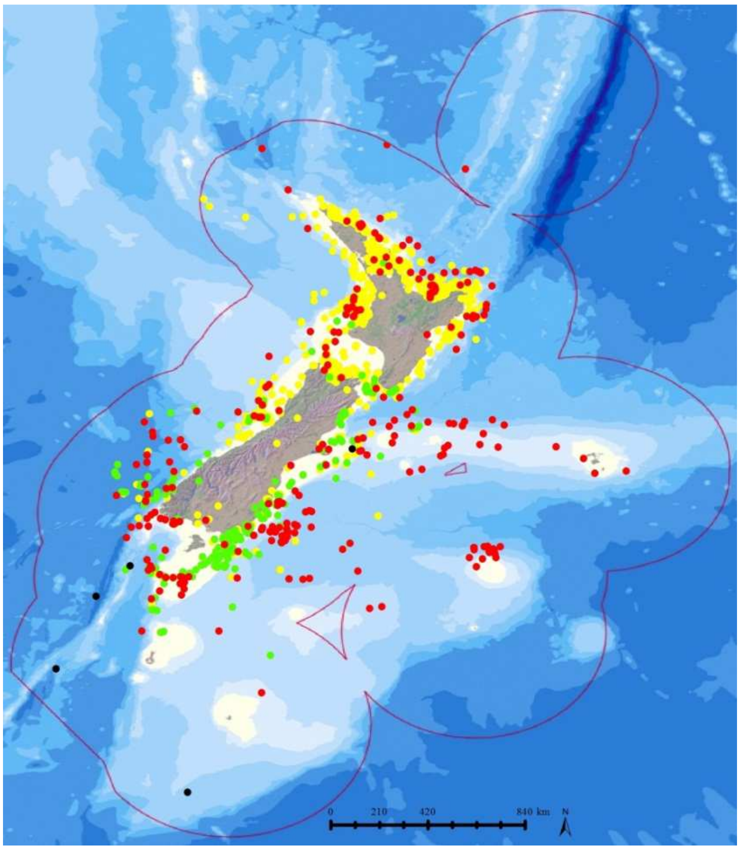


Figure 4.5. Sightings of pilot whales (red dots), short-beaked common (yellow dots), hourglass (black dots) and dusky dolphins (green dots) in New Zealand's EEZ. Source: Department of Conservation.

4.2.2.1.7. Bottlenose dolphin (*Tursiops truncatus* Montagu, 1821)

IUCN Status: Least Concern (2012)

New Zealand Status: Nationally Endangered (Baker et al., 2010)

Bottlenose dolphin is a species widely distributed around the world. This species can be found in almost all warm temperate and tropical seas, both inshore and offshore (Rice, 1998; Wells & Scott, 2009). In the northern hemisphere, they can be found as far as the Faroe Islands, southern Okhotsk Sea, the Kuril Islands, and central California, in the Pacific. In the Atlantic, they can be found off New England, offshore of Nova Scotia, and off Norway and the Lofoten Islands. In the southern hemisphere they have been reported as far as Tierra del Fuego (Argentina), South Africa, Australia, and New Zealand (Wells & Scott, 2009) (Appendix 4.1; map 6).

In New Zealand waters, there have been reported three discontinuous populations around the North Island, Marlborough Sounds, and Fiordland (Bräger and Schneider 1998; Constantine 2002; Tezanos-Pinto et al., 2009; Baker et al., 2010). The latter population seems to be divided into three different units found around Milford, Doubtful, and Dusky Sounds (Brager & Schneider, 1998). In North Island, the distribution of this species has been reports to be from Cape Reinga to Tauranga (Constantine, 2002; Gaborit-Haverkort, 2012). Although its distribution may extend on the west coast, from Manukau harbour and on the east coast to Gisborne (Tezanos-Pinto, 2009). In addition, the species has been sighted in the Hauraki Gulf (O'Callaghan & Baker, 2002; Berghan et al., 2008), Central Bay of Plenty (Gaborit-Haverkort, 2012); Mercury Bay area (Neumann, 2001); Bay of Islands (Visser et al., 2010) and at the Cook Strait region (Gaskin & Cawthorn, 1967) (Figure 4.7).

On the other hand, the Malborough Sounds population ranges from Westport to Cloudy Bay (Merriman, 2007; Tezanos-Pinto, 2009). Finally, the Fiordland population distribution ranges from Jackson Bay to Preservation Inlet (Bräger and Schneider, 1998). This species have been reported from Fiordland region, inhabiting 7 of the 14 fjords in this area (Lusseau, 2005). Bottlenose dolphins also have been reported around the West Coast (Brager & Schneider, 1998); Tasman Bay (Gaskin, 1968a) and Chatham Rise (Torres et al., 2013). Other places where this species has been reported includes Kaikoura (Visser, Fertl, & Pusser, 2004), some strandings in New Plymouth and Waitarere, Akaroa Peninsula and Stewart Island (Tezanos-Pinto, 2009). Additionally, there is a known population of bottlenose dolphin (*Tursiops* sp.) from the Kermadec Island, but due to the lack of information about this population no assessment has been done (Figure 4.7).

4.2.2.1.8. Orca, killer whale (*Orcinus orca* Linnaeus, 1758)

IUCN Status: Data deficient (2013)

New Zealand Status: Orca Type A: Nationally Critical (Baker et al., 2010)

Orcas are the marine mammal most widely distributed around the world. They can be found in all oceans and most seas, but is most common in coastal and temperate waters (Ford, 2009) (Appendix 4.1; map 7). Within the Genre *Orcinus*, only one species have been recognised, but in the Antarctic, three different ecotypes have been recognised, based on morphological and dietary characteristics (Figure 4.6) (Ford, 2009).

In New Zealand has been recognised the presence of the four ecotypes of orcas A, B, C and D (Baker et al., 2010), but only the ecotype A is recognised as resident (Berkenbusch et al., 2013). Orcas have been sighted frequently at Chatham Islands (Visser, 2000; Torres et al., 2013), Hauraki Gulf (O'Callaghan & Baker, 2002; Stockin et al., 2008b), Central Bay of Plenty (Gaborit-Haverkort, 2012) and Bay of Islands (Visser et al., 2010). In the South Island, Orcas have been reported in the Kaikoura area (Dahood, 2009), Otago Peninsula (Hawke, 1989), around the Fjords region (Lusseau, et al., 2002; Lusseau & Slooten, 2002), Westland, and Greymouth (Brager & Schneider, 1998). Regarding the other types of orcas, Visser (1999) reported the presence of eight orcas with different external characteristics to those regularly sighted in New Zealand waters. These orcas were sighted at the Bay of Plenty, and showed a lighter coloration, dorsal capes and bigger eye patch, whereby the author suggested that they could be "Antarctic orcas" or orcas type B (Visser, 1999). On the other hand, in 1955, there was a stranding in the west coast, of 17 orcas that, according with their external characteristics, they were defined as orcas "type C", although they presented different patterns of coloration recorded in other orcas from the same type (Visser, 2007) (Figure 4.7).

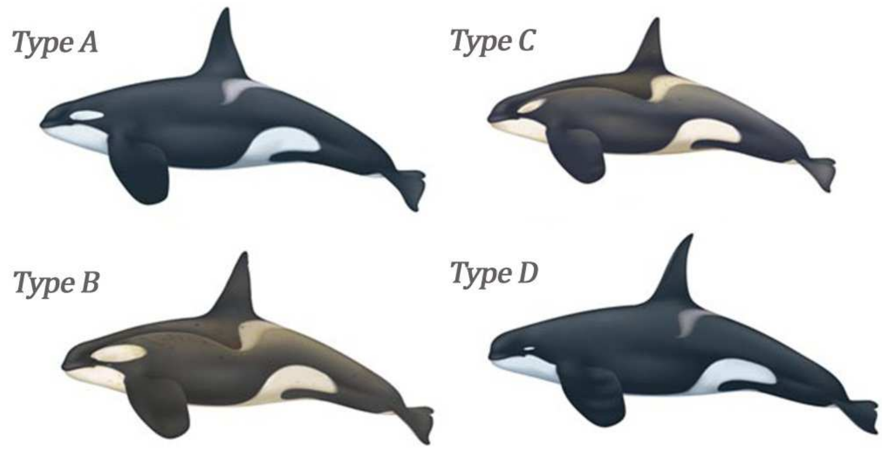


Figure 4.6. Recognised ecotypes of killer whales (*Orcinus orca*). Image modified from http://antarcticsun.usap.gov/science/images4/whales-killer-types-chart.jpg.

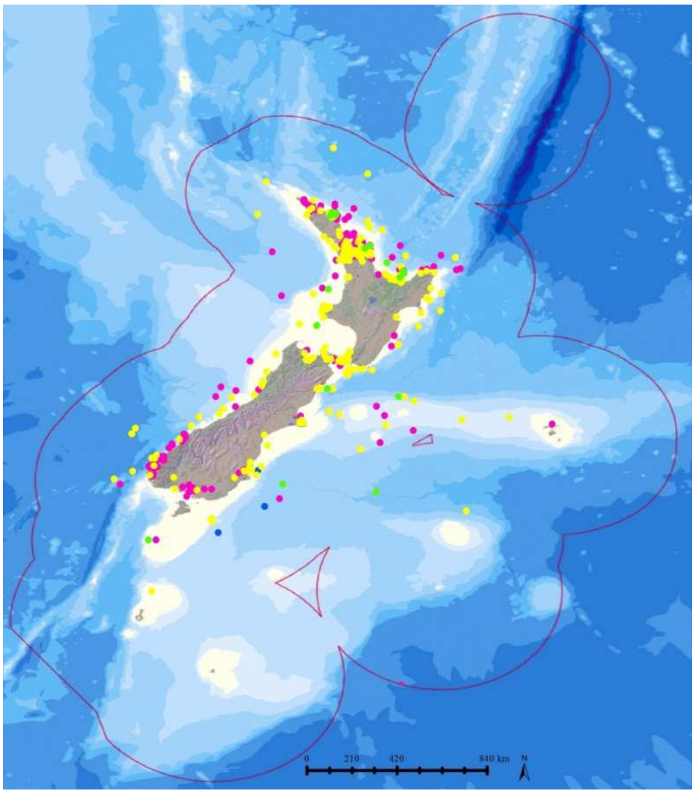


Figure 4.7. Sightings of southern right whale dolphin (blue dots), bottlenose dolphin (pink dots), orca (yellow dots) and false killer whale (green dots) in New Zealand's EEZ. Source: Department of Conservation.

4.2.2.3. Family Physeteridae

4.2.2.3.1. Sperm whale (*Physeter macrocephalus* Linnaeus, 1758)

IUCN Status: Vulnerable (2008)

New Zealand Status: Not threated (Baker et al., 2010)

Sperms whales are the third mammal most widely distributed around the world, just behind humans and orcas (Whitehead, 2009). In this species, both sexes have different patterns of distribution. Females inhabit more frequently deeper waters (>100m) at latitudes less than 40° (Whitehead, 2009) and far from land. On the other hand, young males can be found in tropical and subtropical waters together with the females, until they leave them, and commence to migrate towards the poles. Finally, the older and bigger males can be found close to the pack ice on both hemispheres, but they can move to warmer water during the reproduction time (Whitehead, 2009) (Appendix 4.1; map 10).

Sperm whales can be sighted in both offshore and nearshore regions in New Zealand. This species has been reported around Cook Strait (Gaskin & Cawthorn, 1967), Kaikoura region (Childerhouse et al., 1995; Richter et al., 2003; Sagnol, 2014; Sagnol, Ritcher, Field & Reitsma, 2014); west of George Sound, Fiordland coast (Webb, 1973) and Chatham Rise (Torres et al., 2013). Strandings have been reported at Kaipara Harbour, Northland and Gisborne, Wellington's coast and at Opoutama beach (Brabyn, 1991), Claverly Beach, Ohau point and Kaikoura peninsula (Torres et al., 2013) (Figure 4.8). Other species of cetacean foun in New Zealand waters are found in table

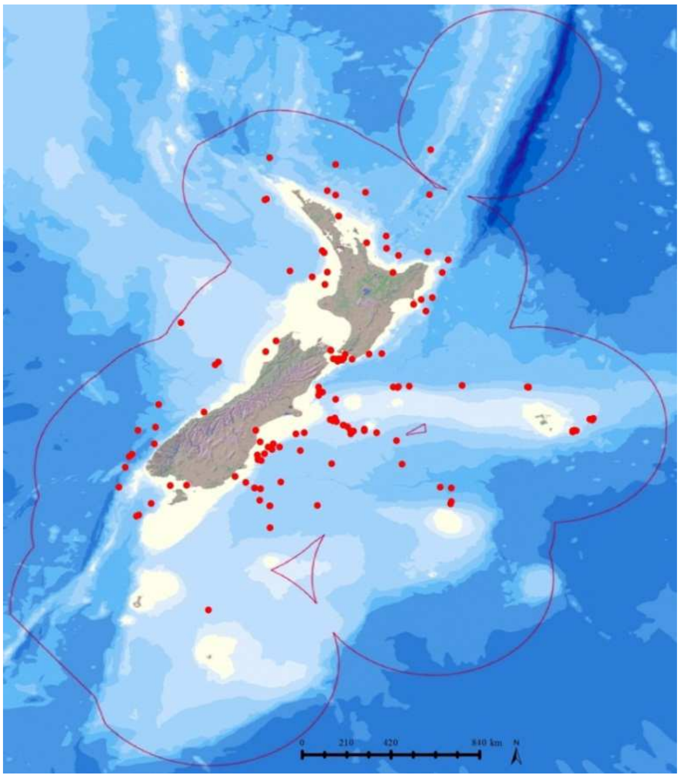


Figure 4.8. Sightings of sperm whales in New Zealand's EEZ. Source: Department of Conservation.

Table 4.1. List of other species of cetacean found in New Zealand waters.

Family	Species	Common name	IUCN Status	NZ Status	Global distribution (Appendix 4.1)
Balaenopteridae	Antarctic minke whale	Balaenoptera bonaerensis Burmeister, 1867	Data Deficient (2008)	Not threatened (Baker et al., 2010)	Map 1
	Sei whale	*Balaenoptera borealis* Lesson, 1828	Endangered (2008)	Migrant (Baker et al., 2010)	Map 2
	Pygmy blue whale	Balaenoptera musculus brevicauda Ichihara, 1966	Data Deficient (1996)	Migrant (Baker et al., 2010)	Map 2
	Antarctic blue whale	Balaenoptera musculus intermedia Burmeister, 1871	Critically Endangered (2008)	Migrant (Baker et al., 2010)	
	Fin whale	*Balaenoptera physalus* L.	Endangered (2013)	Migrant (Baker et al., 2010)	Map 3
Family Neobalaenidae	Pygmy right whale	*Caperea marginata* (Gray, 1846)	Data Deficient (2008)	Data Deficient (Baker et al., 2010)	Map 3
Family Delphinidae	Risso's dolphin	*Grampus griseus* (G. Cuvier, 1812)	Least concern (2012)	Vagrant (Baker et al., 2010)	Map 5
	Hourglass dolphin	*Lagenorhynchus cruciger* (Quoy & Gaimard, 1824)	Least Concern (2008)	Not threated (Baker et al., 2010)	Map 5
	Melon-headed whale	*Peponocephala electra*	Least Concern (2008)	Vagrant (Baker et al., 2010)	
	Southern right whale dolphin	*Lissodelphis peronii* (Lacépède, 1804)	Data Deficient (2012)	Not Threated (Baker et al., 2010)	
	False killer whale	*Pseudorca crassidens* (Owen, 1846)	Data Deficient (2008)	Not threated (Baker et al., 2010)	Map 7
	Pantropical spotted dolphin	*Stenella attenuata*	Least Concern (2012)	Vagrant (Baker et al., 2010)	
	Striped dolphin	*Stenella coeruleoalba*	Least Concern (2008)	Vagrant (Baker et al., 2010)	
		Steno bredanensis			
Family Kogiidae	Pygmy	*Kogia breviceps*	Data	Data	Map 8

	sperm whale	(Blainville, 1838)	Deficient (2012)	Deficient (Baker et al., 2010).	
	Dwarf sperm whale	*Kogia sima* (Owen, 1866)	Data Deficient (2012)	Vagrant (Baker et al., 2010)	Map 8
Family Phocoenidae	Spectacled porpoise	*Phocoena dioptrica* Lahille, 1912	Data Deficient (2008)	Vagrant (Baker et al., 2010)	Map 8
Family Ziphiidae	Arnoux's beaked whale	*Berardius arnuxii* Duvernoy, 1851	Data Deficient (2008)	Vagrant (Baker et al., 2010)	
	Southern bottlenose whale	*Hyperoodon planifrons* Flower, 1882	Least Concern (2008)	Data Deficient (Baker et al., 2010)	
	Andrews' beaked whale	*Mesoplodon bowdoini* Andrews, 1908	Data Deficient (2008)	Data Deficient (Baker et al., 2010)	
	Gray's beaked whale	*Mesoplodon grayi* von Haast, 1876	Data Deficient (2008)	Data deficient (Baker et al., 2010)	
	Blainville's beaked whale	*Mesoplodon densirostris* (Blainville, 1817)	Data Deficient (2008)	Data Deficient (Baker et al., 2010)	
	Ginkgo-toothed beaked whale	*Mesoplodon ginkgodens* Nishiwaki and Kamiya, 1958	Data Deficient (2008)	Vagrant (Baker et al., 2010)	
	Hector's beaked whale	*Mesoplodon hectori* (Gray, 1871)	Data Deficient (2008)	Data Deficient (Baker et al., 2010)	
	Strap-toothed whale	*Mesoplodon layardii* (Gray, 1865)	Data Deficient (2008)	Data Deficient (Baker et al., 2010)	
	Spade-toothed whale	*Mesoplodon traversii* (Gray, 1874)	Data Deficient (2008)	Data Deficient (Baker et al., 2010)	
	Shepherd's beaked whale	*Tasmacetus shepherdi* Oliver, 1937	Data Deficient (2008)	Data Deficient (Baker et al., 2010)	
	Cuvier's beaked whale	*Ziphius cavirostris* G. Cuvier, 1823	Least Concern (2008)	Data Deficient (Baker et al., 2010)	

Chapter Five

Using modelling techniques to mitigate anthropogenic noise impacts on cetaceans

5.1. Introduction

Ocean noise is a topic of current interest for many scientists and Government agencies due to its potential effects on marine fauna (Ocean Studies Board, 2005). This has motivated the search for mitigation measures to diminish and/or prevent harmful consequences for these animals. Mitigation measures vary depending on the source of noise, but existing measures may be insufficient to guarantee protection of marine mammals. Potentially widespread and damaging activities that have received increasing attention in recent years are noise characteristics associated with extraction of mineral (e.g. drilling, dredging, seismic surveys). Although the New Zealand government has developed protocols that seek to mitigate impacts, many of the impacts go unnoticed because mineral extraction operations cover large distances (Bombosch et al., 2014). To increase the effectiveness of these mitigation protocols, planned surveys and modelling of marine mammals, in space and in time, can help to minimise the noise impacts on them (Bombosch et al., 2014).

Regardless of which of the mitigation measures are used, they can be improved with the application of species distribution models (SMDs). Species distribution models are cost effective methodologies that relate spatial distribution and environmental features to predict the species' distribution in a pre-determined area (Elith & Leathwick, 2009). These models have been broadly used in diverse studies involved biodiversity and wildlife management such as effects of climate change, assessment of possible emerging diseases and estimation of the presence of rare or invasive species in a particular area, etc. (e.g., Edrén Teilmann, Dietz, & Söderkvist, 2010; Chunco, Phimmachak, Sivongxay & Stuart, 2013; Ortíz-Yusti, Resptrepo & Páez, 2014; Kumar, Graham, West, & Evangelista, 2015). The results generated from these models offer a base for prioritising conservation and management and can be helpful in improving management policies (Ferrier, 2002).

One method, commonly used in the last years for modelling species distribution has been MaxEnt (Phillips, Anderson, & Schapire, 2006; Lindsay, 2014; Ortíz-Yusti et al., 2014) (http://www.cs.princeton.edu/~schapire/maxent). MaxEnt is a general-purpose machine learning method that uses presence-only data of a determined species and contrast these data with the environmental information associated with each sighting, to provide information about the probability of a species occurrence (i.e., the more uniform distribution) (Phillips et al., 2006; Phillips & Dudík, 2008; Merow, Smith & Silander, Jr., 2013). MaxEnt offers high predictive accuracy, and has some advantages over other SMDs traditionally used such as Generalised Additive Models (GAMs), Generalised Linear Models (GLMs), climatic envelopes or boosted regression trees (Lindsay, 2014). A key advantage of MaxEnt is the use of presence-only data; due to true absences are difficult to prove and in many cases, as with marine mammals, are challenging to obtain (Phillips et al., 2006; Elith et al., 2011). In addition, it provides the opportunity to use both categorical and continuous variables and it is a generative rather than a discriminative model, hence effective for small data sets. Finally, MaxEnt can be used to assess complex relationships among variables, providing researchers with a tool for identifying the variables that contribute most to the models of species distribution (Phillips et al., 2006; Baldwin, 2009).

The overall goal of this chapter is to combine information on marine mammal distributions with known (and proposed) locations of anthropogenic noise production to help inform planning and decision making concerning activities undertaken offshore, such as drilling, dredging and seismic surveys, in order to minimise the impact of anthropogenic noise on marine mammals. The objectives of this chapter are to: 1) generate distribution models of a range of threatened marine mammals in New Zealand, and 2) compare these distributions to locations of ongoing and proposed anthropogenic noise operations.

5.2. Methods

5.2.1. Study area

New Zealand is an island nation located in the South Pacific, approximately 1,600 km from both Australia and Polynesia (Lat 34° to 47°S, spanning more than 2,000 km). New Zealand in made up of three main islands: North, South and Stewart Islands, and more than 700 island and islets mostly within 50 km of the coast. Other important islands around mainland New Zealand include the Antipodes, Auckland, Campbell, Chatham and Kermadec Islands. The three main islands cover an area of approximately 166.940 km^2. Of the three main islands, the South Island is the largest with an approximate area of 150.437 km^2, followed by the North Island with 113.729 km^2, and finally Stewart Island, the smallest of the three with 1680 km^2 (Gordon, Beaumont, MacDiarmid, Robertson & Ahyong, 2010; http://www.teara.govt.nz/en/natural-environment/page-1). New Zealand possesses an Exclusive Economic Zone (EEZ) of approximately 4.2 million km^2, which is around 15 times larger than the land mass and is the seventh largest EEZ in the world. New Zealand's EEZ spans from 30° of latitude, from the subtropics (latitude 26°S, north of the Kermadec Islands) to the subantarctic (latitude 56°S, south of Campbell Island) (Vincent, Wake, Austin & Bradford, 1989; Gordon et al., 2010) (Figure 5.1).

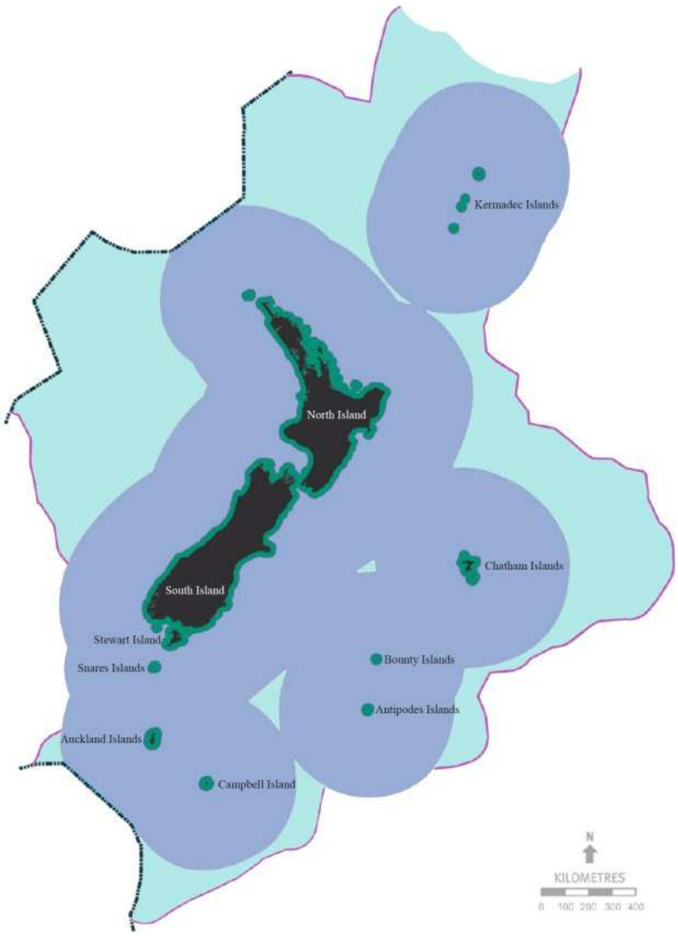


Figure 5.1. Map of New Zealand showing its Territorial Sea (green), the Exclusive Economic Zone (purple) and extended Continental Shelf (blue). Modified from National Institute of Water and Atmospheric Research (NIWA).

5.2.2. Target species and sightings data

Seven species were selected to perform the habitat modelling analysis using MaxEnt (Table 5.1). These species were chosen based on the degree of threat according to the New Zealand Threat Classification System; species classified as "Nationally Critical" and "Nationally Endangered" are prioritised in this study (Baker et al., 2010). In addition, sperm whale was included in the models. Although this species is not endangered, it is exposed to large amounts of tourism pressure and its population are subject of continuous perturbations (Richter, Dawson, & Slooten, 2006). The records of the presence of all target species were obtained through the Department of Conservation's marine mammal sightings database (H. Hendriks pers. comm.). These data include date, location (region and coordinates) of cetacean sightings (i.e. presence-only data) and name of the species sighted (common and scientific).

Table 5.1. Species chosen for MaxEnt analysis, showing the threat classification allocated by IUCN and the New Zealand Threat Classification System.

Scientific name	Common name	NZ threat classification	IUCN threat classification
Balaenoptera edeni	Bryde's whale	Nationally Critical	Data Deficient
Cephalorhynchus hectori maui	Maui's dolphin	Nationally Critical	Critically Endangered
Orcinus Orca	Orca, killer whale	Nationally Critical*	Least Concern
Cephalorhynchus hectori hectori	Hector's dolphins	Nationally Endangered	Endangered
Eubalaena australis	Southern right whale	Nationally Endangered	Least Concern
Tursiops truncatus	Bottlenose dolphin	Nationally Endangered	Data deficient
Physeter macrocephalus	Sperm whale	Not threatened	Vulnerable

*Only Orca Type A is under the category "Nationally Critical".

5.2.3. Environmental variables

Seven environmental variables were used to generate the potential distribution models of the species selected for the analysis: depth; seabed rate of change of slope; sediment type; annual amplitude of Sea Surface Temperature (SST); summertime SST anomaly; wintertime SST and tidal current (Table 5.2). These variables were chosen as proxies of environmental characteristics that could affect the distribution of cetaceans and/or their prey. In addition, some of these variables have been commonly used in other works involving cetaceans' habitat modelling, suggesting that they might be good predictors of their distribution (e.g. Edrén et al., 2010; Thorne et al., 2012; Bombosch et al., 2014; Correia et al., 2015; Gomez & Cassini, 2015). The environmental variables were obtained as GIS raster layers, which were developed as part of the New Zealand Marine Environment (MEC) project (Snelder et al., 2005). These environmental layers were done using multivariate clustering of several spatially explicit data layers to describe the physical environment at the New Zealand Economic Exclusive Zone (See Snelder et al., 2005). The environmental variables were used at a 1 x 1 km nominal spatial resolution.

Table 5.2. Environmental variables used in MaxEnt (Developed by MEC project).

Environmental variable	Abbreviation	Description	Units
Depth	depth	Bathymetry grid (1 km resolution)	m
Seabed rate of change of slope (profile)	bed_prof	The rate of change of slope for each cell	$0.01m^{-1}$
Sediment type	sed	Sediment type as a categorical variable	n/a
Annual amplitude of sea surface temperature	ssta	Smoothed annual amplitude of SST	^{o}C
Summertime sea surface temperature anomaly	sstanom	Spatial anomalies with scales between 20 and 450 km in late February when SST is typically highest	^{o}C
Wintertime sea surface temperature	sstw	Mean of daily data from early September when SST is typically lowest	^{o}C
Tidal current	tidal	Depth averaged maximum tidal current	m/s

5.2.4. Ecological niche modelling

Modelling of the potential distribution of the seven species of cetaceans was done using the software MaxEnt v.3.3.3k (http://www.cs.princeton.edu/~schapire/maxent). MaxEnt is a general-purpose machine learning methodology that produces habitat suitability models by comparing sighting data with environmental covariates in a determined area (Phillips et al., 2006; Lindsay, 2014). As output, MaxEnt gives the relative probability of observing the species in each cell, i.e. those cells with environmental variables close to the means of 'presence' locations have higher probability of suitability (Phillips et al., 2006).

5.2.5. Data transformation

MaxEnt requires that all the environmental layers have the same geographic bounds and cell size. For my dataset, all the environmental layers were in different projections, and had to be re-projected at the same coordinate system. This data transformation process was done using the program ArcGIS 10.2 (ESRI 2013. ArcGIS Desktop: Release 10.2. Redlands, CA: Environmental Systems Research Institute). The projections of all the environmental layers were changed to NZGD 2000 New Zealand Transverse Mercator. Next, using the tool "Extract by mask", in the "Spatial Analyst Tool", all the environmental layers were clipped and the extent and cell size were appropriately modified. Finally, all the raster files were converted to ASCII format. In addition, all sightings coordinates were projected onto NZGD 2000 New Zealand Transverse Mercator system with the help of the same program to match with the coordinate system given to the environmental layers. These data were saved in CSV format.

5.2.6. MaxEnt settings

Once the environmental variables and sightings were in the correct formats, the model was run. Some of the default settings were kept for running the model, but others were adjusted. The output format selected was "Raw", as this type of output does not rely on post-processing assumptions (Merow et al., 2013) and can generate results that are more accurate in this case. For running the model, 15 replications were performed and 25% of the data were selected for testing the model, which allows verifying the efficiency and variability of the model (Young, Carter & Evangelista, 2011). Based on these two features, a subsample replicate run type was chosen, thus one can control the number of repetitions and percentage of withheld test occurrences (the sighting dataset was considerably large than the subsamples). Finally, 5000 iterations were used to allow the model time to converge and avoid an over- or under-prediction of the relationships (Young et al., 2011).

5.2.7. Model validation

The validation of the model was done using the Receiver Operating Characteristic curve (ROC) and the Area Under the Curve (AUC) value. The ROC curve plots sensitivity (true positives) against 1–specificity (false positives); representing how well the data predicts presence and how correctly absences are predicted, respectively (Fielding & Bell, 1996; Thorne et al., 2012). The AUC value is a direct measure of the discrimination ability of the model with a value between 0 and 1. Values close to 1 indicate that there is a good fit of the model; values near 0.5 indicate a fit no better than the models obtained by random (Phillips et al., 2006). Based on other studies with cetaceans (e.g. Thorne et al., 2012; Lindsay, 2014) AUC values of ROC were evaluated as follow: < 0.5 indicates no discrimination; 0.5 – 0.7 indicates poor discrimination; 0.7 – 0.8 indicates an acceptable discrimination; 0.8 – 0.9 indicates excellent discrimination and finally, > 0.9 indicates outstanding discrimination.

For environmental variables, a Jackknife test was performed to measure and determine which of these variables were the most important for the estimated models. This test excludes one variable at a time while running the model, an approach that provides information on the performance of each variable and how each one is important explaining the species distribution (Baldwin, 2009). Finally, correlations between environmental variables were tested before running the model, as the inclusion of highly correlated variables may produce an over-fitting of the model. For example, if two variables have a correlation coefficient > 0.80, only one was entered into the model, based on my assessment of the likely biological importance of the variables for the species. Correlations between variables were assessed using a correlation matrix using the Principal Components Analysis in ArcGIS.

5.2.8. Areas of industrial activities in New Zealand

To examine the areas where cetacean distribution and industrial activities in New Zealand coincide, maps showing active and future areas for these activities and the species maps generated with MaxEnt were overlapped. Using ArcGIS 10.2, the raster maps obtained in MaxEnt were transformed into presence/absence maps. To do so, the average of the maximum training sensitivity plus specificity logistic threshold values were used, and the threshold corresponding to this value for the 'raw' output was taken from the sample prediction datasheets generated by MaxEnt. Because 15 replicates were made, the value most similar to the value obtained in the logistic result was used as a threshold. Subsequently, all the raster maps were converted to shapefiles. Species distributions and industrial activities layers were clipped and the areas where both layers overlap were obtained. Finally, the table of attributes of each shapefile were converted to Excel files (MS Excel Microsoft Corporation) and the percentage of overlap calculated. The maps showing the exploration and exploitation areas were sources from the New Zealand Petroleum and Mineral website and this information correspond for the present year (http://data.nzpam.govt.nz/permitwebmaps?commodity=petroleum).

5.3. Results

5.3.1. Correlation between variables

Only two variables were highly correlated: annual radiation (rad) and wintertime sea surface temperature (sstw) (Table 5.3). Due to this high correlation, rad was excluded from the analysis and sstw was kept; sstw is a better proxy for water productivity (Senelder et al., 2005) and more informative in terms of cetacean biology (Acevedo, 1991b). Therefore, the final model included seven environmental variables: bed profile; depth; sedimentation; annual amplitude of sea surface temperature; summertime sea surface temperature anomaly; wintertime sea surface temperature and tidal.

Table 5.3. Correlation between all environmental variables used in this analysis. Correlations (r) > 0.80 are shown in bold.

Variables	bed_prof	depth	rad	sed	ssta	sstanom	sstw	tidal
bed_prof	-	0.18	0.01	0.02	0.01	0.04	0.02	-0.08
depth	0.18	-	0.00	0.01	0.10	0.11	0.06	-0.50
rad	0.01	0.00	-	-0.17	0.61	0.04	**0.98**	-0.11
sed	0.02	0.01	-0.17	-	-0.03	0.04	-0.20	0.08
ssta	0.01	0.10	0.61	-0.03	-	0.14	0.56	-0.14
sstanom	0.04	0.11	0.04	0.04	0.14	-	0.09	-0.19
sstw	0.02	0.06	**0.98**	-0.20	0.56	0.09	-	-0.15
tidal	-0.08	-0.50	-0.11	0.08	-0.14	-0.19	-0.15	-

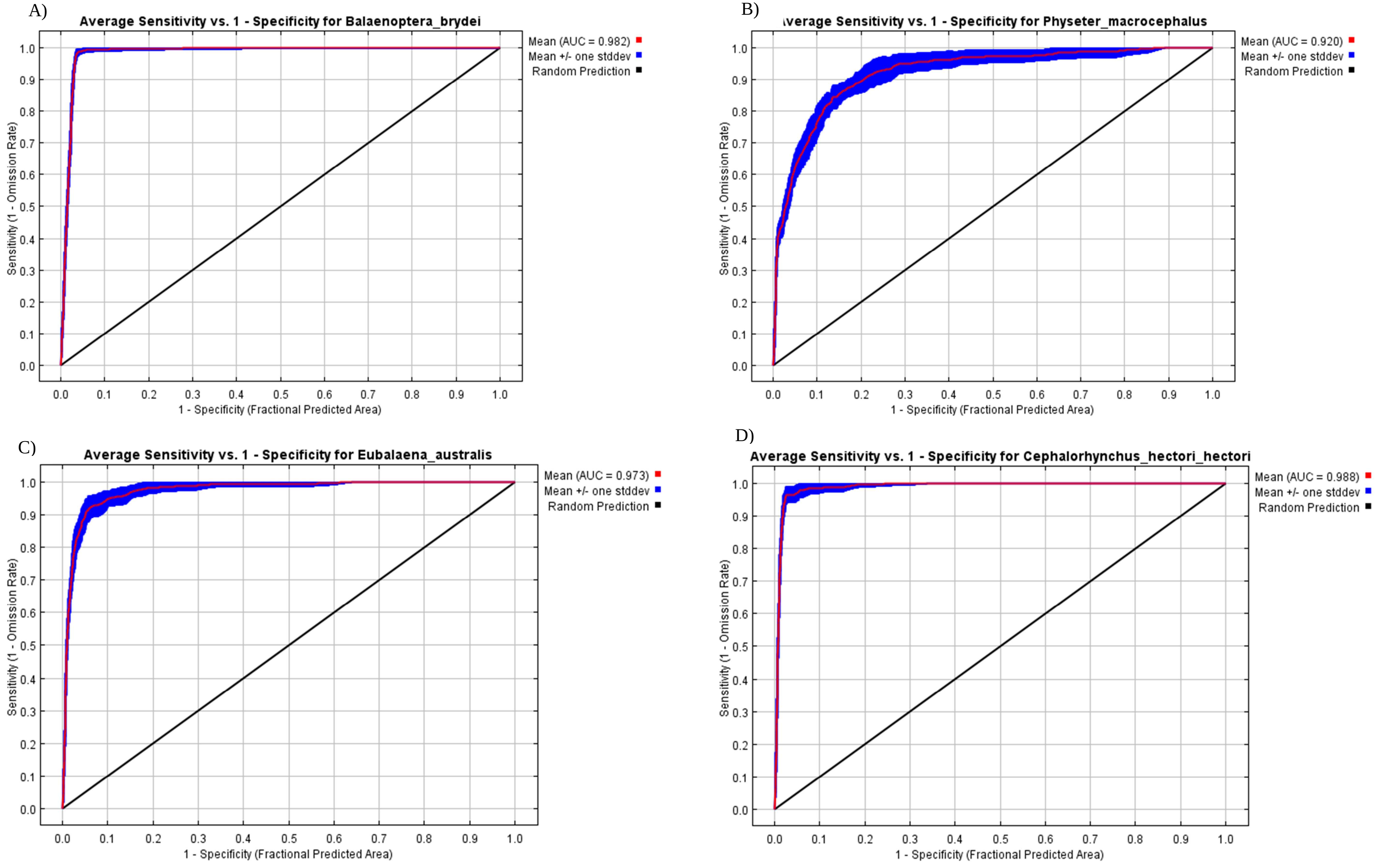
5.3.2. Habitat modelling

5.3.2.1. Models evaluation and contribution of environmental variables

All the models obtained for each species showed an AUC above 0.9, which indicates that they had outstanding discriminatory power (See Methods section; Figure 5.2). Overall, for the environmental variables used in these analyses, depth and sediment had the greatest explanatory (predictive) power. For the sperm whale, the model showed that sediment had the highest predictive power followed by depth (Table 5.4; Figure 5.3).

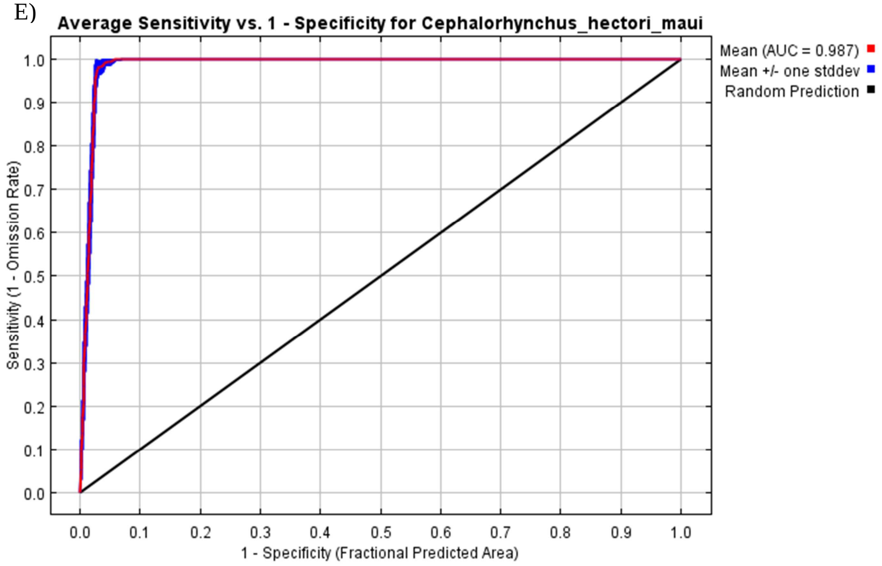
Table 5.4. AUC values and most important predictive environmental variables for each species assessed with MaxEnt.

Species	AUC values	Environmental variable
Balaenopera brydei	0.982	depth, sed
Eubalaena australis	0.973	depth, sed
Cephalorhynchus hectori hectori	0.988	depth, sed
Cephalorhynchus hectori maui	0.987	depth, sed
Tursiops truncatus	0.968	depth, sed
Orcinus orca	0.973	depth, sed
Physeter macrocephalus	0.920	sed, depth

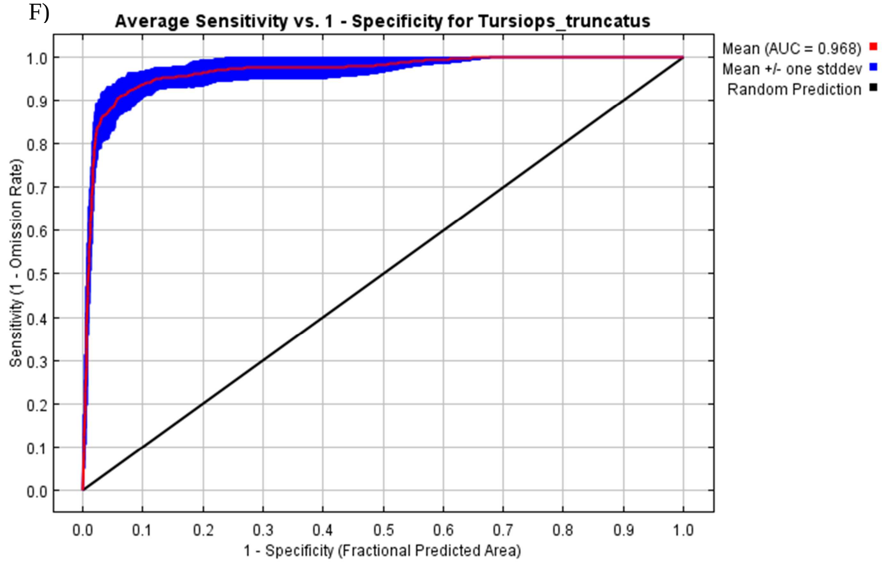


A)
Average Sensitivity vs. 1 - Specificity for Balaenoptera_brydei
Mean (AUC = 0.982)
Mean +/- one stddev
Random Prediction
Sensitivity (1 - Omission Rate)
1 - Specificity (Fractional Predicted Area)
B)
verage Sensitivity vs. 1 - Specificity for Physeter_macrocephalus
Mean (AUC = 0.920)
Mean +/- one stddev
Random Prediction
Sensitivity (1 - Omission Rate)
1 - Specificity (Fractional Predicted Area)
C)
Average Sensitivity vs. 1 - Specificity for Eubalaena_australis
Mean (AUC = 0.973)
Mean +/- one stddev
Random Prediction
Sensitivity (1 - Omission Rate)
1 - Specificity (Fractional Predicted Area)
D)
Average Sensitivity vs. 1 - Specificity for Cephalorhynchus_hectori_hectori
Mean (AUC = 0.988)
Mean +/- one stddev
Random Prediction
Sensitivity (1 - Omission Rate)
1 - Specificity (Fractional Predicted Area)

E)



F)



G)

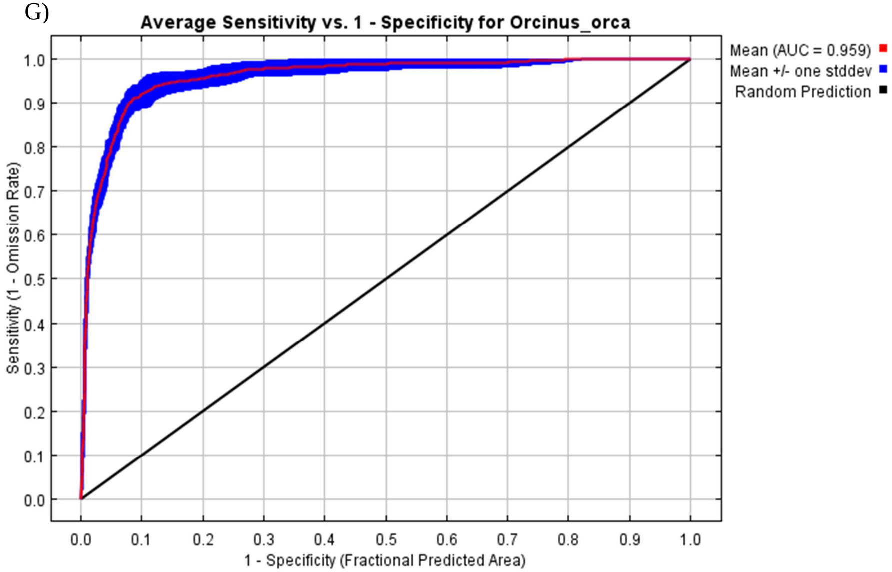
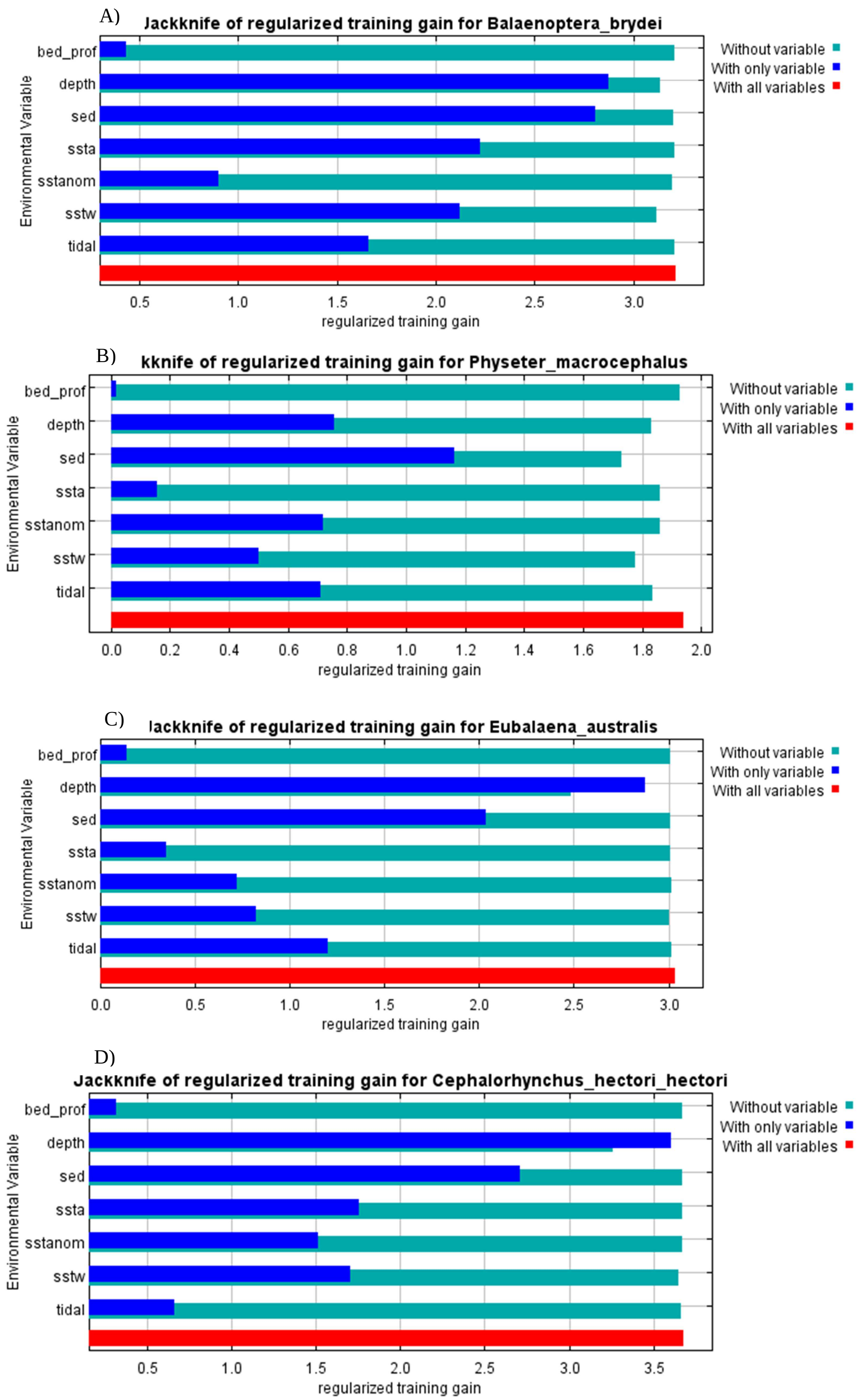


Figure 5.2. Mean AUC (red line) and mean ± one standard deviation (blue line) for assessing the predictive accuracy of suitable habitat for A) Bryde’s whale, B) Sperm whale, C) Southern right whale, D) Hector’s dolphin, E) Maui’s dolphin, F) Bottlenose dolphin and G) Orca.


A)
Jackknife of regularized training gain for Balaenoptera_brydei
Environmental Variable
bed_prof
depth
sed
ssta
sstanom
sstw
tidal
0.5 1.0 1.5 2.0 2.5 3.0
regularized training gain
Without variable
With only variable
With all variables
B)
kknife of regularized training gain for Physeter_macrocephalus
Environmental Variable
bed_prof
depth
sed
ssta
sstanom
sstw
tidal
0.0 0.2 0.4 0.6 0.8 1.0 1.2 1.4 1.6 1.8 2.0
regularized training gain
Without variable
With only variable
With all variables
C)
Jackknife of regularized training gain for Eubalaena_australis
Environmental Variable
bed_prof
depth
sed
ssta
sstanom
sstw
tidal
0.0 0.5 1.0 1.5 2.0 2.5 3.0
regularized training gain
Without variable
With only variable
With all variables
D)
Jackknife of regularized training gain for Cephalorhynchus_hectori_hectori
Environmental Variable
bed_prof
depth
sed
ssta
sstanom
sstw
tidal
0.5 1.0 1.5 2.0 2.5 3.0 3.5
regularized training gain
Without variable
With only variable
With all variables

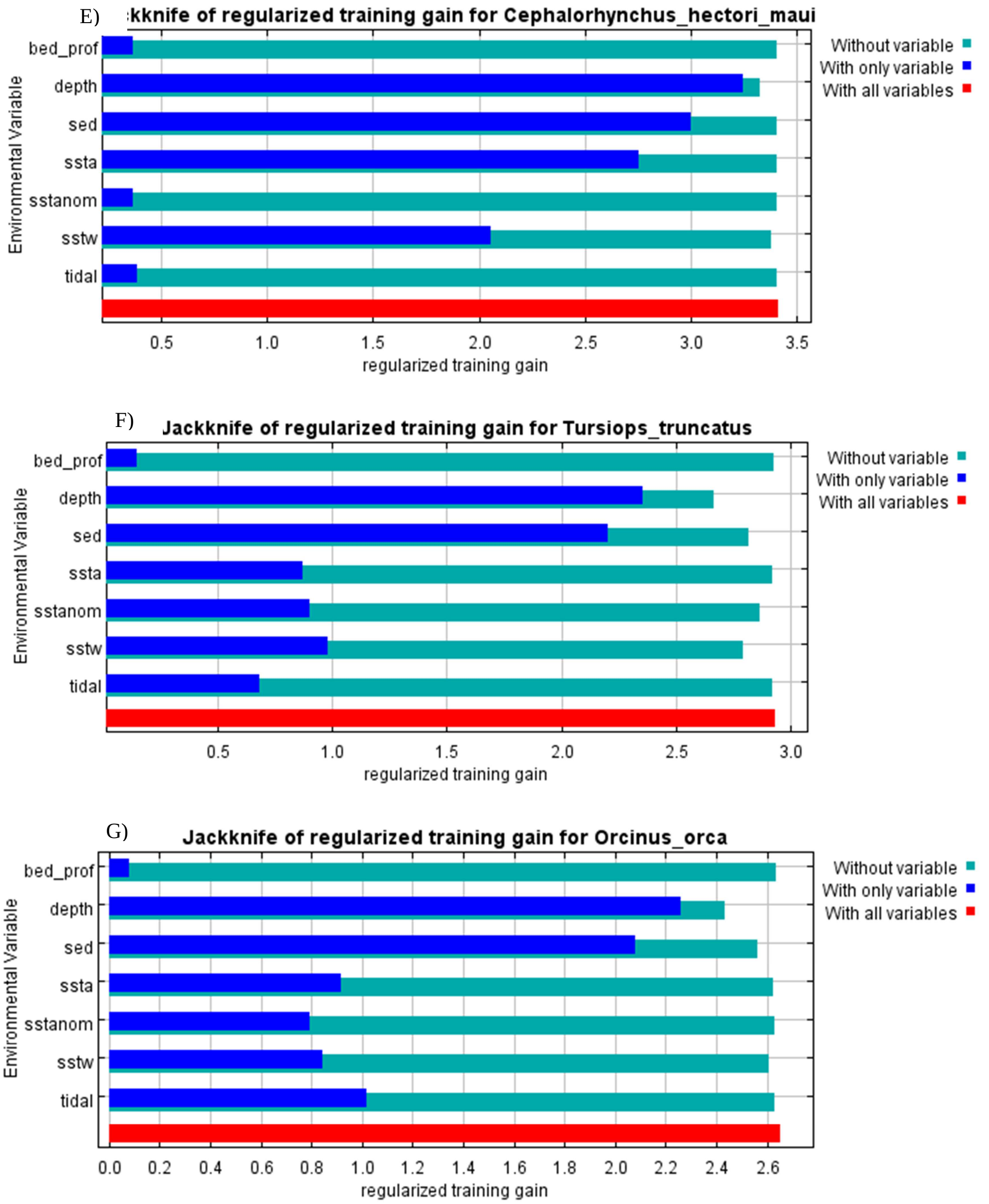
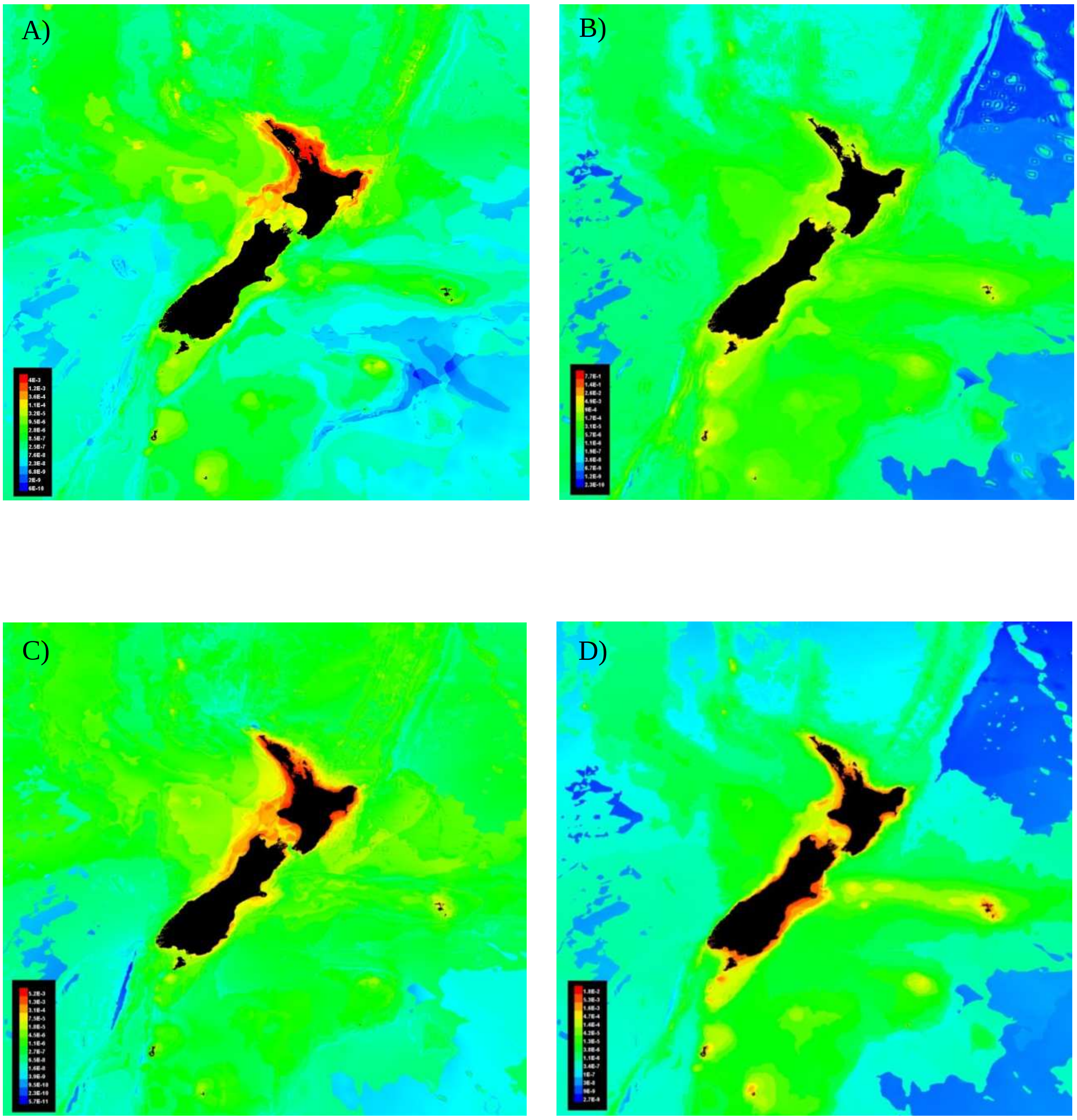


Figure 5.3. Jackknife tests of variable contributions for informing the model training gain for predicting suitable habitat for A) Bryde's whale, B) Sperm whale, C) Southern right whale, D) Hector's dolphin, E) Maui's dolphin, F) Bottlenose dolphin and G) Orca. Models were run with each variable in isolation (blue bars) and with each variable excluded (green bars). The red bar indicates the model run with all variables included.

5.3.2.2. Habitat suitability maps

Predictive maps of habitat suitability for the seven species of cetaceans assessed, showed different patterns of suitability. For Bryde's whale, maps showed a high suitability on both east and west coast of the North Island. On the west coast, the most suitability areas ranged from zones surronding the North Cape to south Taranaki Bight, and the Cook Strait area. For the east coast of the North island, the most suitable areas were the Hauraki Gulf and Bay of Plenty and Gisborne with an extension to northern Hawke's Bay. For small delphinids (Hector's, Maui's, and bottlenose dolphin), the suitability area is concentrated near the coast on both coasts of the North Island. For Maui's dolphin, the suitability areas can reach the northern part of the South Island, including Cook Starit. The Hector's dolphin suitability area also extends along the east coast of the South Island to Foveaux Strait. It should be noted that the models also showed suitable habitat for Hector's dolphin around the Chatham Islands.

Additionally, bottlenose dolphin showed high suitability in the northern part of the South Island (around Cook Strait), around Foveaux Strait in the southern portion of the South Island and around Chatham Island. For orca, suitability areas are wide ranging and cover the coast of both main islands and offshore waters of the east coast of the South Island. Sperm whale suitable areas are located in off shore waters of the South Island, in a region know as Canterbury basin and Bounty Trough, similar to the distribution shown by orca in the same area. Finally, the southern right whale map showed the lowest probality of suitability of all modelled species (characterized by yellow color) but the suitable area for this species included the entire coastal area of New Zealand, and it is extended as far as Campbell island (Figure 5.4).


A)
B)
C)
D)

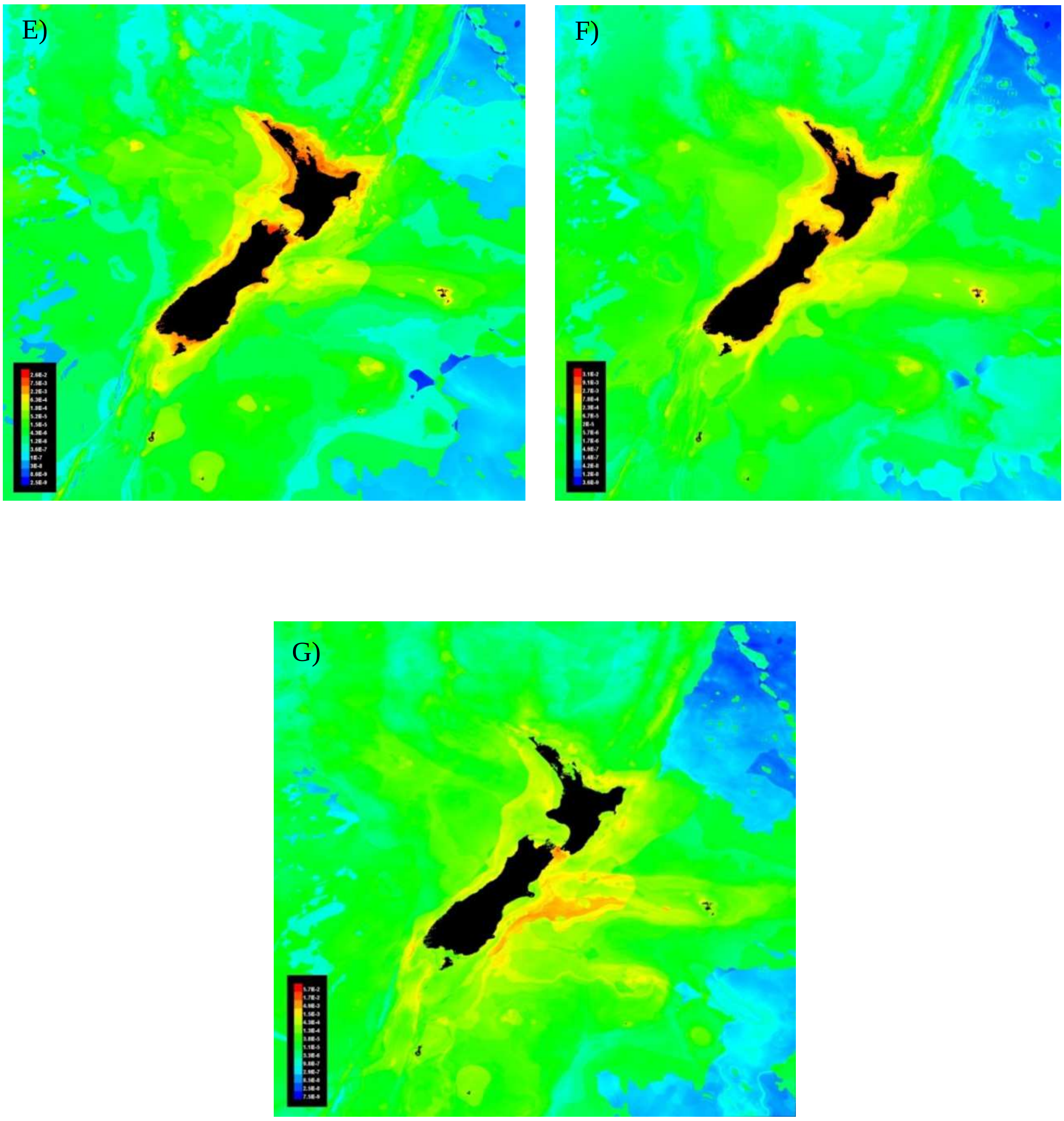


Figure 5.4. Predicted suitability maps for A) Bryde's whale; B) Southern right whale; C) Maui's dolphin; D) Hector's dolphin; E) Bottlenose dolphin; F) Orca and G) Sperm whale. Warmer colors mean higher habitat suitability.

5.3.3. Exploration and exploitation areas and Cetacean distribution in New Zealand

Currently, the extraction and exploitation areas in New Zealand can be analysed based on the basin where these activities are undergoing or are planned. Areas where these activities are undergoing include three main areas. First, (A) the area between Taranaki, New Caledonia and Northland Reinga basins, on the west coast of the North Island. The second area is within the East Coast Basin (B) and the last one, the area around the Canterbury and the Great South Basin on the east coast of the South Island (C) (Figure 5.5).

In addition, there are some areas designated for allocation of strategic permits for exploration regulated by New Zealand's Government. The blocks being tendered for 2015 offshore areas are Northland-Reinga (186,181 km^2), Taranaki (53,253 km^2), Pegasus/East Coast (44,015 km^2) and Great-South Canterbury (141,757 km^2). Additionally, an area of around 370,496 km^2, from Gisborne to Southland, has been made available for petroleum prospecting permits (Figure 5.6).

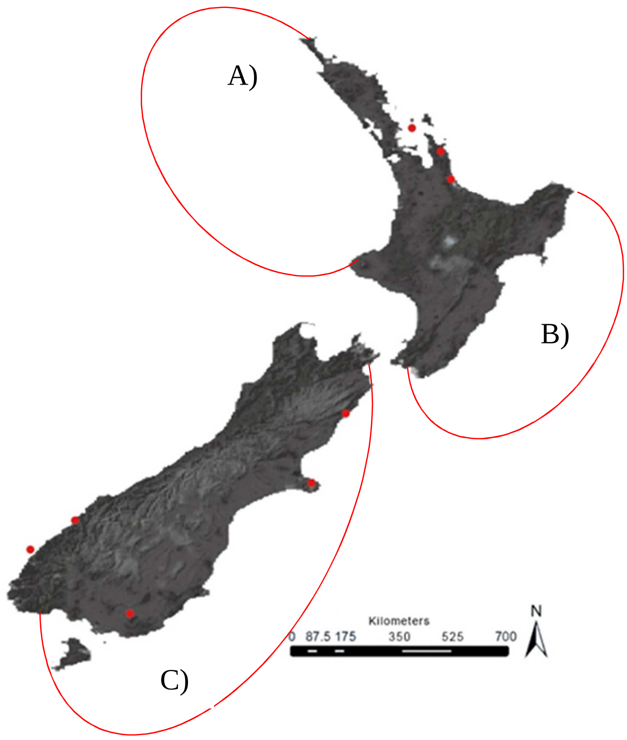


Figure 5.5. Regional division of offshore activities A) Taranaki, New Caledonia and Northland Reinga basins, B) East Coast Basin and C) Canterbury and the Great South Basin.

5.3.3.1. Bryde's whale

Model predictions for Bryde's suggest a suitable area of 90382 km^2. From this area, 32% overlaps with the block offer and 13% with areas available for permit applications and petroleum permits. In total, 45% of the range of Bryde's whales will be in conflict with prospecting and seismic surveys activities (Figure 5.6).

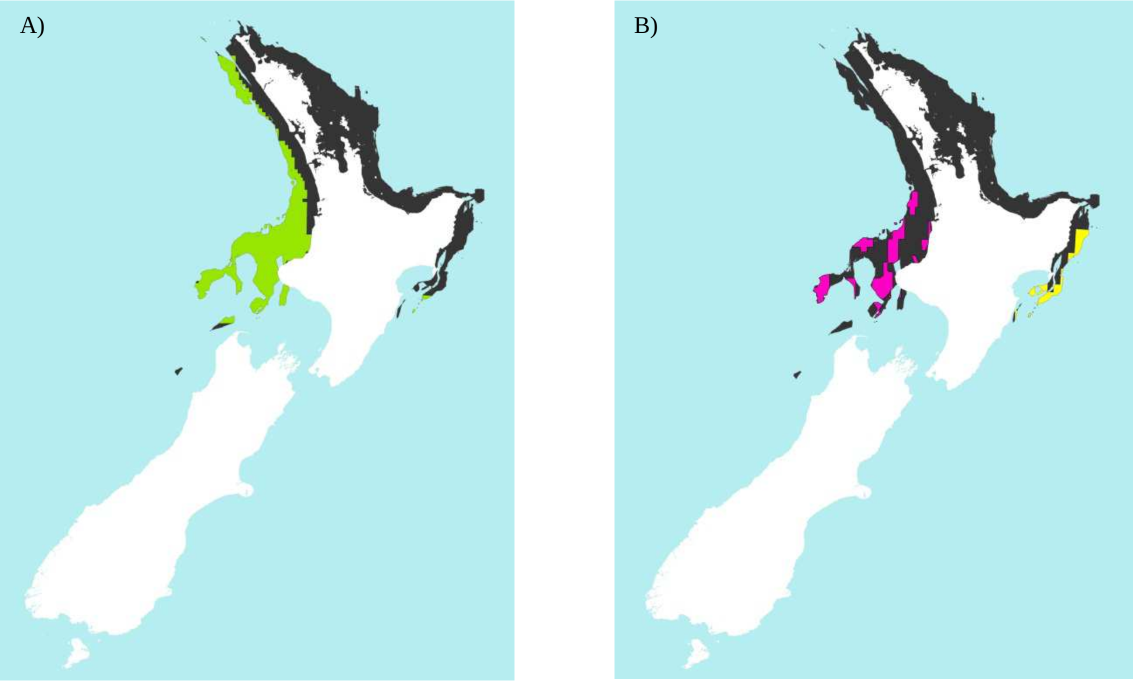
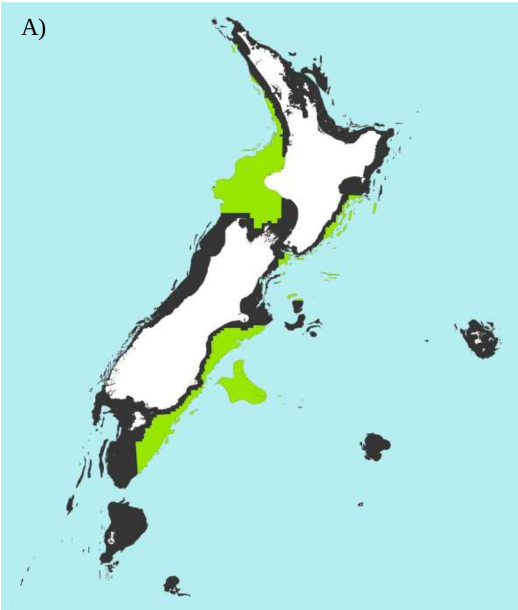
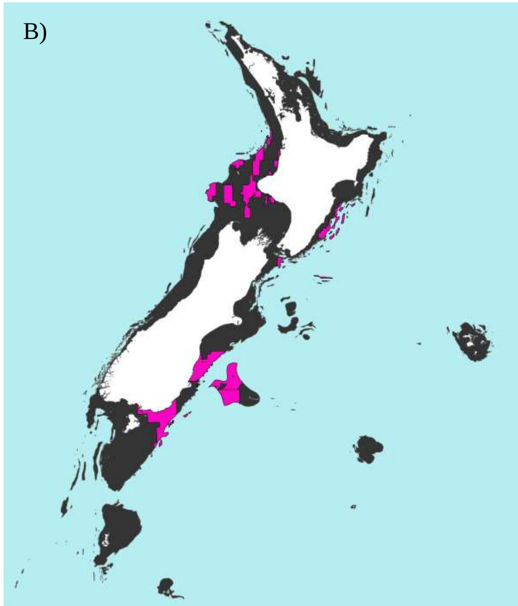


Figure 5.6. Maps showing the overlap between Bryde's whale and A) open block offer release (green area) and B) current petroleum permit (pink area) and permits applications (yellow area). The grey area represents the suitability area for the species.

5.3.3.2. Southern right whale

Model predictions for southern right whale suggest a suitable area of 336303 km^2. Thirty percent of this area overlaps with the block offer, 24% with areas available for permit applications and 12% with areas with petroleum permits. In total, 66% of the range of this species will be in conflict with prospecting and seismic surveys activities (Figure 5.7).





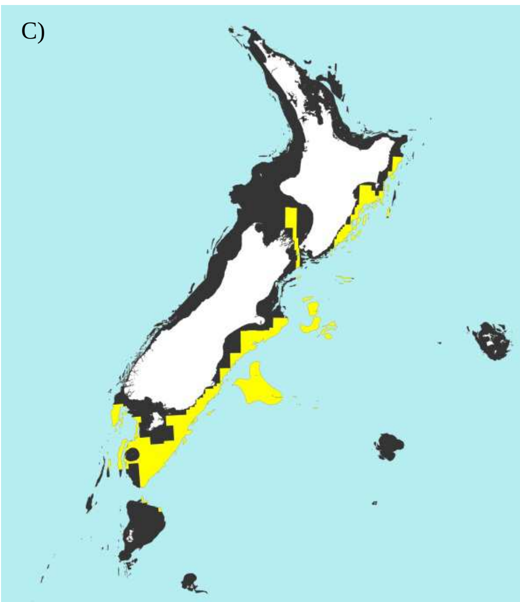


Figure 5.7. Maps showing the overlap between southern right whale and A) open block offer release (green area); B) current petroleum permits (pink area) and C) permits applications (yellow area). The grey area represents the suitability area for the species.

5.3.3.3. Maui's dolphin

The suitable area found with the models suggest and area of aproximatly 80576 km^2 for Maui's dolphin. Twenty-four percent of this ranges overlaps with the block offer, while 10% overlaps with areas available for permit applications and petroleum permits. In total, 34% of the Maui's dolphin range will be in conflict with these types of activities (Figure 5.8).

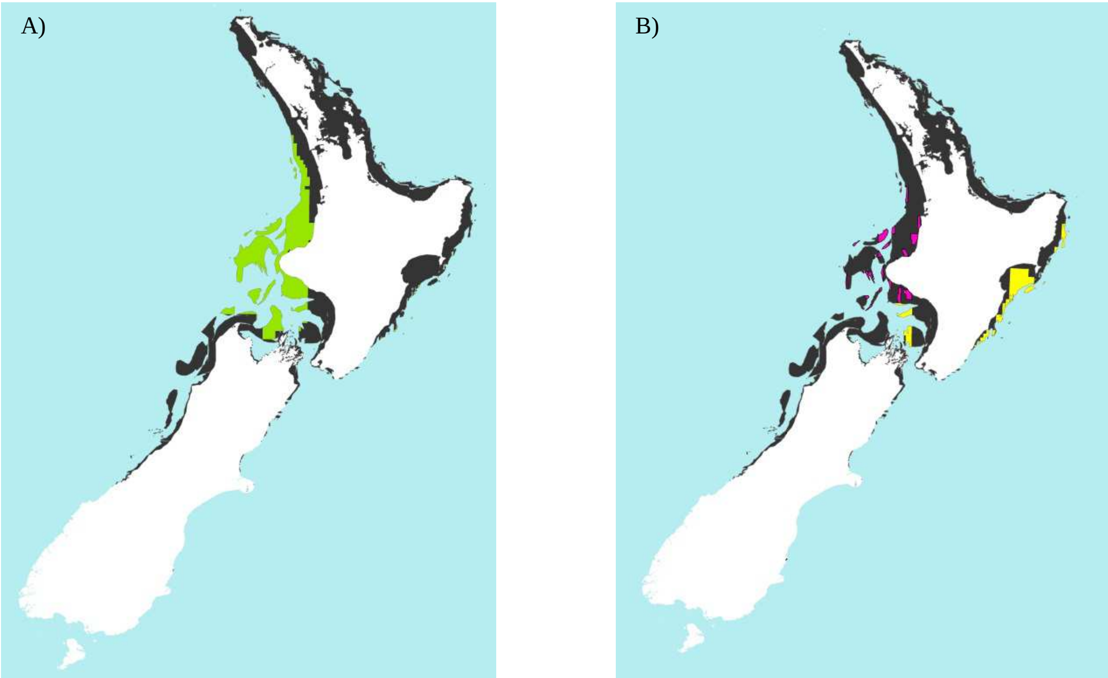
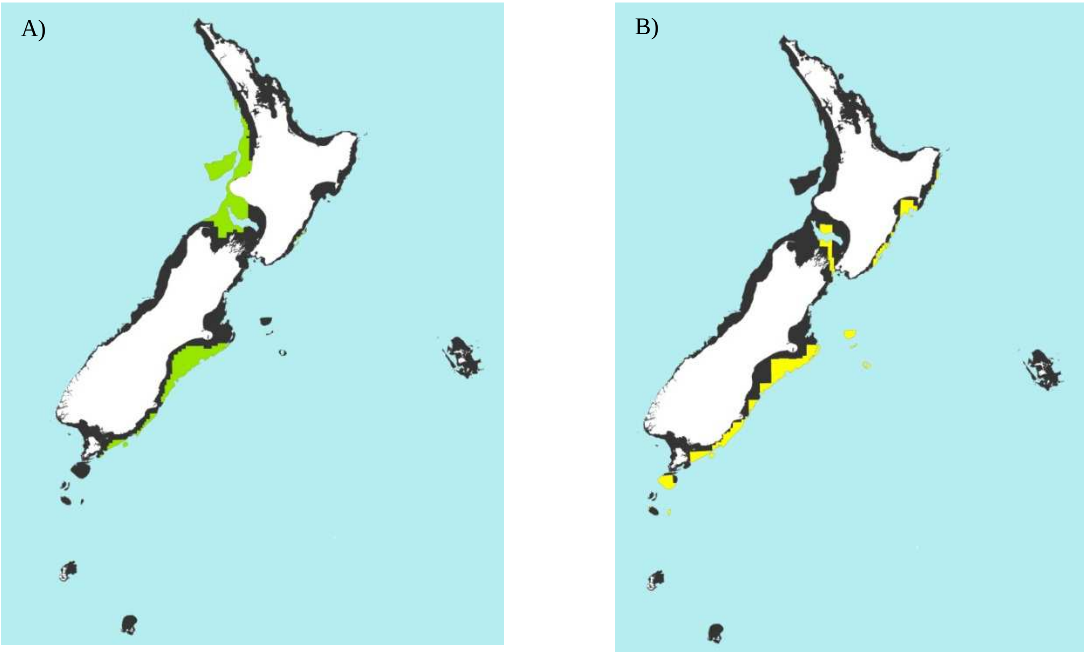


Figure 5.8. Maps showing the overlap between Maui's dolphin and A) open block offer release (green area) and B) current petroleum permit (pink area) and permits applications (yellow area). The grey area represents the suitability area for the species.

5.3.3.4. Hector's dolphin

Model predictions for Hector's dolphin suggest a suitable area of 154874 km^2. From the total area, 23% of this overlaps with the block offer, 15% with areas available for permit applications and 9% with areas with petroleum permits. In total, 46% of the range of this species will be in conflict with extractive and seismic surveys activities (Figure 5.9).



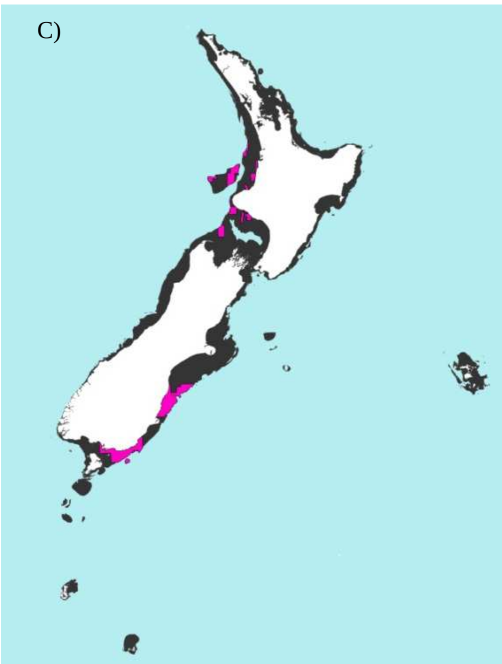
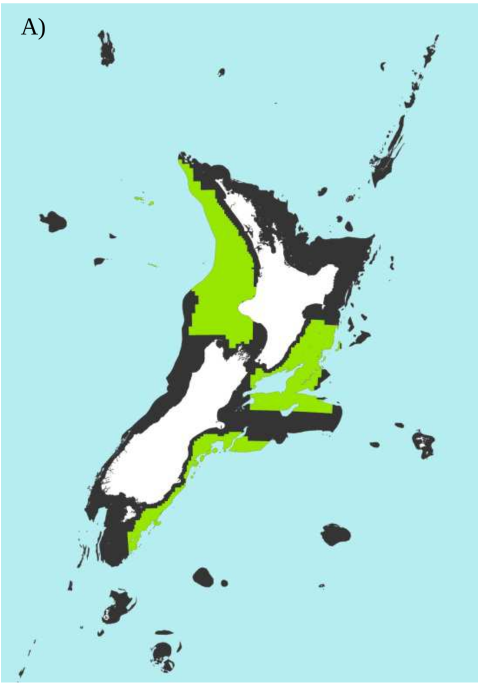
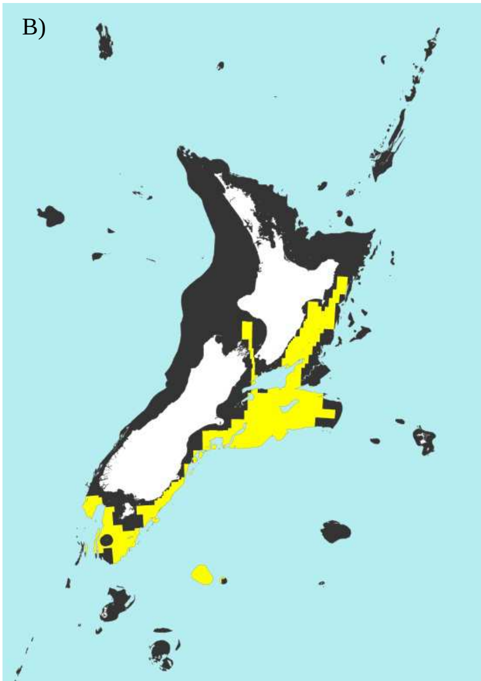


Figure 5.9. Maps showing the overlap between Hector's dolphin and A) open block offer release (green area), B) permits applications (yellow area) and C) current petroleum permits (pink area). The grey area represents the suitability area for the species.

5.3.3.5.Bottlenose dolphin

Model predictions for bottlenose dolphin suggest a suitable area of 625987 km^2. From the total area, 33% of this overlaps with the block offer, 25% with areas available for permit applications, 11% with areas with petroleum permits and 6% with prospection areas. In total, 75% of the range of this species is compromised with prospecting and seismic surveys activities (Figure 5.10).





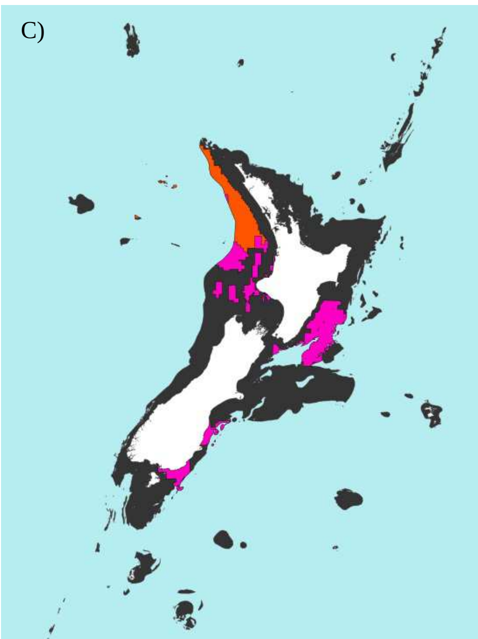
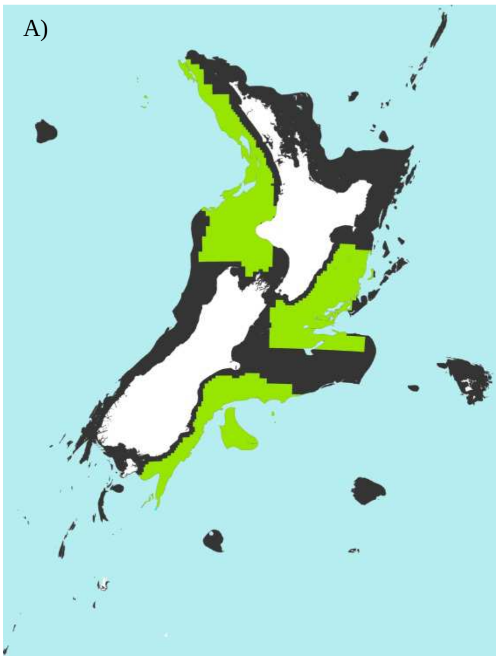
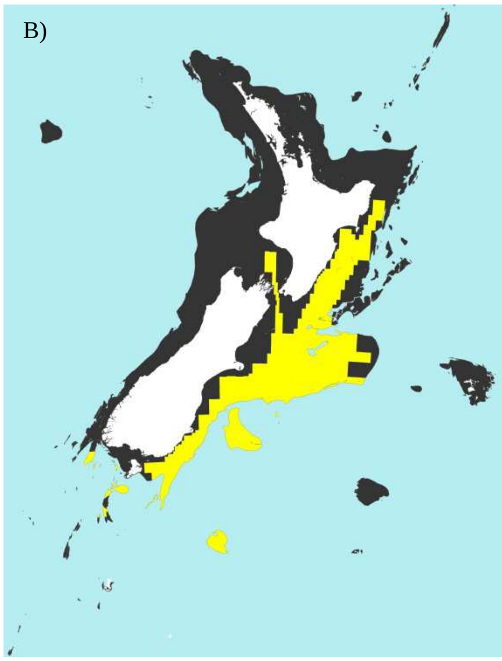


Figure 5.10. Maps showing the overlap between bottlenose dolphin and A) open block offer release (green area), B) permits applications (yellow area), C) current petroleum permits (pink area) and prospection areas (orange area). The grey area represents the suitability area for the species.

5.3.3.6. Orca

Model predictions for orca suggest a suitable area of 607186 km^2. From this area, 91% overlaps with the block offer being the higest of all threatened cetaceans assessed. Thirty percent of the area overlaps with areas available for permit applications, 15% with areas with petroleum permits and 4% with prospecting activities. The entire range of orca is covered by prospecting and seismic surveys activities (Figure 5.11).





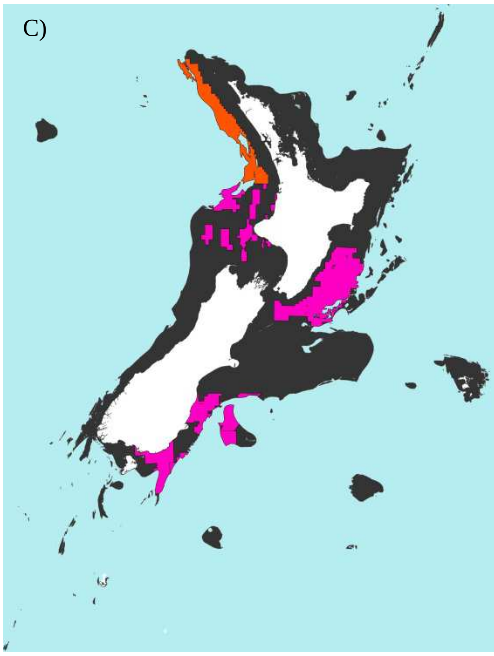


Figure 5.11. Maps showing the overlap between orca and A) open block offer release (green area), B) permits applications (yellow area), C) current petroleum permits (pink area) and prospection areas (orange area). The grey area represents the suitability area for the species.

5.3.3.7. Sperm whale

Model predictions for sperm whale suggest a suitable area of 934789 km^2. From this area, 38% overlaps with the block offer, 41% with areas available for permit applications, 14% with areas with petroleum permits and 4% with prospecting activities. In total, 97% of the range of this species overlaps with prospecting and seismic surveys activities (Figure 5.12).

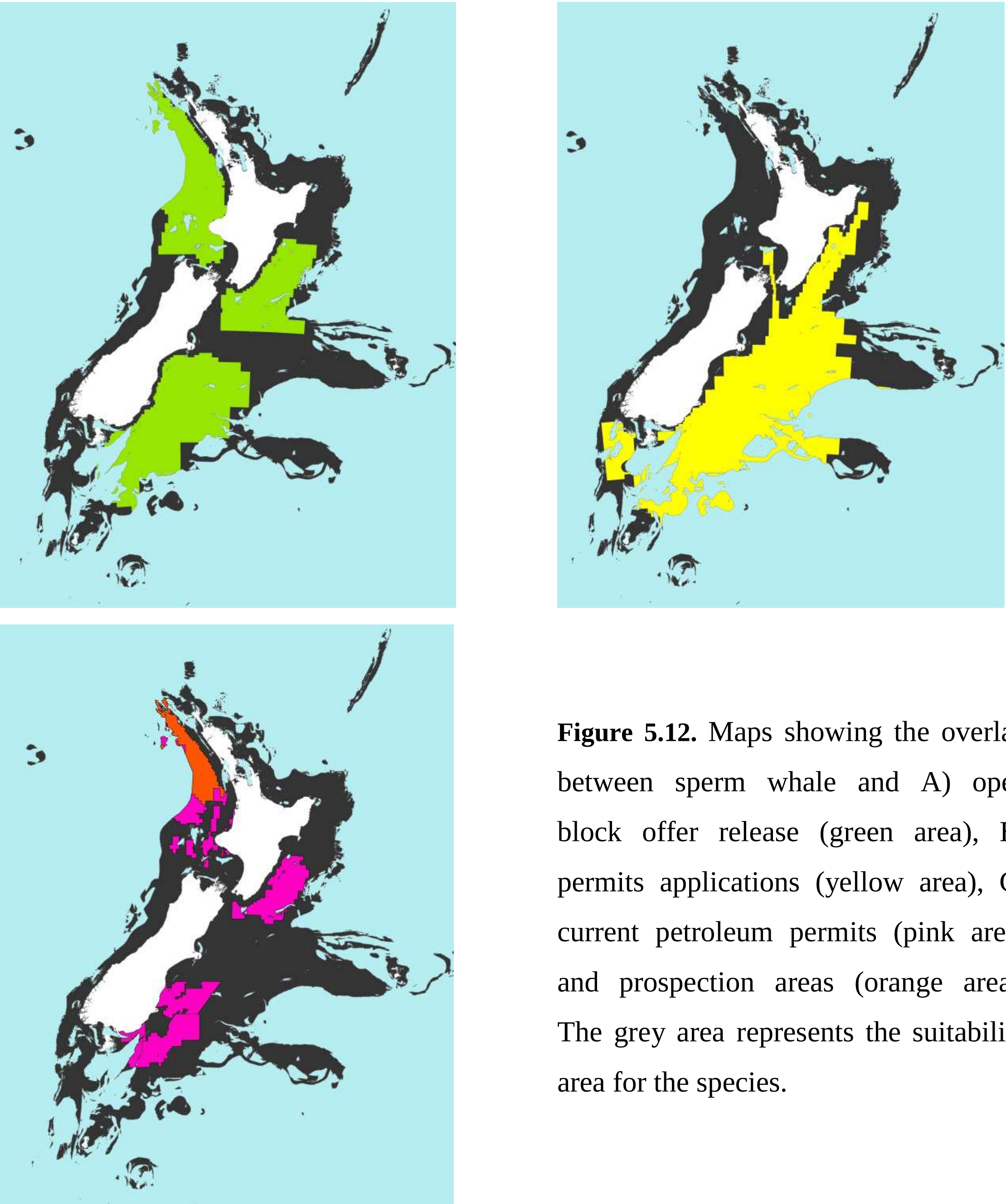


Figure 5.12. Maps showing the overlap between sperm whale and A) open block offer release (green area), B) permits applications (yellow area), C) current petroleum permits (pink area) and prospection areas (orange area). The grey area represents the suitability area for the species.

5.4. Discussion

5.4.1. MaxEnt

5.4.1.1. Model performance and environmental variables

The AUC values obtained for all models were high, similar to the values obtained in other cetacean studies using MaxEnt, which means that these models can very accurately predict cetacean's distribution (e.g. Moura et al., 2012; Thorne et al., 2012; Gómez & Cassini, 2015). However, the reliability of the results obtained in this study may have some bias. AUC values tend to increase when the absences are selected from a large area (Wisz et al., 2008), and in this study, the presence records tend to be bias towards the territorial sea, but the absences include the entire New Zealand EEZ, hence can generate high AUC values. Nevertheless, the models generated in this study, show concordance with published scientific knowledge of cetacean distributions in New Zealand's waters and add useful information for other regions of potential presence of cetaceans.

Results of environmental variables showed that depth and sediment were overall the most important predictors of habitat suitability, but understanding the relationship between environmental variables and species distribution can be difficult as there are often non-linear relationships and additional factors may influence predictions. Among the variables assessed, depth was the variable that contributed significantly to most models (except for sperm whale). This is similar to the findings of Thorne et al. (2012) for spinner dolphin in Hawaiian waters. The fact that depth was the most important variable for most species can be explained by the habits of the species assessed. Most of the focal species of this study tended to be sighted in shallow water, which would explain why deep water might be a limiting factor for some species (Slooten, Dawson, Rayment & Childerhouse, 2005; Wiseman, Parsons, Stockin & Baker, 2011; Gaborit-Haverkort, 2012; Torres, Halliday & Sturman, 2013).

The results found contrast to findings by Edrén et al. (2010) where sediment type was not an informative variable for harbour porpoise habitat modelling in Danish waters.

Although it was found that depth was less important than sediment for predicting sperm whale distributions, my results are generally consistent with a study by Correia et al. (2015), that used GAM, and found that depth and slope had a positive influences on sperm whale distribution. The significance of depth was expected for sperm whales in New Zealand as this species is a deep-diver and tends to be seen in deep waters.

Surprisingly, several variables thought *a priori* to be important did not contribute to the final models as expected. For example, sea surface temperature (sst), a variable that has showed high predictive value in other studies (e.g. Moura, et al., 2012; Gómez & Cassini, 2015), had low explanatory power for all species except then Maui's dolphin. Furthermore, the variable wintertime sea surface temperature (sstw) contributed more than sst for habitat predictions. SSTW was chosen as a proxy for nutrient availability, and as well as availability of potential prey for cetaceans, confirming that cetacean's distribution is highly linked to prey distribution.

The exclusion from this study of some environmental variables that have previously been shown as important predictors in other studies of cetacean's distribution could led to less accurate prediction maps. To increase the predictive power of this type of study, it is may be necessary to include variables such as salinity and chlorophyll. For example, Gómez & Cassini (2015) showed that salinity could have high explanation power in models for Franciscana dolphin. In addition, Moura et al. (2012) found that chlorophyll *a* is good predictor for common dolphin in Portugal. Future models could benefit from the inclusion of more and very specific environmental variables for different groups of cetaceans, (because whales and dolphins likely have different ecological needs). However, the current availability of this type of data over broad geographical scales is limited.

5.4.1.2.MaxEnt limitations

Although MaxEnt is user-friendly software, a number of decisions in how it is applied should be taken to ensure minimising the bias in the models obtained. First, choosing the features (i.e. quadratic, linear, product or hinge) that best suits the type of data used for modelling can be complicated due to the scarcity of information about each feature. For this study, "auto features" was chosen since similar published studies have demonstrated that MaxEnt is able to produce models of the same accuracy using simpler feature types (and auto features) (Merow et al., 2013; Syfer Smith & Coomes, 2013). To verify this, the models in this study, were also run pairwise for features, and the results did not change substantially.

Another issue is the validation of the model. In this study, 25% of the data were chosen to evaluate the model. Using a subsample of the dataset is not ideal situation as it is not an independent validation and the model may lose reliability. To remedy this, it would be necessary to use a different dataset to that used to build the model (Bombosch et al., 2014). For this study, no other dataset was available. Finally, choosing an output format can generate slightly different results in the models. Conflicting advice of output formats exist. For instance, Phillips & Dudík (2008) suggest that the logistic output is the most suitable because this approach improves model calibration. In contrast, Merow et al. (2013) advocate raw output and argue that this type of output does not rely in other assumptions and keeps the model simple and reduces errors. For this study, the latter approach was taken and the raw output was used.

5.4.1.3. Model predictions and management issues

The models obtained as part of this study show that the distributions of cetaceans significantly overlap with the anthropogenic offshore development currently in progress in New Zealand. These activities overlap at least 35% (e.g. for Maui's dolphin) and in orca and sperm whale almost their entire range (100% and 97%, respectively). The activities of extraction and prospecting for petroleum on the west coast of the North Island have the potential to cause impacts on four of the seven cetaceans assessed in this study. In this area, cetaceans such as Bryde's whale, Maui's and Hector's dolphin, and potentially bottlenose dolphin are present. The urgency for improved and more comprehensive mitigation plans to protect these species increases when we consider that their distributions (with the exception of bottlenose dolphins) are restricted to that particular area in the North Island and the degree of threat these activities pose. A good example of the necessity of better mitigation plans is Maui's dolphin; mineral extraction activities are taking place close to its core habitat and noise from these activities, among other factors, potentially add damaging pressure to this population and could contribute to the decline of an already highly decimated population.

New Zealand's mineral extraction and exploration industry is growing fast and is currently at fourth place worldwide in this industry[6]. The government aims to increase the oil exportation to 30 billion NZD a year by 2025, ten times greater than the current level. Importantly, current oil extraction in New Zealand is concentrated in one single basin, the Taranaki basin, hence with the potential reservoirs of this resource in other basins, combined with worldwide expansion of this market, extraction and exploration will increase. This may bring economic advantages (e.g. increasing New Zealand's GDP), nevertheless, from an ecological viewpoint, this kind of large-scale development may have long-term negative impacts and if not properly managed and migitated will intensify the conflict between conservation and economic development.

For the east coast of the South Island, the areas where these projects have been developed include Pegasus, Canterbury and Great South Basins. These projects are located in the key areas of distribution of orca, sperm and southern right whale. Orca, due to the small size of their population in New Zealand, may be affected for the impacts that noise pollution can have on them directly and on their prey. Sperm whale found in the Kaikoura region is under constant pressure from whale watching activities developed in the area. This when combined with exploration activities within the Pegasus basin may lead to deleterious effects on this species. Likewsie, for southern right whales, a species common around New Zealand prior to whaling activities (Lusseau & Slooten, 2002), has started to recover. For this recovery to be unimpeded, important areas such as breeding or feeding grounds must be safeguarded from deleterious impacts.

Although New Zealand, in its marine code of conduct, requires actions to minimise the impacts of marine activities, sometimes minimising is not enough. This approach, planning based on cetacean's distribution, allows reducing the impacts on cetaceans' populations as well as potentially be benefit certain operations, e.g. seismic surveys where the number of shutdowns could potentially be reduced if these activities are planned to take into account current knowledge of cetacean distributions (Bombosch et al., 2014). Above all, mitigation plans should be accompanied by research about the effect of noise pollution and other anthropogenic activities that are affecting cetaceans,

[6] www.newzealandnow.govt.nz/work-in-nz/nz-jobs-industries/oil-gas-jobs

and other marine fauna; without studies of the effectiveness of various mitigations measures, the ones currently employed are likely to be deficient. Moreover, in my opinion, the management plans currently required by the Government to issue licenses, do not have as their primary goal the intent of conserving species and ecosystems, in the end; ecosystems that humans depend on for subsistence.

5.5. Conclusions

In summary, extraction activities overlap with most of the ranges of the species analysed, hence the high probably of deteriorating habitat quality and threats to extant cetacean species. Species such as bottlenose dolphins, a Nationally Endangered species with a declining population in New Zealand, has complete range overlap with these industrial activities. My exploratory study shows that MaxEnt can effectively model cetacean habitat suitability in New Zealand; models obtained were consistent with published distributions. In addition, I obtained important information on the environmental variables that best predicted patterns of habitat suitability for these species. Furthermore, the predictive maps developed in my thesis can be used (and updated with new data) as planning tools to help prioritise anthropogenic activities in areas least important for cetaceans, i.e., outside of feeding and breeding grounds and thereby help mitigate the impact of industrial activities.

5.6. Future research

To develop more accurate and precise prediction maps, future modelling should include environmental variables that are specific for each group of cetaceans (e.g. beaked and baleen whales, small and large odontocetes). This would take into account the ecological niche and requirements of the different groups of animals. In addition, a fine scale modelling approach would be beneficial to identify key areas such as foraging areas, and thereby better inform the planning process. Finally, future research could apply MaxEnt to species that are less well studied once data becomes available. For example, beaked whales are good candidates for future analysis, as they appear to be highly sensitive to different anthropogenic sources of noise. Finally, the Chatham Island region is an area that requires more research on this topic due to the industrial activities developed in that area and because of its known richness of cetaceans.

Regulations for underwater noise mitigation in New Zealand: an international context

Acronyms

AAM: Active Acoustic Monitoring.

ACCOBAMS: Agreement on the Conservation of Cetaceans in the Black Sea, Mediterranean Sea and contiguous Atlantic area.

ASCOBANS: Agreement on the Conservation of Small Cetaceans in the Baltic, North East Atlantic, Irish and North Seas.

EIA: Environmental Impact Assessment.

EZ: Exclusion Zone.

GIS: Geographic Information System.

GPS: Global Positioning System.

IA: Impact Assessment.

IWC: International Whaling Commission.

km: Kilometre.

LIDAR: Light Detection and Ranging.

m: Metre.

MMIA: Marine Mammal Impact Assessment.

MMC: Marine Mammal Comission.

MMOs: Marine Mammal Observers.

MMPA: Marine Mammals Protection Act 1978 (New Zealand).

MMPA USA: Marine Mammal Protection Act of 1972 (USA).

MPAs: Marine Protected Areas.

nm: Nautical Miles.

N/S: Not specified.

PAM: Passive Acoustic Monitoring

PTS: Permanent Threshold Shift.

SoC: Species of Concern.

The Code: The 2013 Code of Conduct for Minimising Acoustic Disturbance to Marine Mammals from Seismic Survey Operations.

The Commission: Marine Mammal Commission (USA).

The Statemet: Statement of Canadian Practice with respect to the Mitigation of Seismic Sound in the Marine Environment.

TTS: Temporary Threshold Shifts.

UNCLOS: United Nations Convention on the Law of the Sea.

6.1. Introduction

In the ocean, there are diverse sources of noise contributing to pollute this environment. Among these sources of noise, those that come from seismic surveys and vessels have prompted great concern because of their potential negative and large-scale impacts on marine fauna (Richardson, Greene Jr., Malme & Thomson 1995; Weilgart, 2007b). For example, the sound produced by seismic survey activities, which uses airguns whose function is to expel high-pressure air into the water column (Richardson et al., 1995), are among the most intense of all anthropogenic sources of noise, and its effect can have important detrimental effects on marine animals, since these activities, generally, are carried out over large areas and long periods of time (Gordon et al., 2003).

During seismic survey activities and depending on the specific activity being undertaken, single airguns or airgun arrays are used, producing low-frequency sounds in the form of pulses, with broadband source levels that can range between 216-232 and 235-259 dB re 1 μPa at 1 m (Richardson et al., 1995; See Chapter 2). Because of some frequencies produced by these seismic arrays overlap with those produced by cetaceans; studies have been conducted with the goal of identifying the impacts of seismic activities on these animals. Observed impacts range from physical and auditory damage to masking, and the response to these include avoidance, changes in vocal behaviour, behavioural activities, respiration and swimming patterns and temporary threshold shifts (TTS) (e.g. Malme et al., 1985; Goold, 1996; Finneran et al., 2002; Madsen et al., 2002; McCauley et al., 2003; Gailey et al., 2007; Miller et al., 2009, Di Iorio & Clark, 2010; Gray & Van Waerebeek, 2011; Lyamin et al., 2011; Blackwell et al., 2013; See Chapter 3).

Vessels are the major contributors of background noise in the oceans (Richardson et al., 1995) and due to the fast-growing of marine tourism around the world (Miller, 1993), there are important concerns about the impacts that whale-watching can pose on cetaceans populations exposed to these activities (Garrod & Fennel, 2004). According to O’Connor et al. (2009), by 2008 there were 13 million people participating in whale-watching activities in 119 countries around the world (O’Connor, Campbell, Cortez, & Knowles, 2009). In New Zealand, where whale-watching is one of the most important industries, in 2008 there were 546,445 whale-watching tourists, who generated over $80 million in expenditure (O'Connor et al. 2009). Due to the fast growth of this industry, there has been an increase in research of the impacts of tourist activities on marine mammals, and a corresponding increase in the necessity to have regulations to protect targeted species (e.g. Erbe & Farmer, 1998; Nowacek et al., 2001; Buckstaff, 2004; Foote et al., 2004; Scheifele et al., 2005; Aguilar-Soto et al., 2006; Castellote et al., 2012; Pirotta et al., 2012; Rolland et al., 2012; Anderwald et al., 2013; Rako et al., 2013; May-Collado & Quiñones-Lebrón, 2014).

Nonetheless, the development of effective laws that adequately regulate anthropogenic noise impacts on marine mammals has been a task that has taken many years to develop. At present, efforts are still in the initial stages where laws have been written but not completely executed or are in need of more investigation to attain a wider and more comprehensive perspective of efficient means of mitigation. New Zealand has enacted National Legislation and Government Policies such as the Marine Mammals Protection Act 1978, Fisheries Act 1996, Marine Mammals Protection Regulations 1992 and NZ Biodiversity Strategy, which are continuingly evolving to provide effective assistance for the conservation management of marine mammals (Suisted & Neale, 2004, p. 75-76).

In this chapter, key policies for underwater noise mitigation are described and compared with methods described by international associations to identify faults within New Zealand's legislation that could be improved. These associations include the *Agreement on the Conservation of Cetaceans in the Black Sea, Mediterranean Sea and contiguous Atlantic area* (ACCOBAMS), *Agreement on the Conservation of Small Cetaceans in the Baltic, North East Atlantic, Irish and North Seas* (ASCOBANS) and the *International Whaling Commission*. Another guidelines included are the *Statement of Canadian Practice with respect to the Mitigation of Seismic Sound in the Marine Environment*, and for commercial cetacean watching activities, guidelines from Australia, Ireland and Canada are also used. Additionally, an overview of general mitigation measures by the *United Nations Convention on the Law of the Sea* (UNCLOS) and the *Marine Mammal Commission* Report of USA are included.

6.2. Regulations for seismic survey activities

6.2.1. General specifications by UNCLOS and Marine Mammal Commision, USA

6.2.1.1. UNCLOS

Section XII of *The United Nations Convention on the Law of the Sea* (UNCLOS) outlines the protection and preservation provisions for the marine environment. These measures are to prevent, reduce and control all sources of pollution (including noise pollution) in the marine environment. States must elaborate an assessment of potential pollution effects when they undertake activities that have genuine grounds to be considered a pollutant or to cause harmful changes to the marine environment. This assessment should then be reported to relevant international organizations, which in turn make these assessments available to all States. In general, the guidelines encourage States to implement actions ‘to prevent, reduce and control pollution of the marine environment from any source’ (UNCLOS, p. 100), likewise to avoid activities that negatively affect other States, or in case of any major incident, that this ‘does not spread beyond the areas where they exercise sovereign rights’ (UNCLOS, p. 100).

States should not interfere with the activities of other States without justification and any activities should be undertaken within their rights according to the Convention. Protection and preservation measures must include fragile ecosystems and endangered habitats species. The convention also specifies that actions should be undertaken to reduce and control pollution derived from the use of technologies, and not ‘transform one type of pollution into another’ (UNCLOS, p.101). Global and regional cooperation must be undertaken through international organisations creating rules, procedures, etc., that are consistent with the Conventions to protect and preserve the marine environment (including regional features). In the case where a State has relevant information about hazards within the marine environment due to pollution, all potentially affected States and relevant international organizations must be notified immediately to eliminate, prevent or minimise damage (UNCLOS, p.102).

In summary, the cooperation among States includes the promotion of studies and scientific research to facilitate the exchange of information data and, with this information, participate in regional and/or global programmes to assess pollution impacts and preventive actions. The information acquired will enable the cooperation of States and international organisations in the creation of '*rules, standards and recommended practices and procedures for the prevention, reduction and control of pollution of the marine environment*' (UNCLOS, p.102) based on solid scientific criteria. UNCLOS establishes a baseline: States must '*observe, measure, evaluate and analyse the risks or effects of pollution of the marine environment*' (UNCLOS, p.103), use appropriate scientific techniques, and disseminate these findings among all States.

6.2.1.2. Marine Mammal Commission, USA

The Marine Mammal Commission (the Commission) was created under Title II of the Marine Mammal Protection Act (MMPA) of 1972 as an independent federal agency with the primary aim of supervising the implementation of the MMPA. The Commission prepares an annual report identifying the main priorities regarding marine mammals at scientific and management levels, and advises other federal agencies on fulfilment of requirements stated within the MMPA. The 2007 report, "Marine Mammals and Noise: A Sound Approach to Research and Management", addresses findings regarding anthropogenic noise and its effects, "survey acoustic 'threats' to marine mammals" (MMC–US Marine Mammal Commission, p. ii) and prevention methods aiming to reduce these risks. Under sections VII, VIII and IX the Commission discusses regulations of taking by anthropogenic sound, mitigation measures and monitoring and reporting activities (discussed below).

To protect marine mammals and yet not impede sound pollutant activities unnecessarily, the MMPA stipulates five authorisations that oversee and permit activities that relate to 'taking' of marine mammals: 1) scientific research permits, 2) small-take authorizations, 3) incidental harassment authorizations, 4) waivers, and 5) sound incidental to commercial fisheries (MMC–US Marine Mammal Commission, p. 26). 'Taking' is defined as 'to harass, hunt, capture, or kill, or attempt to harass, hunt, capture, or kill any marine mammal' (Marine Mammal Protection Act of 1972, 2007, p. 7), and 'harassment' is defined, under the 1994 amendments, as "any act of pursuit, torment or annoyance, that has the potential to injure (Level A Harassment) or to disturb (Level B Harassment) a marine mammal or stock in the wild (Marine Mammal Protection Act of 1972, 2007, p. 8). In general, taken authorizations require mitigation measures that can be compiled into four categories: 1) modification or removal of a sound source, 2) sound attenuation, 3) temporal or spatial limitations on use of the source, and 4) operational requirements. Additionally, monitoring and reporting are required.

To design and develop an effective real-time monitoring plan, information about spatial and temporal characteristics like distribution, behaviour, use of habitat, social structure, and how anthropogenic sound affects the species of the area where activities are going to be undertaken, should be considered. This information can be obtained by using data from a range of sources collected from appropriate monitoring information of marine mammals. Nevertheless, the Commission considers the modification or removal of a sound source as the most effective way of mitigation. Sometimes the complete prohibition of noise sources is undertaken but it is a limited practice (MMC–US Marine Mammal Commission, p. 31). Instead, frequency adaptations, intensity and duration of sound and other modifications are proposed as mitigation methods. Reductions on the use of high-intensity sound sources improving the signal processing or adjusting the focus of the source energy, as well as the use of technologies that decrease the noise produced by ships are examples of modification methods (MMC–US Marine Mammal Commission, p. 31). It is recommended that these methods be adequately studied to reduce the probability of accidents with marine mammals less apt to detect quiet ships.

Sound attenuation methods are an effective means of reducing sound and the expansion of sound through the water column, without modifying the source itself. These methods are mainly used around stationary sources, but they have also been used for moving sources. Bubble curtains, blasting mats and dampening screens are examples of these methods (MMC–US Marine Mammal Commission, p. 31). Spatial and temporal measures are a more specific means of regulating the use of sound. These methods are more effective when the distribution, behaviour, habitat use and other information of the specific species of marine mammals in the area where activities are to be carried out, are known (MMC–US Marine Mammal Commission, p. 31). These measures are aimed at avoiding activities or controlling them, depending on knowledge of spatial factors influencing the species found there, i.e. whether there is a critical area for breeding, a protected area or a migratory route, and temporal factors such as a breeding or calving season and migratory periods. A combination of spatial and temporal limitations can be used (MMC–US Marine Mammal Commission, p. 31).

Other mitigation measures include ramping up, a method that is used to allow time for marine mammals to leave the zone; however, its efficacy has not been demonstrated. Another method is to establish safety zones around the sound source and monitor the presence of marine mammals entering the zone (MMC–US Marine Mammal Commission, p. 32). If a marine mammal is detected, activities must be suspended or altered until the mammal has left the area. This method, however, is hard to implement because marine mammals are difficult to detect even in good conditions and in poor conditions detections decrease considerably (MMC–US Marine Mammal Commission, p. 32).

6.2.1.2.1. Monitoring and reporting

Permit holders are required, typically, to monitor and report on marine mammals, using visual observation and, sometimes, passive acoustic monitoring. These activities are essential to determine mitigation measures efficacy and to better plan activities that use or produce sound (MMC–US Marine Mammal Commission). The most common method to detect marine mammals is visual monitoring. Observers can be trained biologists as well as crewmembers. *Passive Acoustic Monitoring (PAM)* systems are also an essential part of mitigation procedures. Even though, some species that do not produce sound cannot be detected, PAM is very effective with those species that produce sound, and complement visual monitoring, which is limited regularly by weather factors, location, and even natural behaviours of the species (MMC–US Marine Mammal Commission).

Active acoustic monitoring (AAM) is also a supplementary mitigation activity. This method consists of high frequency pulses emitted to detect echoes (MMC–US Marine Mammal Commission). These echoes are expected to be from marine mammals but sometimes can be produced by other objects, which is one of the disadvantages of this method, as well as the method itself being an added source of anthropogenic noise for marine mammals. Other methods that have shown some efficiency in detecting mammals are radar, infrared detection, and LIDAR (Light Detection and Ranging) (MMC–US Marine Mammal Commission, p. 33); nonetheless, since these methods are limited to detecting animals at or near the surface, they do not effectively detect small animals or those species that spend long periods submerged.

6.3. General scopes of the seismic guidelines analysed

6.3.1. New Zealand

Regulations for seismic survey activities in New Zealand are compiled in the 2013 *Code of Conduct for Minimising Acoustic Disturbance to Marine Mammals from Seismic Survey Operations (the Code),* which was developed under the *Marine Mammals Protection Act 1978* (MMPA) and is administered by the Department of Conservation. The Code applies to marine survey activities carried out in New Zealand continental waters and is divided into Level 1, 2 and 3. Level 1 surveys (>427 cubic inches) include large-scale geophysical investigations, commonly for oil and gas exploration activities. Level 2 (151–426 cubic inches) include lower scale seismic investigations often associated with scientific research. Finally, Level 3 surveys (<150 cubic inches) include all other small-scale seismic survey technologies, and are considered to be of low impact and risk (Department of Conservation, 2013, p. 6). The activities covered include procedures executed before, during and after a given activity.

All Level 1 surveys are the principal target of The Code; Level 2 surveys have similar mitigation procedures; while Level 3 surveys are not subject to The Code. Likewise, seismic surveys must follow this classification according to the power of the sound used by each specific investigation. Each Level must follow a specific planning process, except Level 3 (since these vessels are not subject to The Code) (Department of Conservation, 2013).

6.3.2. ACCOBAMS

Resolution 4.17 of the guideline named: "*Guidelines to address the impact of anthropogenic noise on cetaceans in the ACCOBAMS area*", ACCOBAMS has established a series of mitigation measures for diverse sources of anthropogenic sound within the areas covered by this agreement. ACCOBAMS describes general guidelines to address the impact of noise and also specifies the mitigation measures for precise activities: general and specific guidelines for seismic surveys activities are included (Pavan, 2007).

6.3.3. ASCOBANS

The Agreement on the Conservation of Small Cetaceans of the Baltic and North Seas (ASCOBANS) in its final report of the ASCOBANS Intercessional Working Group on the Assessment of Acoustic Disturbance describes a series of recommendations for mitigation procedures, both general and specific to different sources of anthropogenic noise. Recommendations found in this documented are, as they point, "mainly adapted from sections 5.7 and 5.8 of the ACCOBAMS anthropogenic noise guidelines", and it is encouraged that they be used within the ASCOBANS area (ASCOBANS, 2010).

6.3.4. Statement of Canadian Practice with respect to the Mitigation of Seismic Sound in the Marine Environment (*The Statement*)

Mitigation measures for seismic survey activities in Canada are outlined in the *Statement of Canadian Practice with respect to the Mitigation of Seismic Sound in the Marine Environment*. This *Statement* is a compilation of mitigation measures made by the federal and provincial government and which is part of a bigger review on possible effects of seismic survey activities, carried out together with national and international scientific experts in 2014. The *Statement* aims to be implemented in tandem with current environmental assessment processes and other existing regulations for seismic activities. The mitigation measures apply to all Canadian marine non-ice covered waters and seismic activities that use air source arrays (Fisheries and Oceans Canada, 2014, p. 2).

6.4. Mitigation measures for seismic survey activities

6.4.1. Planning stage

6.4.1.1. Impact Assessments

Under New Zealand's Code, all operations must present a written marine mammal impact assessment (MMIA) to the Director-General as early as possible or at least one month prior to the start of the action. This part is a fundamental planning procedure for conducting seismic survey activities and this assessment must be available for consultation by any observer. Similarly, ACCOBAMS and ASCOBANS request an Environmental Impact Assessment (EIA) before permission is granted to start any activity. Furthermore, ASCOBANS, within their seismic surveys mitigation procedures, point out that the most important action at this stage is that the EIA needs to be transparent and useful for spatiotemporal avoidance measures. Finally, Canada applies the form of an environmental assessment process, where all the possible negative effects of planned activities are identify *a priori*, and are mitigated during the execution of the seismic activities.

6.4.1.2. Sensitive areas

In New Zealand's Code, it is stated that for level 1 and 2 surveys, special care must be taken to minimise the impacts of surveys intended to be undertaken in Areas of Ecological Importance, including marine mammal sanctuaries. In addition, these activities should not be planned during key biological periods such as breeding, calving, resting, feeding or migrating seasons. If there is a demonstrated reason for work to commence in these particular areas and timeframes, proponents must elaborate mitigation measures in agreement with, and under advice from, the Director-General of Conservation. ACCOBAMS also states that all activities should be planned and executed to avoid critical areas where animals are likely to be encountered. Hence, for both protocols, data on cetacean spatial and seasonal distributions are necessary during the planning stage. Closed areas, cetaceans' key habitats, and marine protected areas should be avoided, and appropriate buffer zones must be defined around them.

Databases/GIS must show detailed tracking history of anthropogenic noise and other anthropogenic threats to overview cumulative impacts of these activities. Seasonal and historical impacts from different activities within the specific survey area and nearby regions must also be collected.

For ASCOBANS, the regulations state that MPAs, key marine mammals habitats and high marine mammal density areas should be avoided. The avoidance measures include year-round and seasonal restrictions, buffer zones and the selection of ‘low-risk’ zones where it is possible to execute activities without harming marine mammals. During this planning stage, modelling of data including marine mammal abundance, distribution and habitat should be thorough, taking into consideration the characteristics of sound propagation according to the oceanic features of the specific location and operation mode that is going to be used. In comparison, Canada’s mitigation actions during the planning stage highlight the necessity to plan and design seismic survey activities with general consideration to the objectives of known mitigation measures. In particular, to avoid known areas critical for the life cycle and biological functions of marine mammals and marine fish, such as migration periods, breeding and feeding times.

6.4.1.3. Species

Although the guidelines outlined above have been assessed primarily for a very specific group of organisms, mainly limited to cetaceans, other marine life may be protected. For instance, New Zealand’s Code also encourages proponents to expand their planning, to not only protect marine mammals, but also to find mitigation methods to protect other key species such as turtles, penguins and seabirds. Likewise Canada, also seeks to protect fish and turtles. In contrast, in the areas where ACCOBAMS and ASCOBANS apply, only cetaceans are considered.

6.4.1.4. Minimising sound output

As a mitigation measure, some guidelines choose to minimise the amount of noise generated by human activity in the ocean. New Zealand’s Code states that proponents should estimate the lowest power levels of the acoustic source at which their operations are possible to be undertaken without compromising the activities effectiveness and bounding operations to those levels. If Passive Acoustic Monitoring (PAM) is included as a mitigation instrument, then the PAM operator should be involved during the MMIA preparation to guarantee accurate equipment specifications. For its part, Canada establishes that activities have to be designed to avoid unnecessary production of sound thus employing the minimum energy to obtain the survey goals, reduce or regulate horizontal sound propagation and limit the use of high frequency sound to those strictly necessary to undertake activities.

Similarly, ACCOBAMS says that the lowest practicable source of power should be used, but ACCOSBAMS also suggests that the horizontal propagation should be controlled using suitable array configurations, pulse synchronization and eliminating unnecessary high frequencies. In addition, the sequencing of seismic lines should be adapted so as to avoid blocking escape routes and whenever possible anticipating animal movements across the area. ASCOBANS present a more detailed mitigation plan in this aspect. They define mitigation procedures for both sound sources and operational procedures. For sound-based mitigation, guidelines include modification procedures such as rise time, wide beam pattern, long durations and duty cycles, etc., to decrease noise emissions. ASCOBANS also recommend that noise sources use the minimum level of power necessary to achieve the planned activities.

6.4.1.5. Exclusion Zone

The exclusion zone (EZ) is defined as the area (radius) where real-time mitigation measures are applied when an animal is detected (Weir & Dolman, 2007). Since it has been found that survey related sounds can cause temporary threshold shift (TTS) or permanent threshold shift (PTS) if the animal is close to the sound source, this mitigation measure has gained importance (Richardson et al., 1995; Crompton, Goodwin, Handy & Abbott, 2008). For its part, Canada states that a minimum safety zone of 500 m must be established around air source arrays and must be monitored. The 500 m zone may be expanded, if during the environmental assessment process other relevant oceanographic futures are considered as to influence sound propagation beyond the minimum area. In contrast, New Zealand has a 200 m EZ for delayed and soft starts in general, but in the case of Species of Concern (SoC) with calves a 1.5 km EZ is used and a 1 km EZ for other SoC. Alternatively, ASCOBANS states that the EZ must be designated dynamically according to the source characteristics, the species in the survey area, and the propagation characteristics in the area. Thus, EZ should be expanded to prevent disruption in behaviour of the animals, as long as the received noise levels are low or noise emission can be controlled without affecting the seismic activities

Finally, ACCOBAMS states that the EZ must be designated using both scientific and precautionary bases. The EZ should be modelled using the characteristics of the source, expected species in the area and local propagation features and be verified in the field. In case of several EZ, the most precautionary option should be adopted. An expanded EZ may be established when the aim is to reduce behavioural disturbance rather than just reduce direct harm. In addition, similarly to New Zealand, an expanded EZ zone may be possible in order to reduce disturbance for marine mammals.

6.4.2. On board stage

6.4.2.1. Marine Mammal Observers (MMOs) and Passive Acoustic Monitoring (PMA)

MMOs are a common mitigation measure used to detect animals in the project´s influence area. The objective of MMOs is to detect, monitor and identify animals of interest within the safety zone (Crompton et al., 2008). A complementary detection method is the deployment of underwater microphones (hydrophones) that detect sound, this are known as Passive Acoustic Monitoring (PAM); a technique mainly used to detect cetaceans. PAM consists of a series of hydrophones towed behind the seismic vessel able to detect vocalizing cetaceans (Crompton et al., 2008). Both MMOs and PAM mitigation measures are suggested in several legislations. For example, New Zealand establishes that during Level 1 surveys there should always be two qualified MMOs and two qualified PAM operators on board (for level 2 PAM is currently optional). When the acoustic source is in the water during daylight, at least one MMO and one PAM operator should be on watch. Nonetheless, observation activities are encouraged at all other times.

Likewise, ACCOBAMS and ASCOBANS state that there must be two MMOs on watch at one time and at least one PAM operator on watch. PAM operators shifts should be designed to allow 24 hours operation or a proven and reliable automatic detection/alerting system should be available. MMOs and PAM operators must be qualified and experienced, and must be approved before operations start. Finally, Canada legislation only required one MMO on board during each activity and PAM is only required during low visibility, bad weather, shut down for more than 30 min, safety zone not fully visible and when the encounter of cetaceans is highly likely. Both the MMO and the PAM should be qualified.

6.4.2.2. Pre-start observations

Pre-start observations are made by the MMOs before the start of activities (Weir & Dolman, 2007) in order to confirm the absence of animals within the EZ. New Zealand regulations state that the acoustic source activation can only be made within the specified operational areas and when there have been no detections of any marine mammal in the mitigation zones. Pre-start observation requirements are specified for daytime and night-time. During daylight, the source can be activated only if the area around the source has been permanently monitored by at least one MMO using binoculars and the naked eye from the bridge or a higher place and no marine mammals, except for fur seals, have been detected in the relevant mitigation zone for at least 30 minutes. In relation to fur seals, source activation can only be made if there have not been detections for at least 10 minutes. PAM must have been undertaken for at least 30 minutes prior to activation and no vocalising cetaceans have been registered in the relevant mitigation zone. During night-time and poor visibility, the source can be activated only if PAM has been undertaken for at least 30 minutes prior to the activation and no vocalizing cetaceans have been recorded.

However, when operations are going to be executed in a new location for the first time, the source activation must not be carried out at night or during poor sighting conditions, except under the following conditions:

- When no marine mammals have been observed by the MMOs for at least 2 hours prior to the operation starting. The observations have to be made during good sighting conditions and within 20 nautical miles of the start-up location; or

- Where less than 2 hours of observations have been undertaken (within the 20 nautical miles and under good sighting conditions), it is required that 2 hours of PAM monitoring and two MMOs have carried out visual monitoring for the same length of time, and no SoC have been detected. In addition, no fur seals have been detected in the 10 minutes prior to the operations and no other marine mammals have been detected in the preceding 30 minutes of the operation starting.

For Level 2 surveys, the above-mentioned conditions apply but if observations are only being carried out by MMOs, start-up procedures and active surveys can be executed only if:

- 24 hours of active survey operations, under good sighting conditions, have been conducted and no more than three shutdowns or delayed starts due to marine mammals' presence have occurred, or

- If the 24 hours of active survey operations have not been conducted, MMOs have carried out observations before activities start and under good sighting conditions for at least two hours within a radius of 20 nm of the proposed start-up position and no detections of marine mammals have been made.

In addition, New Zealand's Code has a special condition relating to the presence of cetaceans with calves, SoC and other marine mammals. If there is a detection of at least one cetacean with a calf within 1.5 km of the source for level 1 surveys and within 1 km for level 2 surveys, either during pre-start observations or when the acoustic sources have been activated, activities will not be resumed until animals have left the area or 30 minutes has passed since the last time the group was seen within the EZ. The same conditions apply when there is a detection of SoC within 1 km for level 1 surveys, and 600 m of the source for level 2. Finally, if there is a detection of any marine mammal within 200 m of the source during pre-start observations before the initiation of the acoustic source, activities will not begin until animals leave the area or 30 minutes has passed and no mammals have been detected, or 10 minutes have passed since the last sighting of a New Zealand fur seal within 200 m of the source.

ACCOBAMS requires that there be 30 minutes of dedicated watch to detect animals before starting any sound emission. In deep-water areas where beaked whales have been detected diving on the vessel trackline or if the vessel is approaching habitats suitable for beaked whales, 120 minutes of dedicated watch are required so as to increase the probability that deep-diving species are detected. In addition, it is required that there must be two MMOs on watch at one time and at least one PAM operator on watch. At night, during low visibility periods, significant surface-ducting conditions (irregular sea waves), or during weather conditions that prevent visual detection of mammals, high power airgun configurations are prohibited. PAM should be used to improve detection capabilities and is mandatory for operations that are carried out at night or under poor visibility. However, PAM may not be suitable for night operation if cetaceans in the area do not vocalize or their vocalisations are difficult to hear.

In the ASCOBANS region, to ensure that there are not marine mammals in the EZ, 30 minutes of watch must be done before starting sound emissions. ASCOBANS follows the European Cetacean Society Resolution on Active Sonar & Beaked Whales, so it is required to extent the watch to 120 minutes if beaked whales have been seen. However, sonar exercises should be avoided in areas where beaked whales are known to occupy. Finally, in the *Statement* of Canada there must be one qualified MMO on board, who is required to make observations of the safety zone during 30 minutes prior to the activation of the seismic air source array. MMO should keep continuous watching while the source arrays are active and there is visibility of the safety zone.

For all protocols across regions, monitoring using non-visual sources, such as PAM, are required when poor visibility is low. New measures of detecting vocalising marine mammals are being studied and probably will be used in the future, among them are radar, infrared detection and adaptation of fishing industry ‘fish finder’ technologies. PAM or any other technology for detecting vocalizing cetaceans is required when the following circumstances:

- There has been a shut-down of the sound sources array lasting more than 30 minutes;
- The safety zone it is not completely visible;

- The activities are being undertaken in an area where the presence of cetaceans is highly possible, or

- Within the area, there is a high probability of encounter cetacean species that can be negatively affected by the seismic sound at a population level, previously identified during the environmental assessment process.

6.4.2.3. Soft start/ramp up

Canada's legislation states that to activate the sound sources a start-up technique is required, which consists of starting the activation using a pulse from the array with the lowest energy and gradually activating the other sound sources in a pre-established time frame. This approach is implemented to allow marine mammals and fish to leave the area (Weir & Dolman, 2007). In cases where only one energy source is employed, such as vertical seismic profiling activities, and when technically possible, the start-up technique will consist in gradually augmenting the sound intensity until it reaches the necessary power for the planned activities (Fisheries and Oceans Canada, 2014).

For its part, New Zealand's Code encourages soft starts every time a source is turned on. The power must increase for at least 20 min and no more than 40 min. In a new location, soft starts are allowed after two MMOs have done observations for two hours, within 20 nm in good sight conditions. If visual conditions are not favourable, two hours of PAM and two of MMOs for SoC should be implemented, with no fur seals being detected for 10 minutes and no other marine mammals being detected for 30 minutes prior to commencement of sound activation. This mitigation measure is not required after stopping the source for a break in firing of less than 10 minutes and no detections have been made. In contrast, ACCOBAMS and ASCOBANS have less specific definitions concerning this mitigation measure. However, their legislations say that this procedure should be applied every time a source is turned on to allow cetaceans that were not detected, to leave the zone.

6.4.2.4. Delays and shut-downs

Delayed starts and shut-downs, which consist of turning off all sources of noise, are applied when a protected animal enters the EZ. New Zealand's Code states that these procedure should applied for SoC with calves if they are found within 1.5 km; SoC within 1 km of the EZ or for other marine mammals within 200 m.. ACCOBAMS and ASCOBANS require that if cetaceans are observed within the EZ or approaching it, the beginning of the operations should be delayed 30 minutes after the animals leave the zone or have been last seen, for beaked whales is 120 minutes. Canadian guideline states that the start of operations should be delayed when cetaceans (including marine mammals listed in the Schedule 1 of the Species at Risk Act) or turtles have been detected. After that, a soft-start procedure can commence after 30 min without detections or when animals have left the zone.

For their part, ACCOBAMS and ASCOBANS require shutdown when marine mammals enter the EZ or whenever aggregations of vulnerable species (e.g. beaked whales) are detected anywhere within the area. If there is any irregular stranding during the noise activities then in addition to a shutdown, operators must consult with relevant government agencies and experts. Canadian legislation requires that if a marine mammal or sea turtle is detected entering the safety zone, operations must be shutdown. When active survey operations cease the energy sources must be entirely shutdown to decrease unnecessary sound emissions or have only one source operating as a deterrent for cetaceans or turtles.

6.4.3. Post seismic survey stage

6.4.3.1. Recording and reporting

New Zealand's Code requires that all the data taken during the execution of the seismic survey activities should be recorded, and presented within 60 days of the end of the survey. This report will be delivered in a standardised format and will detail, among others, the qualifications of those involved in observations, observer effort, methods, specifications of the seismic source array, GPS track logs of vessel movements, and totals for seismic source operations and power levels employed.

Sighting/acoustic detection records of cetaceans must indicate all the information specified in the Code. This includes method of detection, position of vessel/acoustic source, distance and bearing of marine mammals relative to the acoustic source, direction of travel of both, and vessel and marine mammal numbers. In addition, observers have to submit all raw datasheets within 14 days of the end of the survey. This information will be confidential, but marine mammal data will be made public to enlarge and improve information for areas of ecological importance and to be used for analytical research. This specification applies for both level 1 and 2 surveys.

As in New Zealand, ASCOBANS require all data collected during monitoring activities to be reported to improve and evaluate mitigation methods. These data must be taken responsibly and must provide information about possible effects on animals. Its compilation is the responsibility of the MMO working on the mitigation measures within the specific project. This monitoring process aims to look for changes or absence of changes in behaviour, spatial distribution, abundance and reproductive success. Notably, control data must be taken to make comparisons in these aspects. When developing activities under permit, recording of visual observations and acoustic monitoring, must be done precisely. Abnormalities in behaviour and distribution must be recorded with respect to small and large spatiotemporal scales, and whether changes are temporary or permanent.

Data must allow differentiation among changes produced by seismic or sonar activities, natural factors or other human activities. There are specific requirements regarding Post-Activity Monitoring and Reporting, which state that all data from whale observations have to be in the public domain. Data from monitoring activities, regarding seismic or sonar operations, should be included in studies focussed on variations in the distribution of whales. In addition, data from monitoring activities should be included with other 'oceanographic data and to the automatic logging of ship tracks and acoustic source use' (ASCOBANS, 2010, p. 16) and 'if required, independent monitoring stations could be used to monitor noise levels at different ranges from the source' (ASCOBANS, 2010, p. 16).

ACCOBAMS states that the most important requirement is to present an accurate report to verify the environmental impact assessments (EIA) and the effectiveness of the mitigation plan. In addition, like ASCOBANS, both recommend sharing of data to avoid duplicate surveying. Lastly, Canada does not include any requirements for post seismic survey activities in its Statement. The mitigation measures addressed here are summarised in Table 7.1.

Table 7.1. Summary of some marine mammal mitigation measures used during seismic surveys.				
	The Code (NZ)	**ACCOBAMS**	**ASCOBANS**	**The Statement (Canada)**
Area covered	New Zealand continental waters.	Black and Mediterranean Seas and Contiguous Atlantic Area.	Baltic and North Seas.	All non-ice covered marine waters in Canada.
Impact assessment required?	Yes	Yes	Yes	Yes
Species covered	Marine mammals and other key species: turtles, penguins and seabirds.	Cetaceans	Cetaceans	Marine mammals, marine fish, turtles.
Regional restrictions	Areas of Ecological Importance, mammal sanctuaries, sensitive or ecologically important areas.	Cetacean's key habitats, MPAs and closed areas, areas of high cetacean density.	MPAs, key marine mammal habitats and areas of high marine mammal density.	Avoid areas critical to the life cycle and biological functions of marine mammals and marine fish.
Seasonal restrictions	Yes, for SoC.	Yes	Yes, within MPAs and key marine mammal habitats.	Yes
Sound output	Determine the lowest practicable power levels required to undertake activities.	Use the lowest practical source of power. Limit horizontal propagation using an effective array configuration and pulse synchronization. Eliminate unnecessary high frequencies.	Use the lowest practical source of power. Limit horizontal propagation using an effective array configuration and pulse synchronization. Eliminate unnecessary high frequencies.	Avoid unnecessary production of sound employing the minimum energy. Reduce or regulate horizontal sound propagation and limit the use of high-frequency sound to where strictly necessary.
Exclusion Zone	1500 m for SoC with calves. 1000 m for SoC. 200 m for other marine mammals.	Designated dynamically according to the source characteristics, the species in the survey area and the propagation characteristics in the area.	Designated dynamically according to the source characteristics, the species in the survey area and the propagation characteristics in the area.	500 m
MMO guidelines	Two qualified MMOs on board.	Two MMOs on watch at one time.	Two MMOs on watch at all times on every operative ship.	One MMO on board.
PAM guidelines	Two qualified PAM operators. (For Level 2 surveys, PAM is optional.) 24-hour monitoring.	One PAM on watch. 24-hour monitoring. PAM can be replaced by an automatic detection/alerting system.	One PAM on watch. 24-hour monitoring. PAM can be replaced when proven automatic detection/alerting systems are available.	PAM is only required during low visibility, bad weather, shut down for more than 30 min, safety zone not fully visible and when the encounter of cetaceans is highly possible.
Pre-start	30 min at least one MMO, 10	30 min two MMOs and one PAM.	30 min, two MMOs and one	30 min, one MMO.

observations	min for fur seals. 30 min PAM.	2 h where presence of beaked whales is probable.	PAM. 2 h where presence of beaked whales is probable or had been observed	
Soft start/ramp up	Every time a source is turned on. Power increases at least for 20 min and no more than 40 min. In a new location: 2 h, two MMOs within 20 nm in good sight conditions. If not, 2 h PAM and two MMOs for SoC, 10 min for fur seals, for other marine mammals 30 min.	Every time a source is turned on. (Duration is not stated.)	Every time a source is turned on. (Duration is not stated.)	Every time a source is turned on. (Duration is not stated.)
Delayed starts	For SoC with calves within 1.5 km. SoC within 1 km detections. Other marine mammals within 200 m detections. Then soft start.	For cetacean detections. Then soft start.	For marine mammal detections. Then soft start.	For cetacean or turtle detections. Then soft start.
Shut-downs	For SoC with calves within 1.5 km or SoC within 1 km. For other marine mammals within 200 m.	Cetaceans enter the EZ or vulnerable species are detected.	Cetaceans enter the EZ or vulnerable species are detected.	A marine mammal or turtle enters the EZ.
Day-time operations	Minimum one MMO and one PAM operator.	Two MMOs and one PAM operator.	Two MMOs and one PAM operator.	One MMO and one PAM operator (when required).
Night-time operations	30 min of PAM and MMO.	High-power airgun configurations should be prohibited. PAM is mandatory.	High-power airgun configurations should be prohibited. PAM is mandatory.	PAM is required.
Poor weather conditions	Source cannot be activated until at least 30 min PAM and MMO.	High-power airgun configurations should be restricted. PAM is mandatory.	High-power airgun configurations should be restricted. PAM is mandatory.	PAM is required.
Recording and reporting	Yes	Yes	Yes	Not specified.
Other items	The use of explosives as an acoustic source is forbidden.	Stranding networks during operations must be reported. Data sharing must be done to avoid duplicate surveys.	Stranding networks during operations must be reported and if required the coast should be monitored for deaths. Post-cruise surveys to prove or discount any irregular deaths as a possible consequence of the activities.	None

6.5. Regulations for whale-watching

The International Whaling Commission offers a general framework under which each country or region can establish their own whale-watching regulations according to their situation. The International Whaling Commission's guidelines for whale-watching activities are divided into three parts, covering the development of whale-watching activities, platforms and interactions (International Whaling Commission, n.d.).

1. For an appropriate management of whale-watching activities guidelines are as follow: implement regulations on platforms regarding "size, number, activity, frequency and length of encounters". Additional protection for enclosed areas or due to season should be developed; assess the amounts, distribution and other important characteristics of the target population present in the area where activities are going to take place; monitor the measurements implemented and modify them if necessary according to their effectiveness; new whale-watching activities must be developed gradually, controlling activities until enough information is obtained to expand the activities; management actions include scientific research and collection of information regarding operations, cetaceans and impacts, including acoustic impacts; operators and staff must have training in biology and behaviour of the target species, and must be informed about whale-watching activities and about the measurements to decrease the impacts of these activities; and provide appropriate educational material to the public involved in whale-watching activities.

2. Platforms: any platform should be designed, maintained and operated to decrease any negative impact on cetaceans and their surroundings; operators must know the different responses of each target species to sounds and of the sounds of their own vessel when operating to decrease as much as possible disturbing sounds; a vessel with a proper design and operative protocol can reduce the noise and the risk of injure on cetaceans; tracking whales should be possible for operators if an encounter occurs.

3. Interactions: any interaction and its duration must be determined by the cetaceans; operators must be aware about signals of disturbance and have knowledge about behaviour and sounds produced by cetaceans; maximum platform speed should be set in

accordance with that of the cetacean; cetaceans must be approached from a correct position and an appropriate distance must be maintained; although a friendly interaction with a whale may be welcomed, contact must not be actively sought; abrupt changes in speed, direction and noise should be avoided; speed or direction must not be changed in order to prevent cetaceans leaving the area; do not head off, encircle, pursue or separate groups; approaches to mothers with calves, calves or juveniles must be made with 'special care'; cetaceans must be able to detect platforms, even though zero production of noise during operations is expected, undetected platforms can cause distress to cetaceans.

6.5.1. Mitigation measures for whale-watching activities

6.5.1.1. Permits and impact assessment

Some regions have guidelines that require obtaining a permit prior to the start of whale-watching activities. In the case of ACCOBAMS (2004), an impact assessment is required prior to issuing whale-watching permits. The impact assessment must be detailed and follow best practice protocols using the most relevant scientific information available. Activities should not be allowed if they pose any harm, either behavioural or physiological, to cetaceans, including consideration of the number of existing whale-watching activities and their effect on cetaceans (ACCOBAMS, 2004). Activities should be specially adjusted according to the outcome of the impact assessment, which also must be repeated periodically. A permit will be denied if authorities consider that operators and staff lack experience with cetaceans; have little knowledge of the local area, climate and sea conditions; have any convictions related to harming animals, or the activities submitted lack relevant educational value (ACCOBAMS, 2004).

In addition, a permit may be revoked or restricted if the holder does not follow the requirements stated in the permit, or if it is necessary for the maintenance of favourable conservation status for cetaceans (ACCOBAMS, 2004). In New Zealand's case, an application in writing with obligatory information is required: operation details, operator and staff that may have contact with marine mammals, information about any educational material and, in the case of aircrafts, 'the number of the air service certificate or other aviation document under which the aircraft will be operating' (Marine Mammals Protection Regulations 1992, 2014, p.8).

6.5.1.2. Approaching the animals

This mitigation measure aims to avoid scaring the animals or disrupting their behaviour while the vessels and/or aircraft are approaching. New Zealand's regulation states that a vessel can approach a whale from a parallel direction or slightly to the rear of the whale and that loud or distressing noises should not be made by anyone close to whales. In case of any contact with a sperm whale, approaching must be stopped immediately if the whale changes direction or goes below the surface for 1 to 5 minutes long without showing its tail flukes (Marine Mammals Protection Regulations 1992, 2014). In comparison, Canada's guideline requires the approaching vessel to use an oblique line (not directly towards the animal) and to maintain 100 m of separation from a whale, dolphin or porpoise. People should be wary and keep their distance from the flukes, and ensure that approached animals do not pursue them (Carlson, 2001; Fisheries Act, R.S.C. (1985), c. F-14. 2013).

For ACCOBAMS, they state that approaching a cetacean from a vessel should be only done from the side (ACCOBAMS, 2004); while Australia states that vessels cannot approach from the rear or the front of a whale. Australia's legislation are more specific and highlight that there is a no approach zone of 100 m from a whale and this zone extends to 300 m at the front and rear of the whale (Commonwealth of Australia, 2005). If whales are showing signs of disturbance, any attempt to interact with them should be stopped and vessels should move outside the caution zone at a no wake speed. For dolphins, the no approach zone is 50 m, this includes the zone in front and behind the dolphin, which extends to 150 m. The best way of approaching a whale or dolphin is from the side and slightly to the rear of the animal (Commonwealth of Australia, 2005). Finally, Ireland state that the craft should maintain a stable course when whales or dolphins are first encountered, the course should be kept parallel with respect to the direction cetaceans are following, and that all boats involved in the activities must follow the same course (Department of Communication, Marine and Natural Resources Marine, 2005).

6.5.1.3. Distances to the animals (caution zone)

Vessels and aircraft should keep a distance from the animal with the objective of reducing stress or sudden responses that can be detrimental for the animals. ACCOBAMS establishes that aircrafts should not fly below 183 m above sea level and; that vessels should maintain 100 m of separation from a cetacean and should not cut off its path or prevent cetaceans from leaving the proximity of the vessel. If the distance from cetaceans is less than 300 m, the vessel should maintain constant speed, no faster than 5 knots and no faster than the slowest cetacean in the area, and should stop if the vessel is within 100 m of a cetacean. When leaving the proximity of any cetacean, the vessel should go slowly until reaching at least 300 m from the closest cetacean. ACCOBAMS also states that the shadow from aircrafts should not be imposed on cetaceans.

New Zealand's guidelines state that aircrafts should not fly below 150 m above sea level, unless taking off or landing. If an aircraft is flying at an altitude of less than 600 m, then it cannot get closer than 150 m horizontally from a point directly above any marine mammal. Other distances should be pre-approved. In addition, vessels should not get within 50 m and no person in the water should be closer than 100 m of a whale. If there are three or more vessels or aircrafts, or a combination of them, maximum approach is restricted to 300 m. When two vessels or aircrafts are approaching a single whale, pilots/masters must coordinate their approaches and manoeuvres. Finally, if a vessel or a person is approaching a female baleen or sperm whale with one or more calves, the closest distance permitted is 200 m.

Finally, Australian guideline states a caution zone of 300 m to 100 m either side of a whale. For dolphins, this zone is of 150 m to 50 m either side of the animal. Vessels cannot enter the caution zone if there are cetaceans stranded, entangled or distressed, and approaching calves and pods with calves is prohibited. Canadian legislation requires vessels to be 300 m from the animal and aircraft 450 m above the water. Finally, Ireland's guideline states that a distance of 100 m from whales is required and 200 m between other boats, and that the speed should be < 7 knots and if calves are seen special care must be taken not to separate mother and calf.

6.5.1.4. Requirements for boats during whale-watching activities

ACCOBAMS states that vessel/aircraft should manoeuvre so as not to disrupt cetaceans' normal movements and behaviour. If cetaceans show disturbance or signs of alarm, then all contact should cease. Cetaceans should not be separated from the group and food or waste should not be thrown near cetaceans. Unexpected or constant changes in speed, excluding emergency situations, are forbidden. Engines should be set on neutral when the vessel stops to allow passengers to watch cetaceans.

New Zealand has the most rigorous standards of all the guidelines compared. These include land based vehicles (must be above high tide mark near marine mammals), and prohibiting impeding marine mammals from leaving the proximity of a person, vessel. If the distance from any marine mammal is < 300 m the vessel must maintain a constant slow speed no faster than the slowest marine mammal in the proximity, or at idle or 'no wake' speed. When leaving the proximity of marine mammals vessels should go slowly at idle or 'no wake' speed until at least 300 m from the closest marine mammal. In the case of dolphins, to leave them behind, speed can be higher but must be increased gradually but no greater than 10 knots within 300 m of any dolphin.

Canada also shares similar restrictions such as the 300m caution zone and no direction or speed changes if a whale is spotted close to the vessel. Additionally, sailboats must keep their auxiliary motor on idle or use the echo sounder to be detected by the animals. Moreover, and not taken into account in other guidelines, at all times it is important to be alert to prevent any collisions with animals, even when not undertaking whale watching activities, and more so in areas where whales have been reported.

Australia states that vessels cannot wait in front of the pod or in the direction where cetaceans are traveling. If cetaceans are showing signs of disturbance, any attempt to interact with them should be stopped and vessels should move outside the caution zone at no wake speed. For both, whales and dolphins, bow riding should not be sought deliberately by the vessel operator, if animals do bow ride, then the speed and the course must be kept steady, and to stop the vessel the speed must be reduced gradually. Finally, Ireland's guidelines states that when dolphins approach vessels and bow ride, the operator must always let dolphins come towards the boat instead of pursuing them and boats must not corral any cetaceans and impede escape routes.

6.5.1.6. Requirement for aircrafts during whale-watching activities

Within the guidelines discussed, only Australia has specific measures to mitigate aircraft. Australia divides its guidelines into two categories: Tier 1 and Tier 2. The Tier 1 category covers all people involve in watching activities and sets general guidelines to protect whales and dolphins. The Tier 2 covers mainly commercial activities and other activities that require special guidelines, such as operations that need to be planned in a different manner based on scientific evidence, or are undertaken in a specific region with sensitive species, important populations or marine parks, etc., or in areas where whale- and dolphin-watching activities are very intensive.

Under the Tier 1 category, and for helicopters or gyrocopters, if a whale or a dolphin is within 500 m, aircrafts should not fly lower than 50 m or hover in this area. Aircrafts should avoid flying over the whales and dolphins and prevent the shadows from the aircraft falling on the animals. Approaches cannot be done head on and all activities should stop if whales or dolphins are showing signs of disturbance. Other aircraft, including fixed wing, gliders, hang-gliders, hot air balloons and airships, should avoid flying less than 300m above whales and dolphins. In terms of the Tier 2 category, if for any special reason, such as for scientific, educational or commercial filming it is necessary to make a closer approximation to a whale or dolphin, an authorization by the Australian Government or the relevant state or territory must be obtained and aircrafts should operate under those conditions.

6.5.1.7. Number of vessels and duration of activities

Limiting the number and the duration of encounters can help to reduce the stress on the animals; and some guidelines take this into consideration. For example, in the ACCOBAMS region, only one vessel or one aircraft is allowed at any one time in the watching area, and the time allowed is limited to 15 minutes for vessels or 2 minutes for aircrafts, especially if there are vessels waiting their turn. In Ireland, the maximum time allowed with cetaceans is longer (30 minutes). In Australia and New Zealand, a maximum of three vessels can be in the caution zone at the same time, but in New Zealand, there is no maximum time specified. The mitigation measures addressed here are summarised in Table 7.2.

Table 7.2. Summary of some marine mammal mitigation measures used during whale-watching activities.					
	AUSTRALIA	**CANADA**	**NZ**	**ACCOBAMS**	**IRELAND**
Permit required?	Only for Tier 2 activities.	No	Yes	Yes (V-A)	No
Operator requirements	Suitable training and certifications.	N/S	Experienced.	Experienced.	Knowledge of procedures when encountering a cetacean.
Staff	Suitable training and certifications.	N/S	Demonstrated experience with cetaceans. Knowledge of the area, weather and sea conditions. No convictions for mistreating animals.	Demonstrated experience with cetaceans. Knowledge of the area, weather and sea conditions. No convictions for mistreating animals.	Knowledge of procedures when encountering a cetacean.
Educational programmes	Required	N/S	Required	Required	N/S
No-approach zone	Whales: less than 100 m Dolphins: less than 50 m Prohibited vessels: 300 m (any cetacean).	Less than 100 m	Whales: less than 50 m (vessels), 100 m (person). Dolphins/seals: do not go across pods. All: 300 m max. approach when three or more vessels or aircraft are in the zone.	Less than 100 m	Less than 100 m
Direction to approach animals from	The side and slightly to the rear.	Parallel, making an oblique line.	Parallel, slightly to the rear.	Diagonally from the side.	A course parallel to whales' swimming direction.
Directions forbidden to approach animals from	The rear or front.	Head on.	N/S	The rear, the front must be clear.	N/S
Manoeuvres for leaving the area	Slowly, at a 'no wake' speed.	Slowly until reaching 300 m, following a parallel direction to whales.	Slowly at idle or 'no wake' speed until reaching 300m from the closest cetacean.	Slowly until reaching 300 m from the closest cetacean.	N/S
Caution zone	Whales: 300 m to 100 m Dolphins: 150 m to 50 m	300 m to 100 m	300 m to 50 m	300 m to 100 m	100 m from whales 200 m from other boats
Mother with calves/calves/juvenile	Approaching calves and pods with calves is prohibited.	N/S	Female baleen or sperm whale with calve(s): max. distance 200 m.	N/S	Special care to not separate mother and calves.
Behaviour around animals (people)	Do not make excessive or abrupt noise.	N/S	Loud or distressing noises and any form of harassment are prohibited	Do not disturb or harass animals in any way.	N/S
Behaviour around animals (vessels)	Avoid erratic manoeuvres, do not wait in front of pods or in the direction that whales are travelling in, do not force animals to move towards the shore, avoid	Do not make constant changes in speed and direction; do not pursue animals that approach the boat and keep a distance from the flukes.	Do not disrupt normal movements, separate or disperse groups, make constant changes in speed and direction, cut off paths, prevent animals from leaving	Do not make constant changes in speed and direction, separate groups, disrupt normal movements, cut off paths or prevent animals from leaving the	Keep stable course, do not pursue or corral animals.

	abrupt changes in speed and direction.		the area or go across a pod.	area.	
Behaviour around animals (aircraft)	Do not impose shadow on the animals, approach head on or hover in the 500 m radius.	N/S	Do not impose shadow on the animals, disrupt their normal movements or make changes in speed and direction.	Do not impose shadow on the animals or disrupt their normal movements.	N/S
Behaviour around animals (land)	Be aware of sensitive areas such as coastal dunes and headlands.	N/S	Loud or distressing noises and any form of harassment are prohibited.	Not considered	N/S
Vessel speed (close to animals)	'No wake' speed.	Decrease speed and move slowly.	No faster than the slowest cetacean (300 m) or at idle or 'no wake' speed.	Less than 5 knots and no faster than the slowest cetacean (300 m). Stop vessel (less than 100 m).	Less than 7 knots.
Engine controls (close to animals)	N/S	Distance less than 100 m: change into neutral or idle.	Set on neutral or turn off during the first minute of the vessel stopping.	Set on neutral when vessel stops.	N/S
Maximum number of vessels/aircraft in the caution zone	Three	N/S	Three	One (vessel or aircraft).	One
Vertical distance for aircraft (minimum)	Helicopter: 500 m; other aircraft: 300 m	450 m	150 m	183 m	N/S
Maximum time with animals	Tier 1: not specified. Tier 2: must be specified in order to get a permit.	N/S	N/S	Vessel: 15 min. Aircraft: 2 min.	30 min
Signs of disturbance or alarm	Stop contact and move outside caution zone at 'no wake' speed.	N/S	Stop contact.	Stop contact.	N/S
Feeding animals	Only allowed with a permit for Tier 2.	N/S	Forbidden.	Forbidden.	N/S

V-A: vessel-aircraft; N/S: Not specified.

6.6. Discussion

6.6.1. Seismic survey mitigation measures

Among the different guidelines detailed above, three main aspects can be analysed concerning the effectiveness of the guidelines: 1) enforcement, 2) coverage (stages pre-during-post), and 3) survey design. One of the key components for adequate mitigation procedures is the enforcement of the guidelines established by each government or organization. One effective method of enforcement is to require the mitigation procedures be considered as a prerequisite to obtain a permit to undertake seismic survey activities at every level, covering all areas, noise and noise producers. For example, ASCOBANS and ACCOBAMS have guidelines where a detailed description of the mitigation procedures must be included in the permit request and without the permit activities cannot be developed. In both cases, mitigation measures necessitate a detailed Environmental Impact Assessment. ASCOBAMS explains in detail what investigations and studies must be carried out to undertake an EIA, and consider this as the most important tool to mitigate the impacts of seismic survey activities.

The Statement from Canada provide guidelines for seismic survey activities but these are not needed prior to obtaining a permit, however these guidelines compliment a more all-encompassing set of environmental assessment processes (not detailed here) that provide strong protection for cetaceans. As explain by the Commission's Report, enforcement of the MMPA (USA) have no standardised requirements to obtain a permit to "take" marine mammals and can vary according to the kind of sound produced and the sources, so even when the same guidelines apply, its enforcement changes depending on the activities undertaken, which can be counterproductive in enforcing the mitigation guidelines (MMC–US Marine Mammal Commission, 2007, p. 34-35). In New Zealand, The Code establishes that the Director-General must be informed of level 1 and 2 activities as soon as possible but not less than three months before the operation starts and an appropriate MMIA must be provided. This MMIA contains the mitigation measures and a "consent" by the Director-General is given if the MMIA is approved, but this consent is not a permit itself, operators are approved beforehand without the mitigations measures being a significant part of this approval.

Another key factor in the effectiveness of the mitigation measures relates to coverage of the activities being undertaken, that is the survey stages identified in the guidelines: pre-, during and post-seismic surveys mitigation measures. For example, ASCOBANS, ACCOBAMS and The Code of Conduct (NZ) include these three phases; however the Statement from Canada does not have post-seismic survey specifications. Within ASCOBANS, ACCOBAMS and The Code, the post-seismic survey stage is crucial because it involves the reporting of the cetaceans sightings and reporting on the mitigation procedures carried out during operations. This information is used to update databases and to develop better mitigation measures based on the animal locations and the way operations were undertaken. In addition, reporting is important to keep track of the implementation compliance of mitigation guidelines. An additional requirement for ASCOBANS and ACCOBAMS is the implementation of a system to log the amount of acoustic energy produced; these information is made available to researchers and the public.

An additional feature of coverage is the specificity of certain guidelines. For example ASCOBANS, which bases its guidelines on the ACCOBAMS document, provides more detail in the majority of its recommendations. Likewise New Zealand's Code, details operations in Levels 1, 2 or 3 according to the kind of vessel used, and special guidelines when encountering mothers with calves.

Survey design is the third key aspect influencing mitigation. Survey design is outlined to varying degrees in all guidelines, though much less in the Statement of Canada. Nevertheless, the inclusion of an enhanced and more detailed set of specifications for designing surveys could help to mitigate the impact of the noise produced by the operations. ASCOBAMS and ACCOBAMS have more recommendations regarding to this than The Code, but in general, extra measures, other than the use of an appropriate array configuration and the establishment of the lowest practical source power, must be established. For instance, defining miminum practical levels and enforce them, e.g., no airguns in use during line changes, to prevent habituation or positive approach, and the development of 'low sound intensity replacements for airgun arrays and suppressor devices to eliminate unwanted high frequency sound' (Weir & Dolman, 2007).

6.6.2. Whale-watching mitigation measures

The key aspects for improving New Zealand´s whale-watching guidelines, in comparison with the other guidelines detailed above are the regulations to obtain a permit, fulfillment of the general regulations, areas and species considered in the guidelines, and recording and reporting of sightings.

Firstly, ACCOBAMS and New Zealand, unlike the other guidelines assessed, have established very detailed procedures for obtaining a permit to undertake whale-watching activities. However, only ACCOBAMS requires, among its specifications for a permit, the development of a complete Environmental Impact Assessment. The implementation of this prerequisite to obtain a permit could help to improve the mitigation measures, since activities will be better planned if they incorporate the results of such assessments.

Secondly, the fulfillment of the regulations; while the prerequisite to obtain a permit, such as experience of operator and staff, knowledge of the area where activities are taking place, educational aspects of the activities, etc., are verified before activities start, once started there are no means to assure that the guidelines are being followed. Therefore, to assist ongoing meeting of regulations some extra measures could be developed, among these could be the use of a person on board with the exclusive duty of reporting about the activities carried out and the fulfillment of the guidelines.

Thirdly, more specific guidelines could be developed according to the location of whale-watching activities and the species involved. Canada, of the countries assessed, is the only one that has established several guidelines to regulate whale-watching activities according to the species, such as orcas, bottlenose whales, right whales, threatened or endangered species, etc. and for areas, which include bays, marine parks and reserves. Such specific mitigation measures implemented in New Zealand, could give a more complete coverage to protect more thoroughly its high diversity of marine species.

Finally, out of the above guidelines only Ireland encourages the reporting of sightings, but it is not mandatory. A recording and reporting guideline could be very helpful to progress the regulations already established, since the data obtained can be used to improve cetacean databases and to develop further investigations aiming to reduce, more significantly, the impact of noise on cetaceans.

6.7. Conclusions

One of the strongest features of The Code of New Zealand is its set of comprehensive guidelines divided into specific levels according to the size of the vessels used in seismic activities. The New Zealand Code also has special requirements and mitigations for vessel encounters with mother/calve pairs. Furthermore, the MMIA and the guidelines are divided into pre, during and post-survey activities. This design of survey mitigations provides a means of improving the mitigation measures through the data accumulated in every survey. Nonetheless, aspects of the Code could be improved such as the enforcement of the guidelines, because even though a notification before starting activities and a MMIA is required and must be developed under the advice of the Department and the Director-General, the permit to undertake any seismic survey activity is not subject *a priori* to MMIA approval.

In addition, it is important to use the data already recorded and implement new investigations to improve the mitigation measures and make efforts to assess its effectiveness, because as stipulated by ASCOBAMS there is a set of guidelines but no proven evidence of their effectiveness. Therefore, ongoing investigations are needed and greater cooperation with the companies undertaking seismic survey activities is needed. Finally, The Code could include more detailed guidelines regarding the survey design, which could also be developed through new investigations, data from previous surveys, and the cooperation of the companies involved in this activities.

In terms of New Zealand's whale-watching guidelines, although comprehensive, could similarly be improved. In particular, the implementation of an impact assessment, as part of the prerequisites to obtain a permit could be very relevant. Such study could assist planning of activities according to specific locations and species present. Finally, it is important to develop an efficient mechanism that allows tracking the ongoing fulfillment of guidelines established by all operators. In addition, an appropriate protocol for recording and reporting sightings should be implemented for all operators, since this could help to improve cetacean databases and refine existing guidelines. Ongoing improvement of the permitting process, whale watching guidelines and adherence to regulations is essential to accomplish greater protection for animals exposed to whale watching activities.

Chapter Seven

Conclusions and future research

7.1. Final conclusions

My systematic review has shown that there are knowledge gaps in important areas, and for many species, addressing the issue of the impact of noise in cetaceans. Regions such as Latin America, Africa and Southeast Asia, as well as regions in the Arctic and Southern Ocean lack such information. Furthermore, only a handful of the total species have been studied, with work focussing on species common in laboratories or with wide, coastal distributions. Among the most studied species are bottlenose dolphin, harbour porpoise, orca and humpback whale. My review also shows that, worldwide, vessels are the source of noise most widely assessed for impacts on cetaceans. It should be noted that most of these studies evaluate the presence of the vessel as the source of the disturbance but not the noise as the main factor of these disturbances. This includes research in New Zealand where studies focus on vessels and only a few species, due to the economic importance of eco-tourism. In future, more attention should be placed on other activities, also of high economic and ecological impact, such as seismic explorations. Despite seismic activities increasing in New Zealand, I found no published studies evaluating the impacts on marine fauna. Indeed, current regulations rely on environmental impact assessments that often do not mitigate known impacts.

MaxEnt is a robust method for modelling cetacean habitat suitability in New Zealand; my models were consistent with other studies. In addition, I found that the distribution ranges of the species modelled overlapped with current and future projects of seismic prospecting, which could worsen the situation of highly endangered species, e.g. Maui's dolphin. While anthropogenic noise is unlikely to be a direct cause of extinction of Maui's dolphin, in combination with other factors such as over-fishing and incidental mortality, it increase the probably of decline of this population. Therefore, tools such as MaxEnt can help to mitigate potentially harmful impacts for different species by informing planning of activities such as seismic surveys by mininsing conflicts e.g. identifying exclusion areas and times for avoiding breeding and calving activities. It is also is important to highlight the absence of basic information about beaked whales, a group of animals highly diverse in New Zealand, known to be sensitive to diverse sources of anthropogenic noise.

Lastly, it should be acknowledged that The Code of Conduct of New Zealand for seismic surveys is one of the best developed. It has among its strong points, a set of guidelines that are very thorough and complete, specific sections according to the size of the vessels to use in different activities, and also special measures for sensitive aggregations (e.g. mother/calve pair). Nonetheless better enforcement of this policy, and better data collection would improve mitigation measures and allow for assessment of effectiveness. Likewise, New Zealand's whale-watching guidelines fulfil all the international requirements, but could be improved. In my view, an Impact Assessment should be included as part of the prerequisites to obtain a permit. In addition, an appropriate standard protocol for recording and reporting sightings should be implemented for all operators, in order to obtain data that can be used in research to improve the existing guidelines and accomplish a greater protection for animals exposed to whale watching activities.

7.2. Future research

I recommend that further research be undertaken on the impacts that seismic activities pose on cetaceans and other marine fauna in New Zealand, since, to date, there have not been studies about this topic. Research for a wider range of species and distributions is needed with a priority for beaked whales. I conclude that, although, New Zealand's legislation and guidelines for seismic survey and whale-watching activities are appropriately designed, more enforcement is required to protect cetaceans from disturbance. In addition, the creation of legislation and encouraging voluntary codes of conduct to protect specific areas and species could benefit the most vulnerable populations. For example, in Doubtful Sound, where bottlenose dolphins are threatened due to high calf mortality and impacts of tourism (Lusseau, Slooten & Currey, 2006; Guerra, 2013), voluntary codes were adopted in 2008, resulting in fewer dolphin-boat interactions (Guerra, 2013).

7.3. Study limitations

The systematic review conducted as part of this thesis was limited to accessible documents; unpublished documents such as internal reports and management plans were excluded. This could generate bias, especially, on issues related to seismic surveys, since most information is mostly unpublished. In addition, MaxEnt models output likely suitability area, not exact distribution ranges, hence they are best interpretated in conjunction with information about distribution, behaviour and habitat use of cetaceans from multiple sources. In addition, it is ideal to have an independent set of cetacean sightings to validate each model.

7.4. Final remark

This research will serve as a base for future studies about the impacts of noise pollution on cetaceans in New Zealand, since there are still gaps in knowledge about this topic. I suggest some areas for future research. My study also highlights gaps in current legislation to protect marine animals from anthropogenic disturbances. The most important recommendation is that these legislations are enforced and it is necessary to be more specific with such policies in areas of high industrial and tourism activities.

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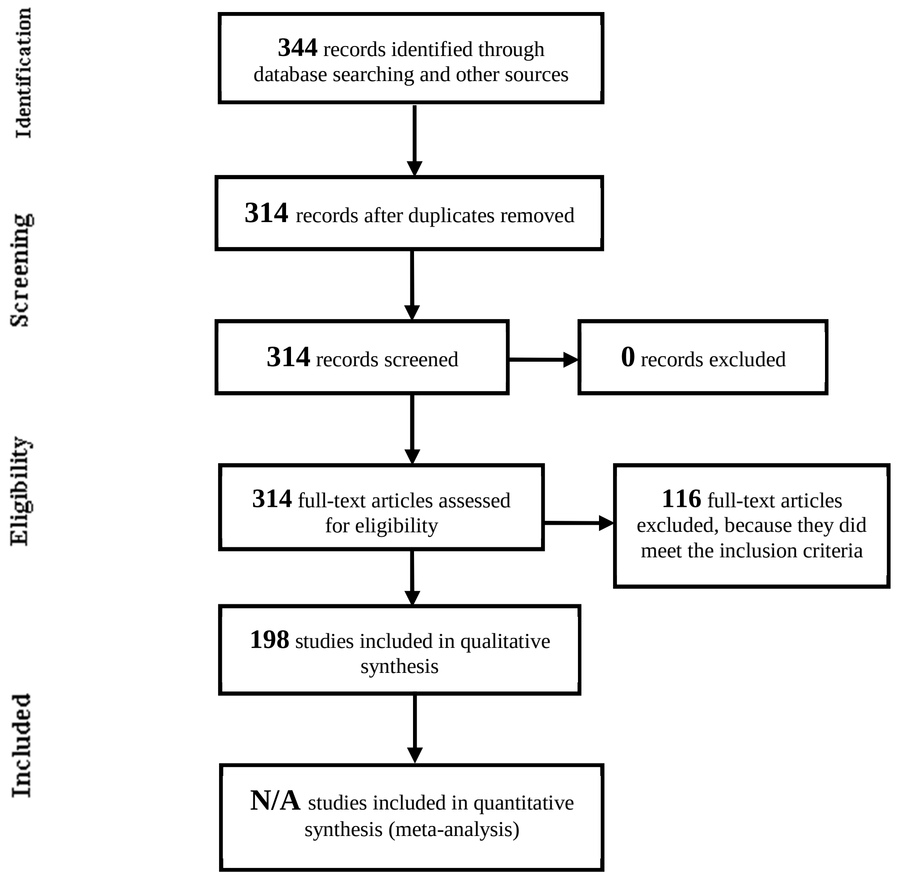
Appendices

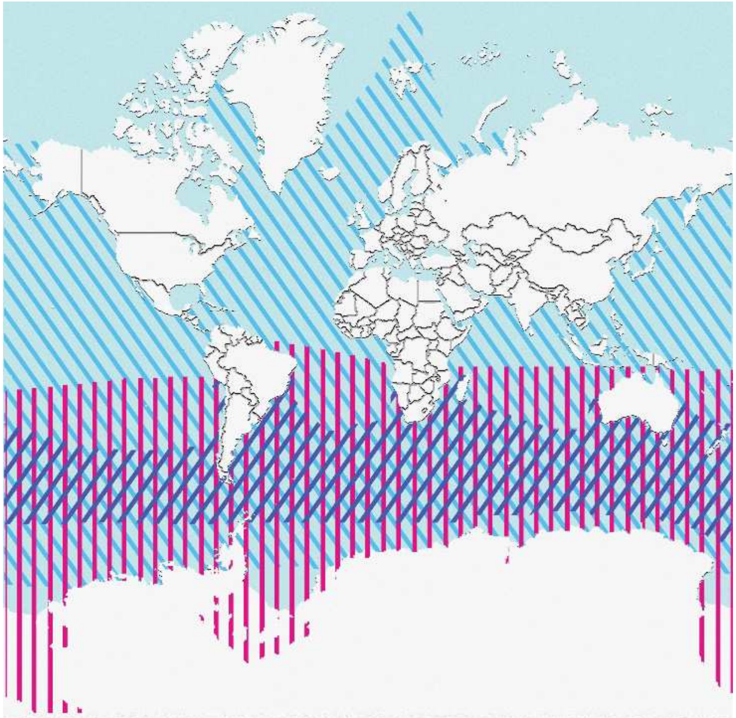
Appendix 3.1. Modified PRISMA flowchart providing the steps of data collection for the systematic review.



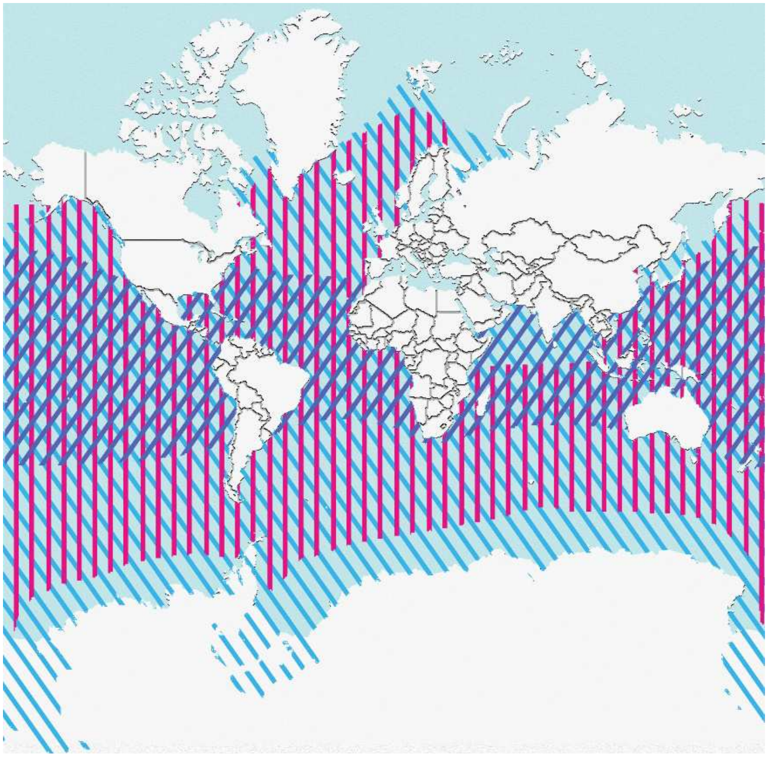
Appendix 3.2. Full name of the journals cited in the systematic review.

- Animal Conservation
- Animal Welfare
- Aquatic Conservation: Marine and Freshwater Ecosystems
- Aquatic mammals
- Artic
- Biodiversity Conservation
- Biological Conservation
- Biology Letters
- Biotemas
- Bulletin-Japanese Society of Scientific Fisheries
- Canadian Journal of Fisheries and Aquatic Sciences
- Canadian Journal of Zoology
- Conservation Biology
- Deep-Sea Research and Oceanographic Abstracts
- Deep-Sea Research I
- Deep-Sea Research II
- Doklady Biological Sciences
- Endangered Species Research
- Environmental Conservation
- Environmental Monitoring and Assessment
- Environmental Research Letters
- Fishery Bulletin
- Frontiers in Physiology
- Hydrobiologia
- ICES Journal of Marine Science
- International Whaling Commission
- Journal Cetacean Research and Management
- Journal for Nature Conservation
- Journal of Environmental Management
- Journal of Experimental Marine Biology and Ecology
- Journal of Marine Animals and Their Ecology
- Journal of the Acoustic Society of America
- Journal of the Marine Biological Association of the United Kingdom
- Journal of Zoology
- Latin American Journal of Aquatic Research
- Marine and Freshwater Behaviour and Physiology
- Marine Ecology Progress Series
- Marine Environmental Research
- Marine Mammal Science
- Marine Pollution Bulletin
- Nature
- North-western Journal of Zoology
- Plos One
- Proceedings of the Royal Society of London. Series B
- Revista Brasileira de Zoociências
- Revista Brasileira de Zoologia
- Scientific Reports
- The Journal of Experimental Biology
- Zoo Biology

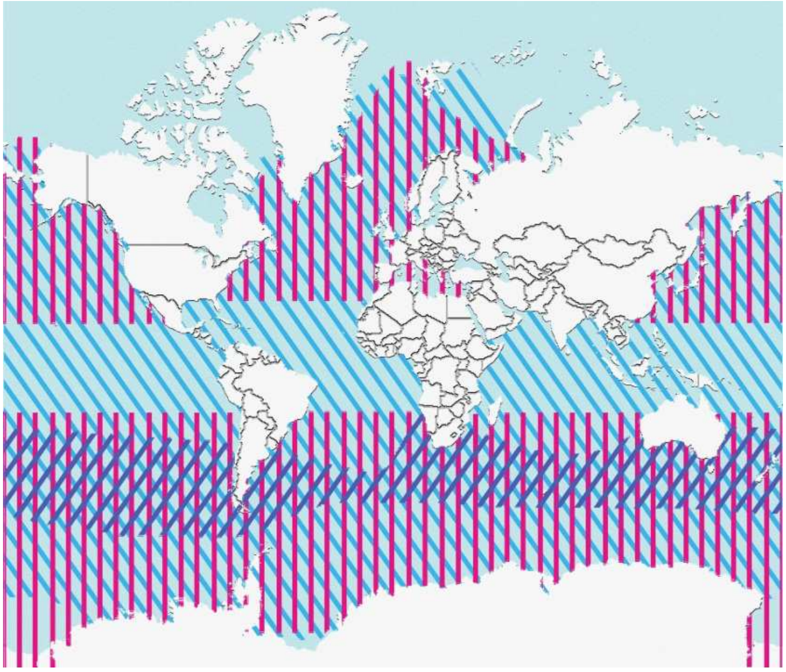
Appendix 4.1. Global distribution of cetaceans. Maps were based on IUCN cetaceans distribution maps.



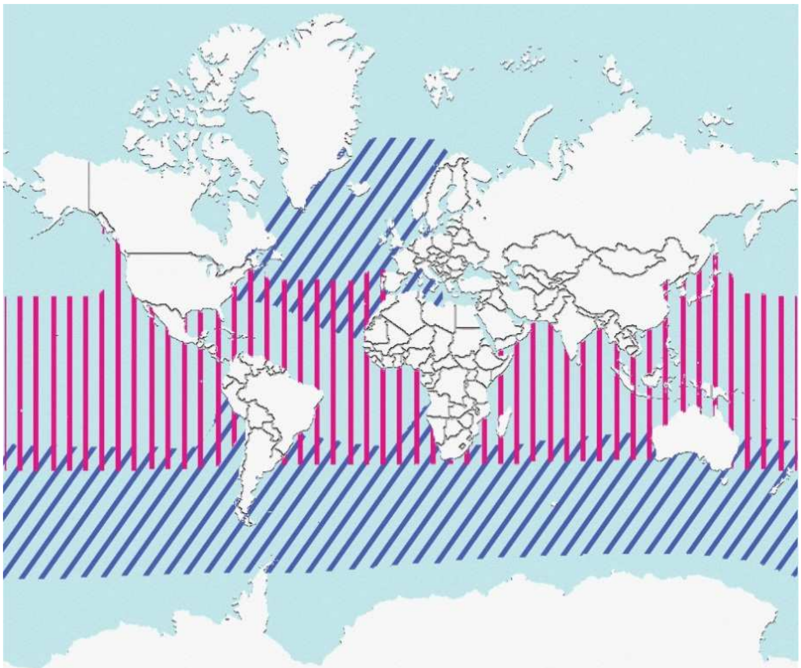
Map 1. Global distribution of *Eubalaena australis* (dark blue), *Balaenoptera acutorostrata* (light blue) and *B. bonaerensis* (pink).



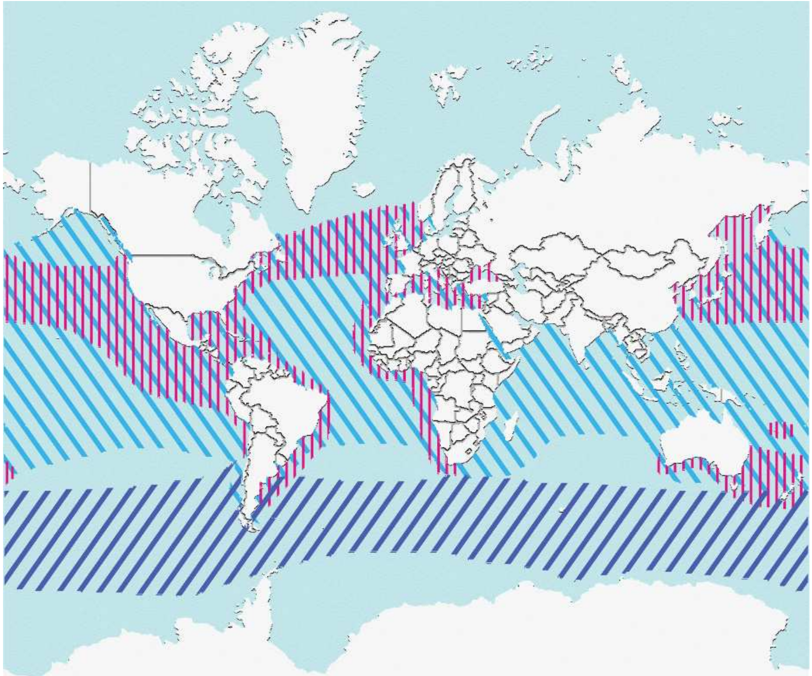
Map 2. Global distribution of *Balaenoptera edeni* (dark blue), *B. musculus* (light blue) and *B. borealis* (pink).



Map 3. Global distribution of *Caperea marginata* (dark blue), *Megaptera novaeangliae;* (light blue) and *Balaenoptera physalus* (pink).

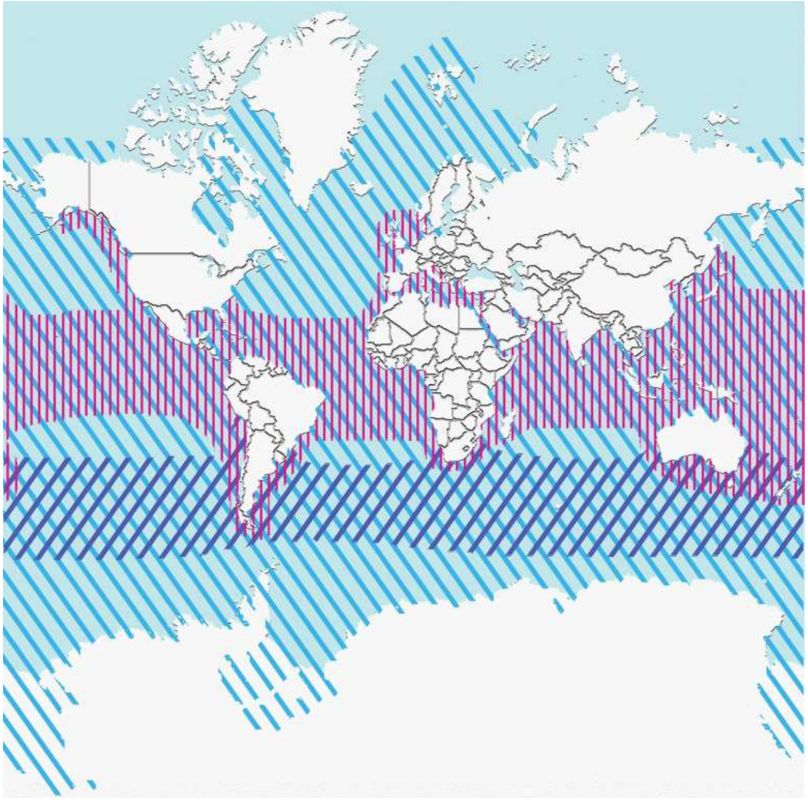


Map 4. Global distribution of *Globicephala melas* (blue) and *G. macrorhynchus* (pink).

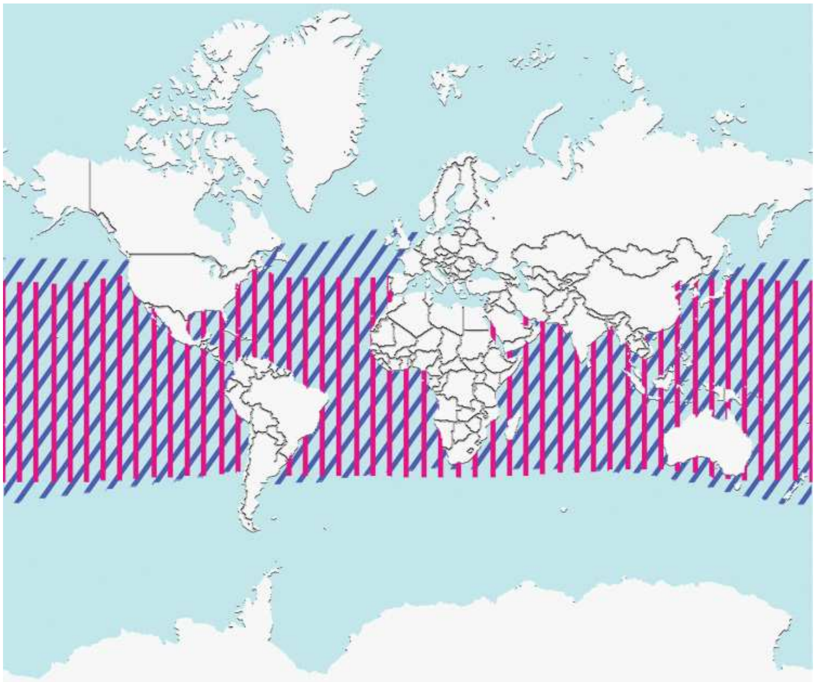


Map 5. Global distribution of *Lagenorhynchus cruciger* (dark blue), *Grampus griseus* (light blue) and *Delphinus delphis* (pink).

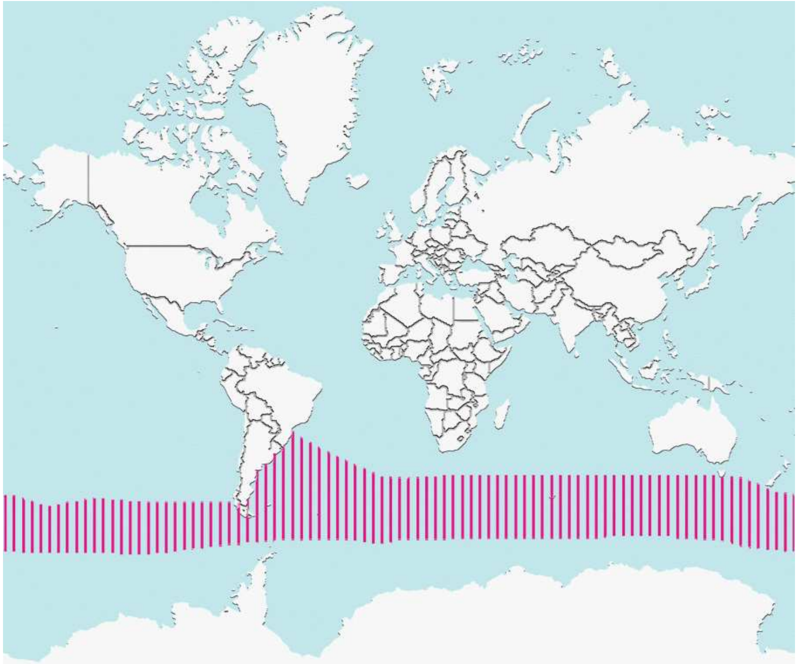
Map 6. Global distribution of *Lagenorhynchus obscurus* (dark blue) and *Tursiops truncatus* (light blue stripes).



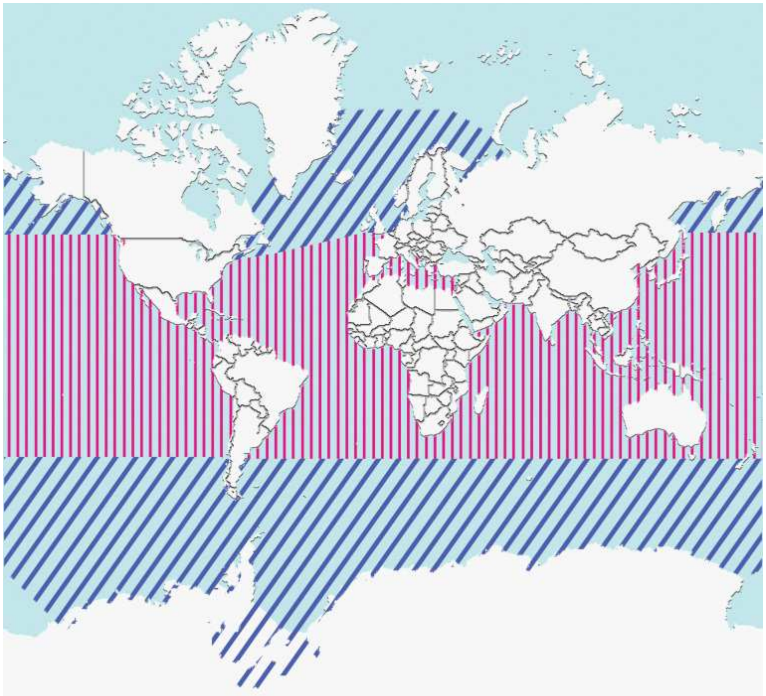
Map 7. Global distribution of *Lissodelphis peronei* (dark blue), *Orcinus orca* (light blue) and *Pseudorca crassidens* (pink).



Map 8. Global distribution of *Kogia breviceps* (dark blue) and *K. sima* (pink).



Map 9. Global distribution of *Phocoena dioptrica*.



Map 10. Global distribution of *Physeter macrocephalus* adult males (blue) and females and young males (pink).