Entanglement of cetaceans in pot/trap lines and set nets and a review of potential mitigation methods

BPM-17-DOC-New Zealand entanglement mitigation review-1.0

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1. Executive Summary

Between 1984 and 2017, there are 44 reported large whale entanglements in New Zealand waters, of which 39 are attributable to pot/trap and set net fisheries[1]. Twenty-five (64%) humpback whales, eight (21%) killer whales, three southern right whales, one minke whale, one blue whale, and one unknown baleen whale were documented as entangled. 62% of large whale entanglements involved rock lobster and 'likely' rock lobster gear, 21% of entanglements involved set net gear and 18% of entanglements involved either rope from an unknown gear type, or the gear involved in the entanglement was unknown.

Most documented entanglements occurred on the east coast of the South Island and the Bay of Plenty/Coromandel Peninsula region of the North Island although it is important to note that this is the location of the report and not necessarily the location of the actual entanglement. Almost one third (11 of 39) of all entanglements occurred in the month of June, and these were exclusively humpback whales. Of these eleven entanglements, eight occurred in the region of Kaikoura, two in Marlborough and one in the Banks Peninsula area.

The outcome of entanglement events was variable. 36% of all documented entanglements were fully disentangled, with 8% partially disentangled. 15% of whales shed gear on their own (without intervention). Conversely, 15% of entanglements were linked to the death of the individual, either directly or indirectly, and the fate of 28% of entangled whales remained unknown.

Tables of consequence and likelihood were used to assess the risk associated with large whale entanglements in New Zealand waters. This high-level approach indicates that the risk of entanglement to whales at a population level is low, however the risk to individual whales is medium. The risk of entanglements of large whales to stakeholders (DOC, commercial rock lobster and set net fisheries, and whale watch operators) was also assessed. Risks were currently assessed as low, but the incidence of entanglements is expected to increase as whale populations recover from exploitation, with a corresponding increase in risk to stakeholders.

The levels of risk identified support the importance of a review of these issues including the current levels of entanglement mitigation undertaken in New Zealand waters; mitigation actions undertaken worldwide; the applicability of current mitigation techniques to the New Zealand market. Eighty-four papers and reviews relating to large whale entanglement worldwide were reviewed. Of these, only 26 (31%) contained information specifically relevant to the development, testing and implementation of entanglement mitigation techniques.

There are three main categories of mitigation employed to address the entanglement of large whales: acoustic deterrents; gear modifications; and management modifications. The examination and review of gear modifications included: weak links; reducing rope strength; using negatively buoyant line; reducing rope slack; conducting rope-less fishing (via remote releases); and using different rope colours. The review of the effectiveness of management modifications included actions such as: reducing the crude number of lines in the water column; spatial and temporal closures; and disentangling whales. Despite global efforts to mitigate the entanglement of large whales, few gear modifications have proven successful in reducing documented entanglement numbers. Acoustic deterrents have shown mixed results with large cetaceans, with most studies indicating no response by large whales.

[1] Note that this will be an underestimate of the actual number of entanglements because not all entanglement data records were available for this analysis. In addition, the number of known entanglements will be an underestimate of actual entanglements since not all will be observed.

Options for mitigating entanglement range in their effectiveness and impact on whales. In their strictest form, mitigation aims to prevent entanglement. At the other end of the spectrum, mitigation is a response to an entanglement event. In general, the most effective form of mitigating against entanglement is to prevent it occurring at all – by removing fishing gear from habitat so that whales never encounter gear and, thus, never become entangled. The next level of mitigation measures permit fishing gear to be in the water, but reduce the risk of entanglement to whales by reducing the likelihood of them encountering and interacting with gear. This includes measures such as modifying gear to reduce the amount of rope in the water column. If prevention has been unsuccessful and an entanglement occurs, there are mitigation measures that may minimise the physical impacts to whales, such as ropes with reduced breaking strengths. Failing all else, disentanglement is a tool that may be used to mitigate individual whales experiencing serious entanglements, but this is will not mitigate against all entanglements (only those that are reported, resighted and acted on). It is important to note that, even with safety procedures in place, there remains a risk to personnel during a disentanglement event.

With regards to large whale entanglement in New Zealand waters, given the high economic value of the pot/trap and set net fisheries involved, as well as the current low documented incidence of entanglements, seasonal or temporal closures are not a viable mitigation tool. Other developments in preventative mitigation measures (such as rope-less fishing, reduced rope strengths or changing rope colour to a more visible hue) are either still under development, or where the results of implementation have yet to be documented. The results of these developmental studies might lead to recommendations for use in the New Zealand market in the future. For now, seasonal, mandatory gear modifications focused on reducing the amount of slack rope in the water column is a more measured approach to reduce risk, and one that the fisheries may be more open to, considering many such measures are already recommended by industry representative bodies and implemented by some fishers. Disentanglement efforts will continue to be a vital mitigation measure in New Zealand until effective preventative measures are developed and implemented.

2. Introduction

Direct interaction with fishing gear is a serious problem facing marine mammals worldwide (Johnson et al. 2005, Read 2008, Knowlton et al. 2016), and is a major anthropogenic cause of morbidity and mortality in large whales (Knowlton and Kraus 2001; Alava et al. 2012, Moore et al. 2013, Knowlton et al. 2016). One component of this is interaction is large whale entanglement with the issues facing conservation managers twofold: the preservation of vulnerable populations and concerns regarding animal ethics.

While the effect of entanglement on an individual animal may be severe (e.g. death), understanding the effect on a population of whales is not as straightforward. Populations that are large, robust and recovering well from whaling have more resilience against entanglement, even when the population regularly interacts with fisheries. For example, the Western Australian humpback whale stock (IWC designated Stock D), has an increasing population numbering in the tens of thousands and documented entanglement events averaging in single digits annually. Each entanglement events impact on only a tiny fraction of the population; and even if all events lead to mortality, it would not impact the overall viability of the population (Groom and Coughran 2012, How et al. 2015).

However, smaller populations of whales are inherently more vulnerable to bycatch removals than larger demographic units (Read 2008). The North Atlantic right whale has a history of pressure from whale hunting, but despite 80 years of protection from commercial whaling, the population has failed to recover and presently numbers about 500 individuals (Pettis and Hamilton 2015 in Kraus et al.

2016). This population has low reproductive and population growth rates, with about 4% of the population dying annually and a 5% recruitment (birth) rate (Moore 2009). Some studies suggest the population was declining in the early 2000s (Caswell et al. 1999, Johnson et al. 2005) with the decline in population growth rate linked to increased mortality among mothers with calves, which also affects overall population life expectancy and mean lifetime number of reproductive events (Fujiwara and Caswell 2001). Fujiwara and Caswell (2001) asserted that preventing the deaths of just two female right whales per annum would increase the population growth rate to replacement level. A decade later, population numbers were estimated to be higher than previously: approximately 500 in 2015 versus 350 in the early 2000s. While the incidence of mortality from vessel collisions has declined for this population, the incidence of entanglement in fishing gear is increasing in number and severity. The resulting injuries and mortalities may be hampering recovery efforts across the full range of northern right whales and not just in the areas where they are entangled (Kraus et al. 2016). In a vulnerable population such as this, every death or survival event can affect the future of the entire population.

The ethical considerations of physical suffering of entangled whales are also cause for concern (Moore 2009). Some experts consider whale entanglement as much an animal welfare issue as a conservation one (Read 2008, Moore 2009). While the physical effects of entanglement may logically seem more extreme for small cetaceans that become entangled – small cetaceans are less able to free themselves from gear and can quickly drown – large whales have been shown to carry fisheries gear for months and many will likely die if not freed (Clapham et al. 1999, Vanderlaan et al. 2011). The effect of entanglements on large whales can vary considerably; from minor, where whales may shed gear without assistance and causing no, or very minor trauma to the animal; to extreme, where animals may either drown quickly, or alternatively suffer a protracted death via serious lacerations that may cause debilitation, infection or both, or become emaciated from starvation due to increased drag and inefficient foraging, or a combination of both (Clapham et al. 1999, Cassoff et al. 2011, Moore and van der Hoop 2012, Moore et al. 2013, Knowlton et al. 2016).

Interactions with fixed fisheries, along with ship collisions, have been documented as the highest anthropogenic processes affecting populations of endangered northern right whales and protected humpback whales in the North Atlantic (Knowlton et al. 2012, Kraus et al. 2016). Collection of fisheries gear from documented North Atlantic right whale and humpback whale entanglements have shown that, when gear is identifiable, 89% (32 of 36) of entanglements were attributed to pot and gill net gear, with a wide range of gear types implicated within these groups including buoylines and groundlines (Johnson et al. 2005). The gear types and parts involved in lethal versus non-lethal cases were not substantially different. A study conducted in Canadian waters that assessed the threat of various gear types to right whales there, found that groundfish hook-and-line gear posed the greatest threat to right whales during the summer (resident) period in critical habitat, and lobster fisheries gear posed the greatest threat to right whales during the spring and autumn migratory periods when whales were travelling to and from their critical habitat (Vanderlaan et al. 2011).

The United States and Canadian governments have introduced a suite of mitigation efforts to combat the incidence of fishing gear entanglements and ship strikes in the North Atlantic (Van der Hoop et al. 2013). In the United States, the Atlantic Large Whale Take Reduction Plan (ALWTRP) introduced initially in 1997 then expanded to include broad-based fishing gear modifications in 2007, aimed to reduce mortality of right whales, humpback whales and fin whales in the region, caused by fishing activities (NFMS 1997, 1999, 2000, 2002a, 2002b, 2002c, 2007, 2008, 2014a, 2014b, 2015, Pace et al. 2014). In Canada, conservation initiatives have centred on creating Critical Habitat areas for right whales (Brown et al. 2009), within which activities that destroy habitat are prohibited. The establishment of these areas effectively warns mariners of the presence of right whales and recommends voluntary methods to reduce risk of vessel strike (Vanderlaan et al. 2011). The Canadian

Government do not, however, provide specific recommendations or regulations to minimise risk of entanglement in fishing gear (Vanderlaan et al. 2011).

Despite these efforts, the incidence of entanglements of humpback and North Atlantic right whales has not declined (Knowlton et al. 2012). In addition, Knowlton et al. (2012) describe an increasing trend in entanglement severity documented for right whales (Knowlton et al. 2012, Van der Hoop et al. 2013, Pace et al. 2014, Kraus et al. 2016), even after taking detection bias into account.

In Western Australia, humpback whales are known to interact with fishing gear, particularly pot gear involved with the Western Rock Lobster Fishery (WLRF). Entanglements in WRFL gear have been documented since 1982, and the WRLF, in collaboration with the West Australian Government, introduced a Code of Conduct in 2006/07 aimed at reducing the occurrence of entanglement events (Groom and Coughran 2012). The measures outlined in the Code of Conduct, in conjunction with reduced fisheries effort (implemented for reasons of fisheries sustainability), jointly appeared to reduce large whale entanglement rates after 2006 (Groom and Coughran 2012).

In 2010/11, the management of the WRLF was gradually changed from an input, or effort control system (with temporal closures, restrictions on pot numbers and other biological controls) to an output quota-based system (expanding season length, pot usage) (How et al. 2015). By 2013, the fishery operated on a quota system year-round. Previously, the number of entanglements attributable to the WRLF were between 0 and 6 per annum (How, pers. comm. 2017), but entanglements rose to 5, 12, and 17 in 2011, 2012 and 2013 respectively (How et al. 2015). In 2014 the WRLF's Code of Conduct was updated to include measures that reduce the amount of slack rope at the water's surface (WRLC 2016) and reported entanglements have appeared to decline steadily in the years since then (How, pers. comm. 2017). The West Australian Fisheries Department is currently investigating the link between gear modifications and any change in entanglement rates.

Fixed fisheries such as pot and set net/gillnet fisheries also occur in New Zealand waters. Given these fisheries utilise vertical lines in the water column to set their pots and nets, and any vertical line is a risk to large whales (Johnson et al. 2005), these fisheries pose an entanglement risk to large whales. Humpback whales, southern right whales and killer whales occur seasonally in New Zealand waters, and all three species have been known to experience entanglements along the New Zealand coast.

Although the total number of cetaceans reported entangled annually in fishing gear in New Zealand waters is low in comparison with other countries, the Department of Conservation (DOC) has observed an increase in entanglements outside of Kaikoura (a focal point for entanglement of humpback whales, especially in winter months), including species other than humpback, killer and southern right whales. Accordingly, DOC has determined that "It is timely to assess the level of risk posed to cetaceans from commercial pot/trap and set net fishing activity, and determine whether or not the current level of risk warrants development or implementation of improved mitigation measures." This report provides a summary of the state of knowledge about large whale entanglement in New Zealand and explores potential mitigation options.

3. Project Scope

Blue Planet Marine (BPM) was contracted by DOC to (i) compile data from all available sources to characterise the nature and extent of cetacean interactions with commercial pot/trap lines and set nets and (ii) to make recommendations on whether the current levels of risk warrant development or implementation of improved mitigation.

The scope also required BPM to identify and assess the current mitigation techniques for cetacean capture in pot/trap lines and set nets both domestically and internationally, and make recommendations as to their applicability in the New Zealand market.

4. Methods

4.1 General approach

BPM liaised with DOC, MPI, fishing industry and relevant experts to compile data from available sources relating to:

- The current status of pot/trap line and set net fisheries;
- Cetacean abundance/distribution/trends in New Zealand waters;
- Documented entanglement events; and
- Mitigation techniques.

Based on the definition of *cetacean* provided in Section 3.2 of the original *Request for Proposals*, the review of species abundance and trends focussed on humpback whales, southern right whales and killer whales. The range of species entangled in overseas waters is wider than this group, however, and so mitigation techniques developed overseas are apply to this larger group. When considering mitigation, the scope was broadened to include all large whales (including killer whales).

4.2 Review of current status of New Zealand pot/trap line and set net fisheries

This review gathered all available information on the current status of New Zealand pot/trap line and set net fisheries from government websites such as MPI New Zealand Fisheries site, New Zealand's National Aquatic Biodiversity Information System (NABIS), and commercial websites and their associated documents, such as the New Zealand Rock Lobster Industry Council (NZRLIC).

Data on fisheries effort is compiled by the Ministry of Primary Industries, who provided BPM with an extract of the MPI commercial fisheries (WAREHOU) database which is populated with Catch Effort data provided by commercial fishers. Additional, specific information regarding the New Zealand rock lobster industry and practices was also provided by personal communications with Daryl Sykes from the NZRLIC. Additional information regarding commercial set netting fisheries and practices was provided by Tom Clark from Fisheries Inshore New Zealand Ltd.

It was determined that raw data supplied by MPI on total number of ‘pot lifts’ and total length of set net hauled (in metres) were the most reliable and consistent data for estimating effort of commercial rock lobster and set net fisheries respectively. This was due to:

- The apparent inaccuracy of rock lobster fishery effort data (vessel fishing days) mapped on NABIS. Rock lobster fisheries effort should be mapped within Rock Lobster Statistical Areas, but NABIS displays effort data within General Statistical Areas. These data are only a subset of the whole dataset on effort, as they represent only those data incorrectly assigned to General Statistical Areas, and are the only effort data mapped by NABIS for this fishery.
- NABIS mapping the effort of set net fisheries is based upon vessel fishing days. One vessel fishing day is equivalent to any number of fishing events by a vessel on a given day and in any number of Statistical Areas. It is impossible to gain a clear insight into actual fishing effort based on the mapping data rendered in NABIS.

4.3 Cetacean abundance and trends in New Zealand waters

Information regarding large whale abundance and trends in New Zealand waters was collected from several sources in the available literature, including a review of Berkenbusch et al. 2013. Information on the movement patterns of large whales were also gathered from the literature and we contacted the following New Zealand researchers: Nadine Bott, Roger Williams and Chevy Allen (Whale Watch Kaikoura), and Dr Simon Childerhouse (BPM) regarding humpback whales, Dr Ingrid Visser (killer whales) and Dr William Rayment (Otago University), Dr Emma Carrol (University of St Andrews), and Dr Simon Childerhouse (southern right whales).

4.4 Review of documented entanglement events

Excerpts from the DOC marine mammal sightings and incident databases were provided to BPM. Data from the DOC sightings and incident databases were searched for entanglement-related events, for all large whales and killer whales. These data were cross-checked with:

- The Ministry for Primary Industries' (MPI) Central Observer Database (COD – populated with data collected by observers placed on commercial fishing vessels);
- The MPI commercial fisheries (WAREHOU) database (populated with Catch Effort data provided by commercial fishers); and
- Google searches of online media reports of entanglement events in New Zealand waters using search terms such as: whale, whales, cetacean, entangled, entanglement, rock lobster, set net, and bycatch.

Personal communications were also made with: Mike Morrissey (DOC), Dr William Rayment, Dr Emma Carroll, Roger Williams, Chevy Allen, Dr Simon Childerhouse and data or information were also supplied by them. Several other researchers were contacted but never replied. Data were summarised by year, species, gear type and outcome.

The '*Whalesafe Identification Guide'* produced by the NZRLIC, refers to whale entanglement data back to 1977. As the location of these early data is currently unknown (Sykes, pers. comm. 2017) they were not included in these analyses. The NZRLIC were attempting to locate these data at the time this report was submitted to DOC.

4.5 Risk analysis

Entanglements are not simple events, and evaluating risk to whales at an individual or population level depends on the nature and extent of entanglements over time. A risk analysis of large whale entanglements was conducted for several pressure groups[2] in New Zealand, by developing tables of consequence and likelihood of entanglement. These were used in conjunction with a standard Risk Assessment Matrix. A risk matrix is a valuable tool for assessing risk for situations where neither the probability of the event occurring nor the severity of harm of an event can be estimated with certainty. Using various 'levels' of consequence and likelihood allows risk to be estimated given a range of factors.

The risk of large whale entanglement to individual whales, whale populations and other major stakeholders, such as New Zealand rock lobster and set net fisheries, whale watching operators, and DOC were also examined.

[2] In this context pressure group means the affected animal/population/organisation etc.

4.6 Review and analysis of mitigation literature

The literature review included the following sources: international scientific literature, government agency commissioned reports, conference proceedings, commercial research and results from industry and scientific trials. Electronic search engines and databases were used, including Web of Science, Current Contents, Google Scholar, and general internet searches. Keywords such as: whale, cetacean, pot, line, set net, mitigation and bycatch were used.

The source material was reviewed against the following criteria:

1) Description of the mitigation technique:
    a. Target fish species;
    b. Region of interaction;
    c. Gear configuration (e.g. bottom, mid water, pelagic);
    d. Relevance to the protected species (e.g. whales, killer whales, dolphins, etc.);
    e. Level of scientific rigor of any reported trials;
    f. Level of proven efficacy in any reported trials (i.e. in both mitigating entanglement and in maintaining target fish catch);
    g. Any caveats or uncertainties in the methods;
2) Potential for making recommendations for future research in New Zealand; and
3) Relevance to New Zealand fisheries.

4.7 Sample sizes and reporting

Throughout this report analyses and figures are based upon different sample sizes. For the purpose of clarity these sample sizes are outlined below:

- N=44: the total number of documented entanglements of large whale species in New Zealand waters from 1984 to 2017 reported in this document, including animals entangled in set net, rock lobster, longline, mussel farm (or possibly from these fisheries), and unknown fisheries gear.
- N=39: the total number of documented entanglements of large whale species in New Zealand waters from 1984 to 2017 reported in this document, except the five documented entanglements associated with mussel farm and longline fisheries.
- N=38: as for n=39, except for the one entanglement event occurring in 1984.
- N=30: as for n=39, except for nine entanglement events that do not have latitude and longitude details.

5. Results

5.1 Status of selected New Zealand whale populations and fisheries

5.1.1 Humpback whale (*Megaptera novaeangliae*)

Humpback whales migrating past New Zealand are considered part of the Oceania breeding stock of whales; those from Eastern Australia (IWC breeding stock E2), New Caledonia (E2), Tonga (E3) and the Cook Islands/French Polynesia (F). Genetic samples taken from whales migrating past New Zealand showed that these whales had the least genetic difference to the New Caledonia breeding stock and also had links to the east Australian stock (stock E1) (Steel et al. 2013).

The abundance of the E2, E3 and F populations were estimated to be 4,329 in 2005, making Oceania the least abundant humpback whale breeding population in the southern hemisphere (Constantine et al. 2012). The Oceania population is considered '*Endangered'* under the IUCN Red List of Threatened Species. This population has previously shown no significant trend in recovery (Constantine et al. 2012), although recent sightings data in New Zealand indicate that the rate might be beginning to increase (Bott, pers. comm. 2017).

The abundance of the E1 population was estimated as 14,522 in 2010, and this population has an estimated recovery rate of 10.9% (Noad et al. 2011). In 2015, the estimate for this population was 24,500 whales, and the population was still growing strongly (Noad, pers. comm. 2017).

Humpback whales move northbound during autumn (May-Aug) on route to their winter breeding grounds, and southbound during spring (Sept-Dec) on their way to summer feeding areas in Antarctic waters (Gibbs and Childerhouse 2000, Berkenbusch et al. 2013, Childerhouse pers. comm. 2017, Figure 1). Sightings surveys conducted around New Zealand showed that, during the northbound migration, most sightings occur on the east cost of the South Island, while during the southbound migration, most sightings occur along both coastlines of the North Island (Gibbs and Childerhouse, 2000). While the relative level of sightings effort in various areas may skew results slightly, the results correlate broadly with those of Dawbin (1956). Sightings of humpback whales from 1970 to 2013 were mapped by Berkenbusch et al. 2013 (Figure 2). It is important to note that most of these sightings are not from research and so the sighting effort is highly skewed and not representative of the complete distribution of this species. Steel et al. (2013) suggest that the whales migrating past New Zealand may use different migration corridors during different times of year (i.e. migrating along different parts of the New Zealand coast for north- or south-bound migrations). They also suggest whales migrating past New Zealand do not have the same fidelity to migratory routes as they do to the breeding grounds (i.e. that whales may travel along different routes each year to reach the same destination; Steel et al. 2013). In February/March 2017, a juvenile humpback whale was observed to remain in the Kaikoura area for a period of seven weeks, including periods of feeding behaviour (Roger Williams and Chevy Allen, pers. comm. 2017).

Previous studies have suggested that the migratory pathway of humpback whales is concentrated in the Cook Strait area, due to inshore and offshore migrating whales joining to pass through Cook Strait (Dawbin 1956, Gibbs and Childerhouse 2000).

Humpback whales are considered 'Migrant' under the New Zealand Threat Classification system (Baker et al. 2016).

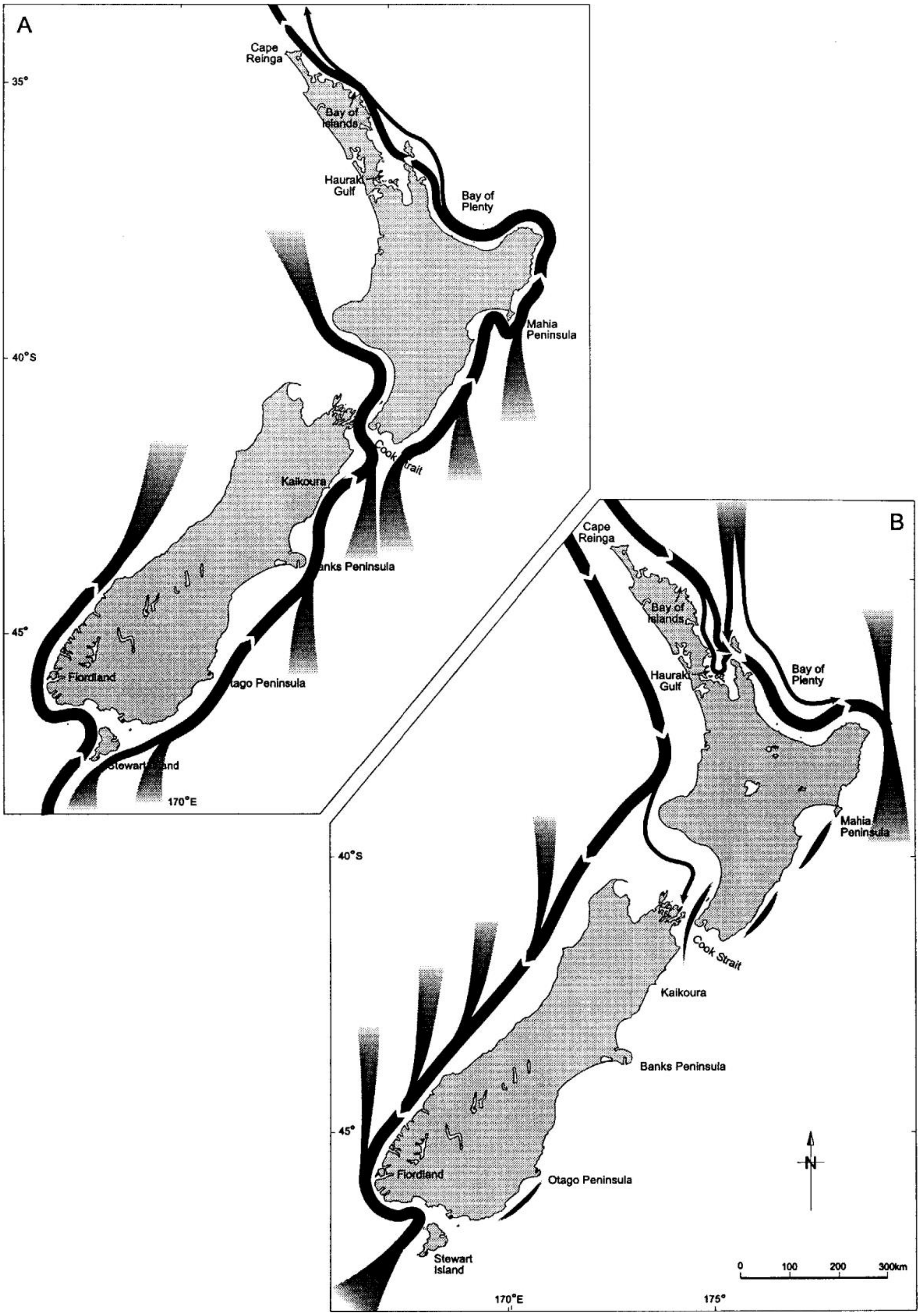


Figure 1: The (a) northern and (b) southern migratory routes of humpback whales in New Zealand waters.

Fan indicates main areas where humpbacks are inferred to approach or leave coastal waters (modified from Dawbin 1956, in Gibbs and Childerhouse 2000).

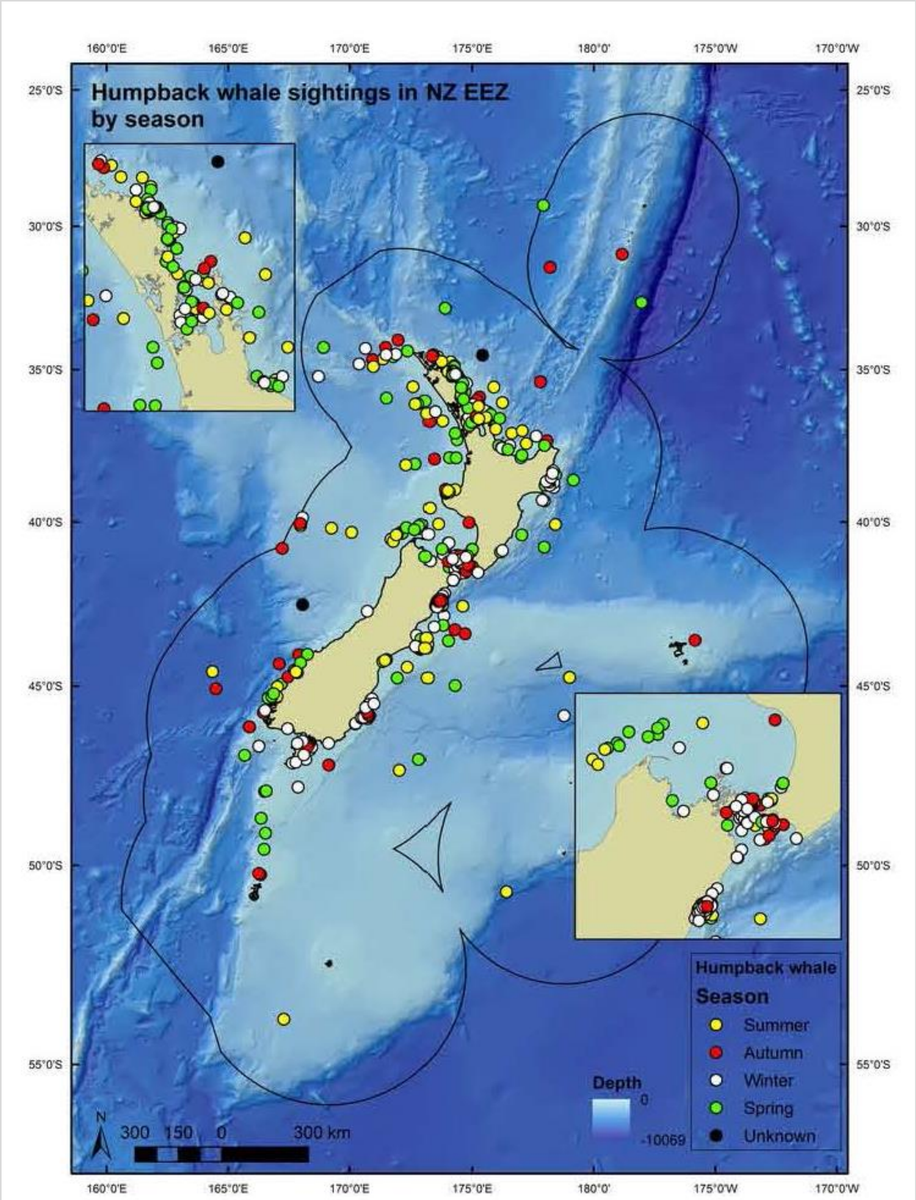


Figure 2: Distribution of humpback whale sightings in New Zealand waters between 1970 and 2013. From Berkenbusch et al. 2013. Reported sightings are from a variety of sources and must be considered indicative only, as identification may not be correct.

5.1.2 Southern right whale (*Eubalaena australis*)

Southern right whales in New Zealand waters are slowly increasing in numbers. This population, with wintering grounds in both subantarctic and mainland New Zealand waters, was estimated at 2,169 between 1995-2009 (Carroll et al. 2011, Carroll et al. 2013a), with rates of increase estimated at 5% for females and 7% for males in the subantarctic population (Carroll et al. 2013a). Southern right whales are considered '*Nationally Vulnerable*' under the New Zealand Threat Classification system (Baker et al. 2016).

Southern right whales have started to frequent mainland New Zealand waters, seemingly recolonising former calving grounds around the coast, presumably by range expansion of the New Zealand subantarctic population (Carroll et al. 2013b). Most sightings of these animals along the coast occur in winter and spring (Berkenbusch et al. 2013), with calving occurring in winter. Whales appear to move offshore to feeding areas in summer (Berkenbusch et al. 2013). Sightings of southern right whales from 1970 to 2013 were mapped by Berkenbusch et al. 2013 (Figure 3). It is important to note that most of these sightings are not from research and so the sighting effort is highly skewed and not representative of the complete distribution of this species.

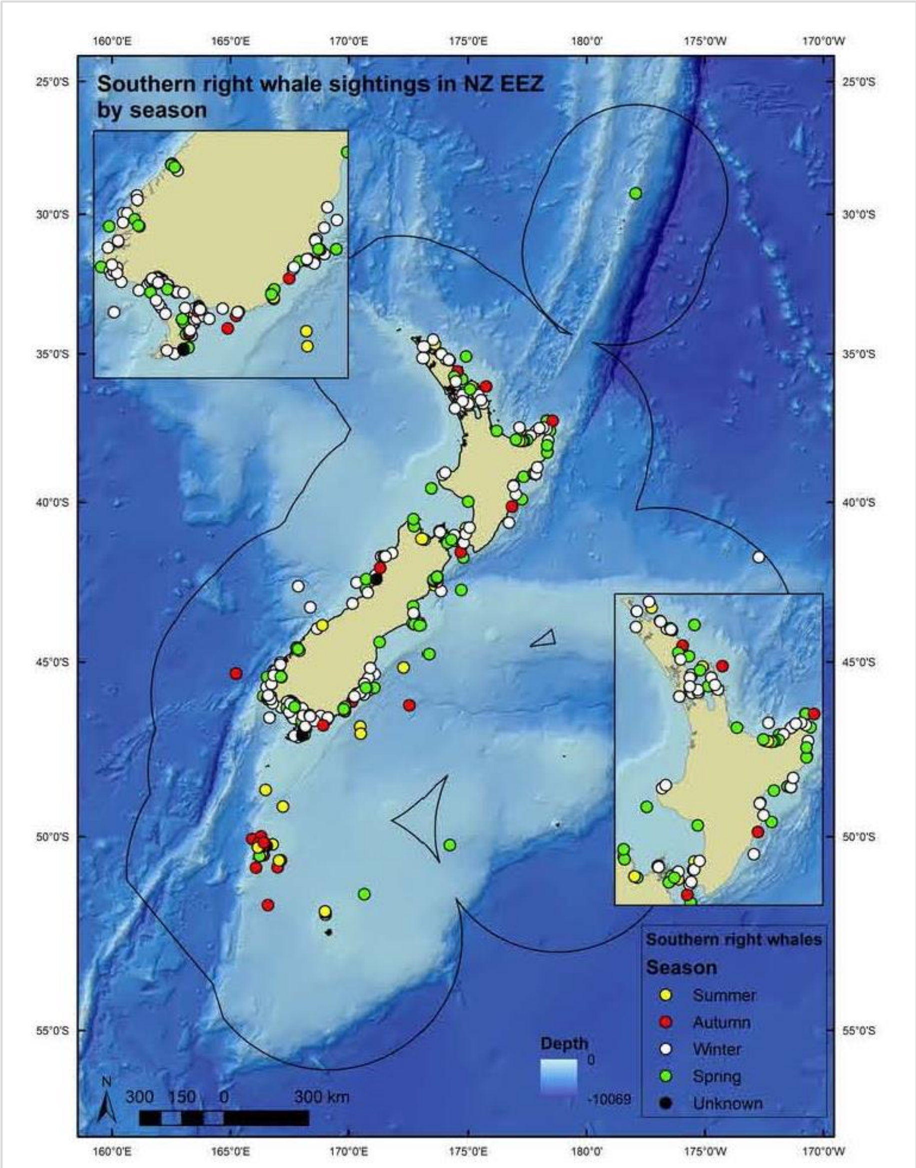


Figure 3: Distribution of southern right whale sightings in New Zealand waters between 1970 and 2013.

From Berkenbusch et al. 2013. Reported sightings are from a variety of sources and must be considered indicative only, as identification may not be correct.

5.1.3 Killer whale (*Orcinus orca*)

The New Zealand photo-ID catalogue of killer whales included 132 animals in 2006 (Visser 2007), and the population is considered '*Nationally Critical*' under the New Zealand Threat Classification (Baker et al. 2016). Killer whales are regularly sighted in New Zealand waters with records along the coastline of North and South Islands, Chatham Islands and from offshore and subantarctic waters (Berkenbusch et al. 2013). Visser (2007) suggested that there are three killer whale subpopulations around New Zealand; one off the North Island, one off the South Island and one population that moves between both (Visser 2007; Berkenbusch et al. 2013).

Some individual killer whales are resighted irregularly, with years between resights, whereas others are resighted regularly (Visser 2007). Visser (2007) suggests that the high resighting rate of some killer whales indicates that these animals are likely to live permanently or semi-permanently close to the New Zealand coastline.

Sightings of killer whales from 1970 to 2013 were mapped by Berkenbusch et al. 2013 (Figure 4). It is important to note that most of these sightings are not from research and so the sighting effort is highly skewed and not representative of the complete distribution of this species.

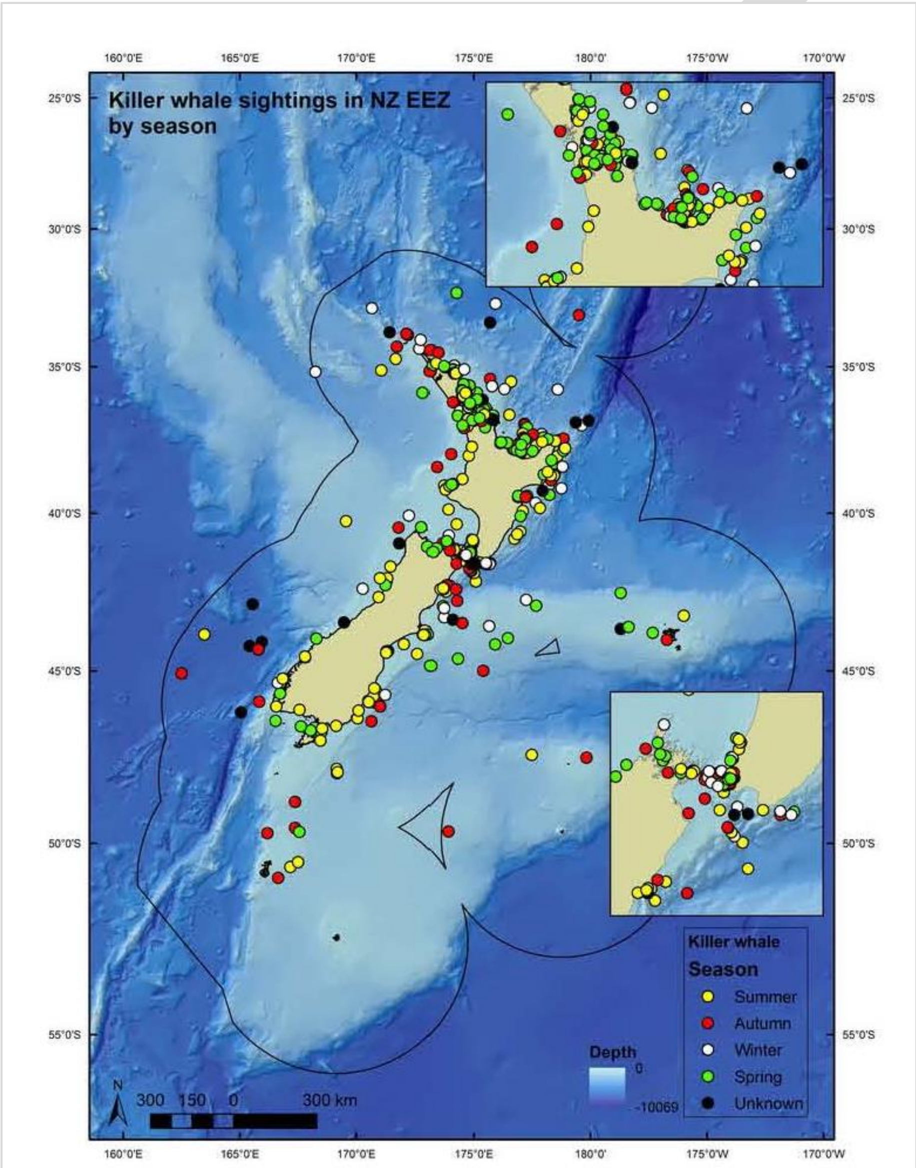


Figure 4: Distribution of killer whale sightings in New Zealand waters between 1970 and 2013.

From Berkenbusch et al. 2013. Reported sightings are from a variety of sources and must be considered indicative only, as identification may not be correct.

5.1.4 Commercial pot/trap and set net fisheries in New Zealand

Commercial fisheries in New Zealand waters are managed under a Quota Management System (QMS), whereby Total Allowable Commercial Catch (TACC) for a species is apportioned among Quota Management Areas (QMA).

A variety of fisheries in New Zealand waters utilise pots as the method of capture. MPI identify the following methods in their databases: cod pots (CP), crab pots (CRP), pots (other) (POT), rock lobster pot (RLP) and scampi pot (SCP) (Berentson, pers. comm. 2017). Only rock lobster potting has been documented in large whale entanglements and so this report focuses on this method of potting but noting that these other methods also have the potential to entangle whales.

Commercial fishers use many forms of net fishing, including inshore drift nets (DN), Lampara nets (L), pair set netting (PSN), ring netting (RN) and set netting (SN) (Berentson, pers. comm. 2017). Of these, only set netting was the only method for which documented large whale entanglements were found, and so this report focuses on this method of netting but noting that these other methods also have the potential to entangle whales.

Commercial rock lobster potting

Commercial rock lobster potting targets spiny red rock lobsters (rock lobster – *Jasus edwardsii*), which is the most valuable of New Zealand's inshore fisheries species, earning NZ$250 million a year in export receipts (NZRLIC, 2017). The rock lobster (CRA) fishery is divided into 10 QMAs[3] (Figure 5). In 2015, rock lobster stocks were assessed as performing well, apart from rock lobsters in the Bay of Plenty (CRA2; MPI 2016).

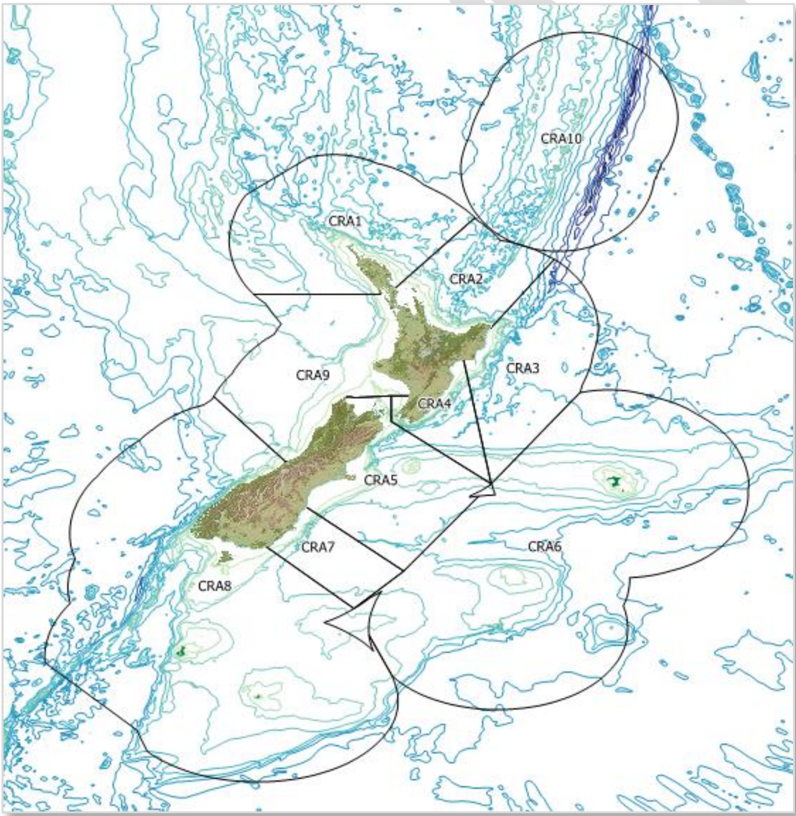


Figure 5: Spiny red rock lobster Quota Management Areas (NABIS 2017).

[3] CRA 10 is purely an administrative QMA, with no fishing occurring there.

Although design varies, commercial pots: are generally square or rectangular; are of a size that can be deployed and retrieved by 1-2 people (normally with an hydraulic winch); are a steel frame covered with a form of mesh (most likely steel but also potentially netting); are baited; and have an entrance designed so that once inside, rock lobsters cannot escape (Figure 6). The pots are lowered to the seafloor, where they sit unanchored. A line (rope) extends from the pot to the sea surface connected to a buoy. The time of day when pots are set is variable among fishers and areas, and they are generally hauled and baited in 24-hour cycles, dependent on weather (Sykes, pers. comm. 2017).

Figure 6: Example of a commercial rock lobster pot.

Rock lobsters have been potted to a water depth of 275 m (Annala and Bycroft 1984), but this species may occasionally occur to at least 350 m (NIWA 2012, Figure 7). Commercial fishing of rock lobster is reported using 43 Rock Lobster Statistical Areas (Figure 8). Using total number of pot lifts as an indication of rock lobster fishing effort, there are three broad areas of higher overall effort in New Zealand: on the south-west coast of the South Island between Jackson Bay and Te Waewae Bay; on the east coast of both North and South Islands between Christchurch and ~Flat Point; and on the north coast of the North Island, between ~Hicks Bay and Bream Bay (Figure 9).

The peak rock lobster catch varies temporally between CRAs, both within and between years (Figure 10), although each CRA seems to follow a similar general pattern of catch between years. The total catch per CRA generally equals the TACC each year, with rare exceptions (MPI 2017a).

The rock lobster fishery in New Zealand does not currently enforce any mandated whale entanglement mitigation practices, however the NZRLIC has been pro-active with the issue, and has published a set of recommendations for fishers as part of their *Whalesafe Identification Guide* (NZRLIC 2016). These recommendations are very similar to those implemented in Western Australia by the West Coast Rock Lobster Managed Fishery in their '*Code of Practice for Reducing Whale Entanglements'* (WRLC 2016), and include:

- Remaining vigilant between May, June and July;
- Avoiding excessive slack in pot ropes;
- Avoiding setting pots in clusters;
- Not leaving pots in the water if not fishing;
- Regularly checking pots;
- Reporting entanglements as soon as possible;
- Collecting any abandoned/lost or cut pot lines, rope or fishing gear;
- Investigating new technologies that may reduce entanglements; and
- Adopting a cooperative approach to avoiding entanglements and responding to entanglements when they occur.

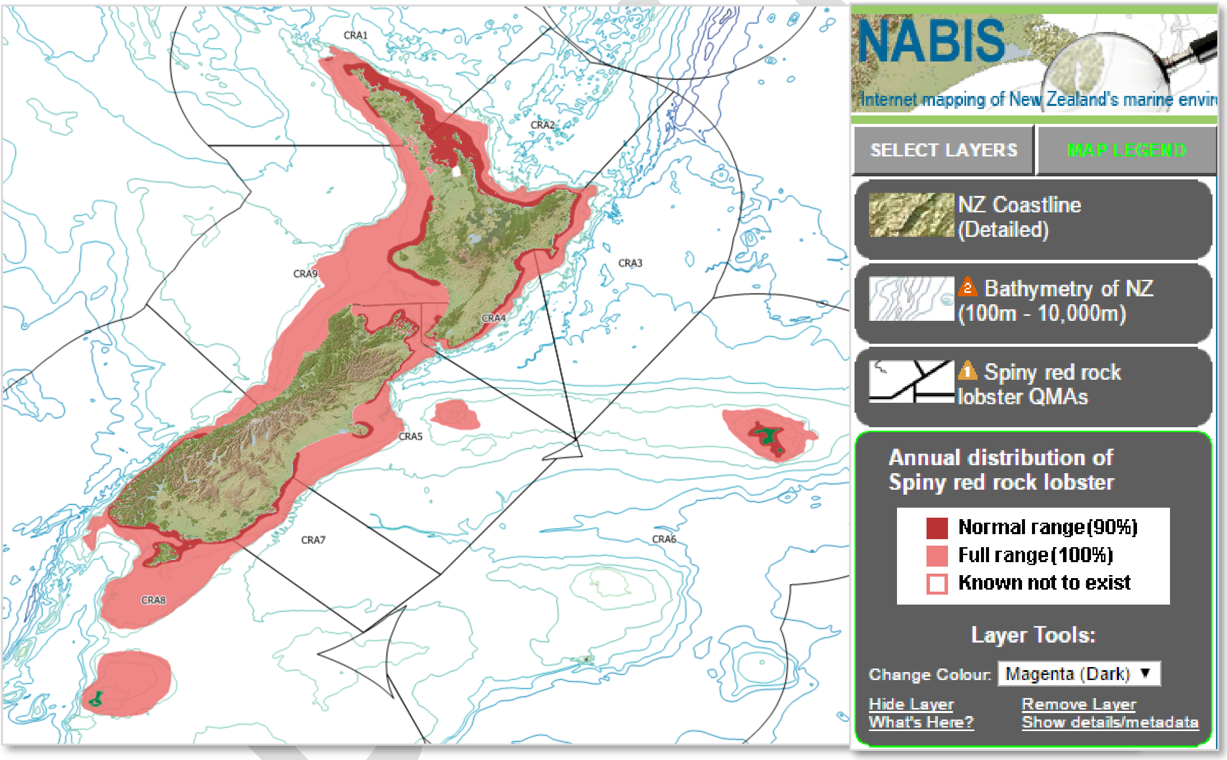


Figure 7: Annual distribution of spiny red rock lobster (source NABIS 2017).

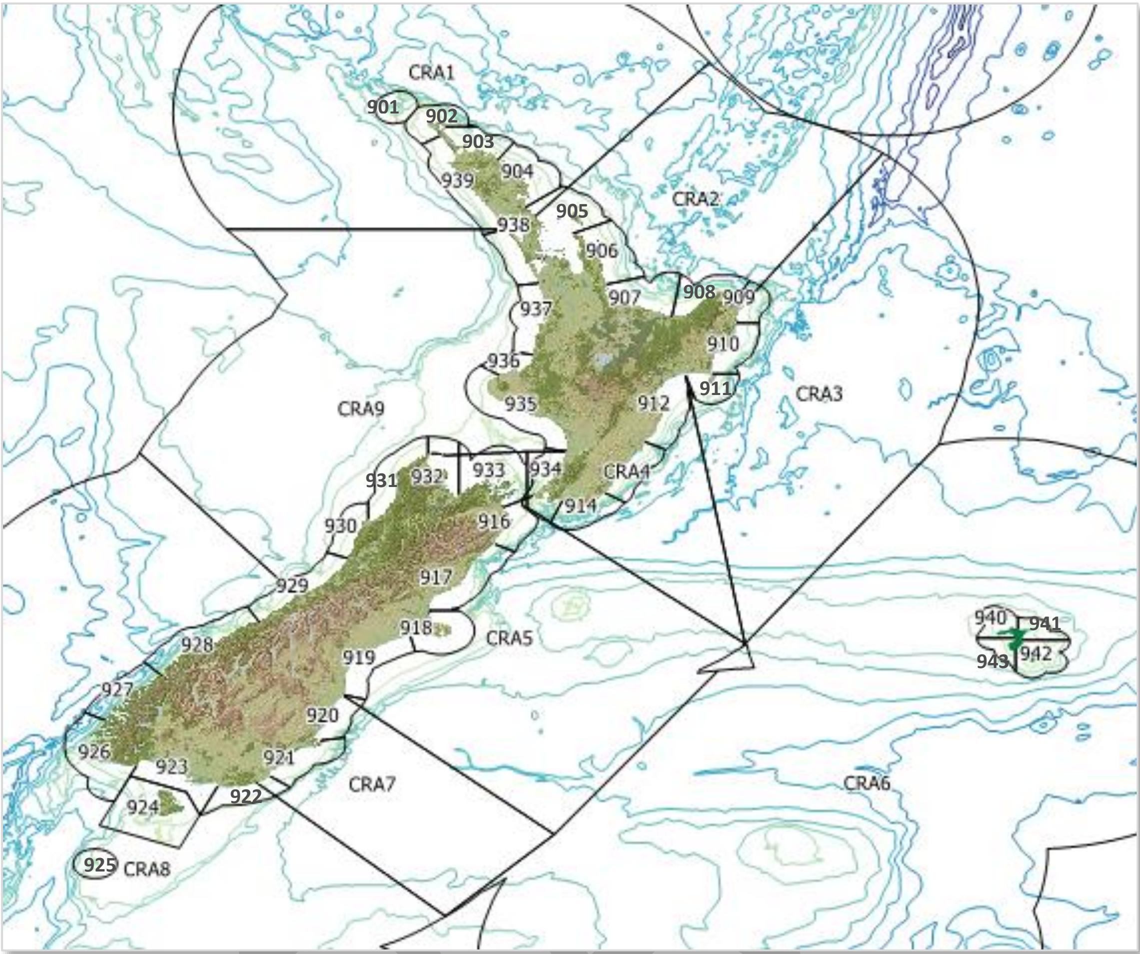


Figure 8: Rock lobster Statistical Areas within Quota Management Areas (source NABIS 2017).

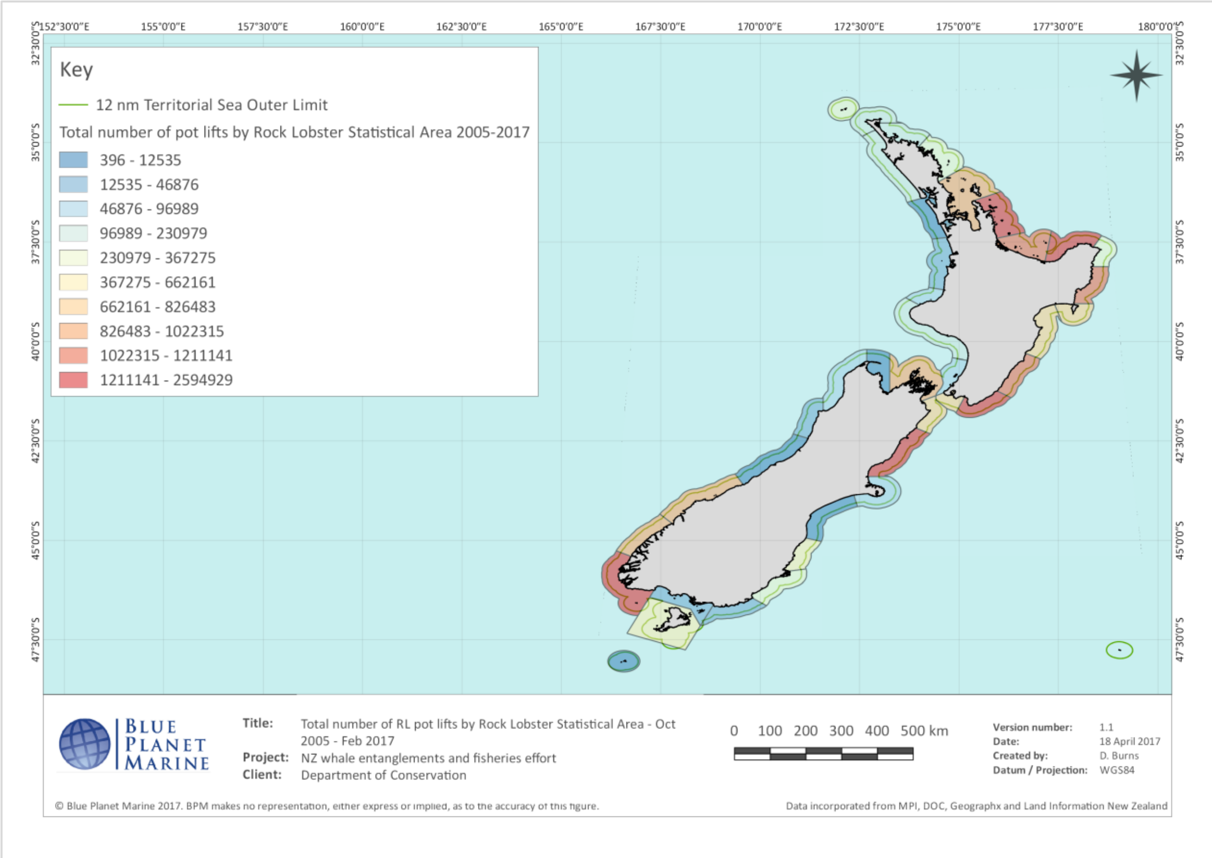


Figure 9: Rock lobster fishing effort (pot lifts) between 2005 and 2017 (effort data provided by MPI 2017).

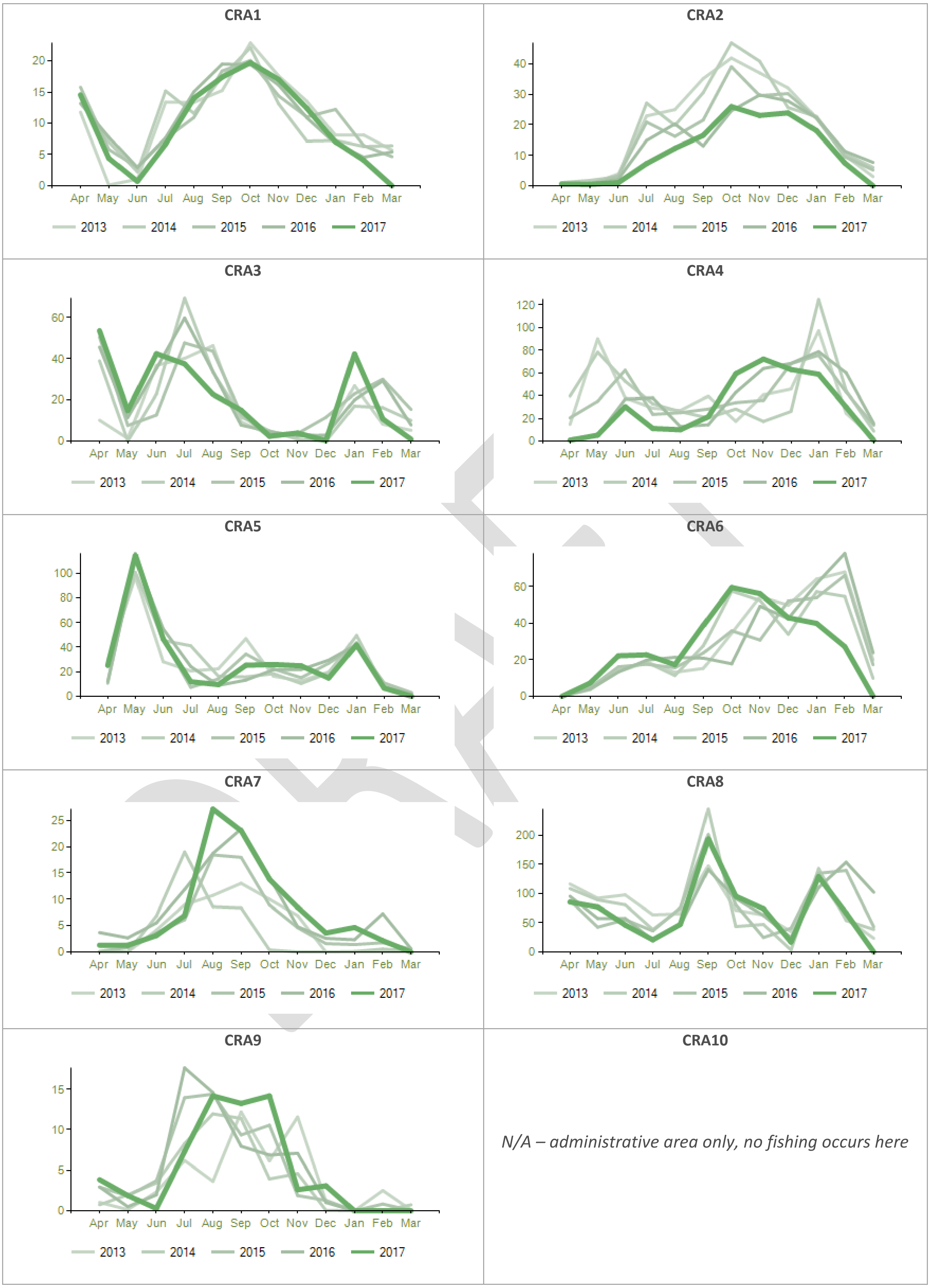


Figure 10: Reported catch by month (thousands of kilograms) per lobster CRA QMA 2013-2017 (MPI 2017a).

Commercial set net fisheries

Commercial set net fisheries target numerous pelagic, demersal and benthic fish species in New Zealand waters such as flatfish, bluenose, kahawai, butterfish, trevally, mullet, school shark, rig, elephant fish, and blue moki (Clark, pers. comm. 2017). By regulation, commercial set net fishers may set up to 3 km of net per day. Depending on the target species and habitat/bathymetry, the net may be one long net, several short nets set in a series (e.g. across a contour), or several short nets not set in a series (Clark, pers. comm. 2017).

Set nets have floats at the top and weights at the bottom, creating a vertical wall of net into which fish swim and become entangled (Figure 11). Nets are not necessarily set tight (i.e. they may have a ‘belly’ due to tidal and current flow pushing the mesh), and may be set straight or curved depending on the target species and benthos (Clark, pers. comm. 2017).

Set nets exist in a variety of mesh sizes and may be set on the seafloor or at a certain distance above it – dependent on the target species. Nets are held in place by anchors or ground weights at each end of the net (FAO 2017). By law set nets can remain set for a maximum of 18 hours at a time, although there are some exemptions to 24 hours (Clark, pers. comm. 2017). The actual time fishers leave nets in the water varies from about 20 minutes (where net is actively worked in a harbour) up to 24 hours (at sea) (Clark, pers. comm. 2017). During these times nets are not necessarily attended.

Since set netting targets many species, each with their own QMAs, seasonality and distribution, this report focuses on the fishing method rather than the target species.

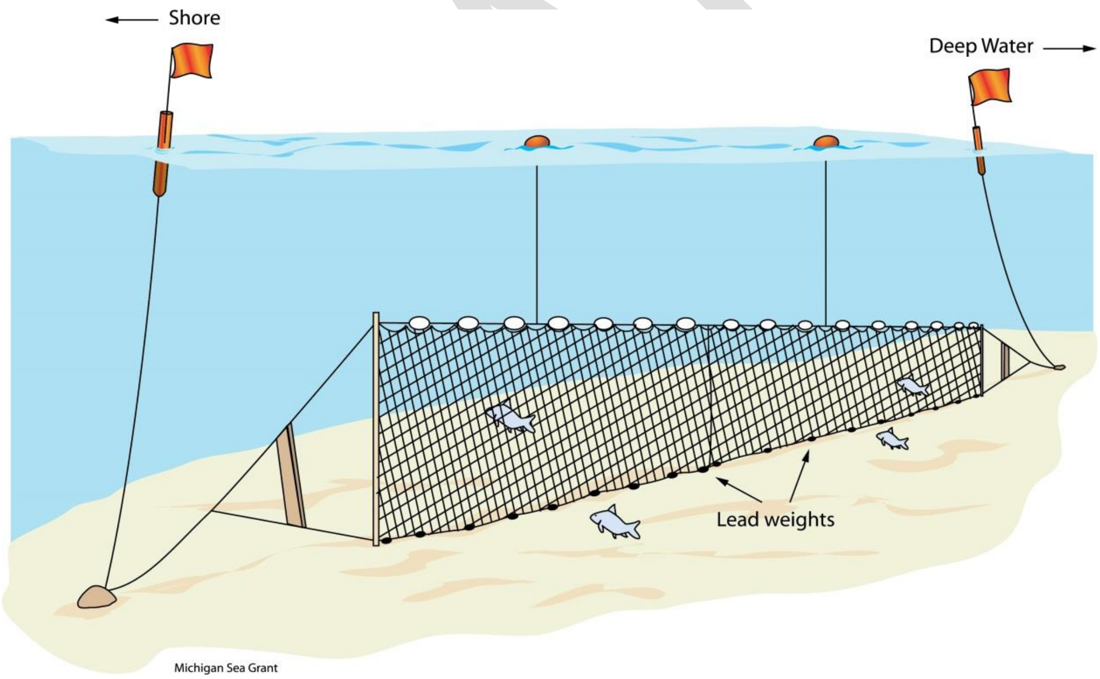


Figure 11: Illustration of a set net anchored to the seafloor (Credit Michigan Sea Grant).

Set net fishing is reported within General Statistical Areas (Figure 12). Between 2005 and 2017 commercial set net fishing occurred around the entire coastline of mainland New Zealand (Figure 12). The areas of greatest fishing effort (net length (m) hauled) were approximately: Oamaru north to Banks Peninsula; Cheviot north to the southern end of Clifford Bay; Bay of Plenty; inner Hauraki Gulf; Bream Bay north to Cape Reinga; Kaipara Harbour; Manukau Harbour; and Kāwhia Harbour south to

Whanganui (Figure 12). This is consistent with information supplied by Clark (pers. comm. 2017) whom outlined that harbours in the regions of Auckland and Northland, as well as the coastal areas of Hauraki, Taranaki, Timaru, Marlborough, Kaikoura, Southland and Fiordland had the heaviest concentration of set net activity.

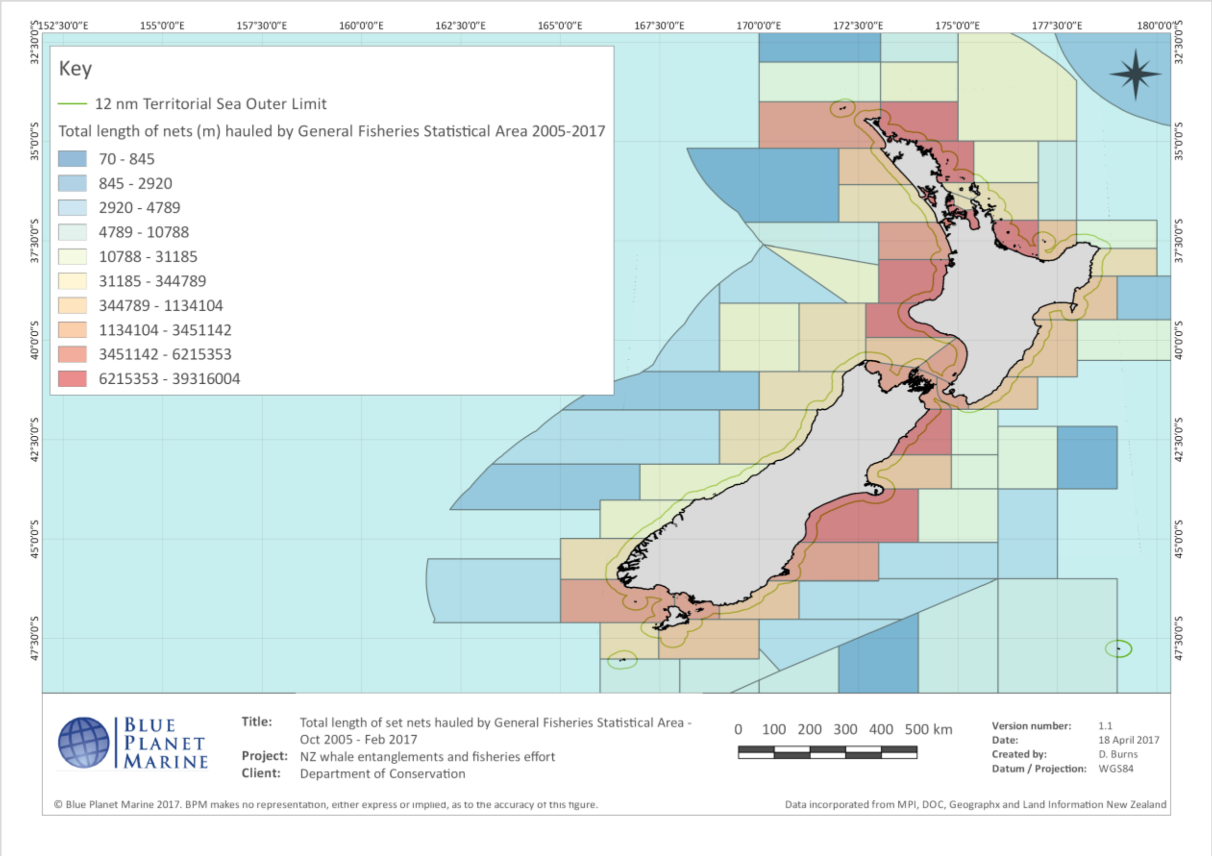


Figure 12: Commercial set net fishing effort (total net length (m) hauled) between 2005 and 2017. Effort data provided by MPI 2017.

There are many locations where the use of commercial set nets is seasonally restricted or completely prohibited. Set netting is prohibited in marine reserves (Type 1 Marine Protected Areas), established under the Marine Reserves Act 1971. These area closures are intended to protect all biodiversity, habitats and ecosystems within the boundaries of a marine reserve, including marine mammals.

Type 2 Marine Protected Areas (MPAs) include a suite of management tools established under various legislation and for different reasons, but which meet a specific MPA Protection Standard. Tools include MPAs, marine parks, Mātaitai reserves, fisheries closures, and submarine cable and pipeline protection zones. The aim of each management tool varies and only some areas designated as a Type 2 MPA prohibit commercial set net fishing.

Other marine protection tools such as marine mammal sanctuaries (MMS) may prohibit the use of commercial set nets. Two examples include the Auckland Islands MMS, within which all commercial fishing is prohibited, and the West Coast North Island MMS, which prohibits commercial and recreational set net fishing between two and seven nautical miles offshore between Pariokariwa Point and the Waiwhakaiho River, Taranaki. Another form of mitigation employed by some in the set net fishery is to include gaps between nets (Clark, pers. comm. 2017).

5.2 Documented entanglement events in New Zealand waters involving large whale species

5.2.1 Overview

There were 44 entanglement events in New Zealand waters involving large whale species between 1984 and 2017 (Table 1). Thirty-six of these records were from the DOC marine mammal sightings and incident databases. One record was obtained from fisheries observer data (COD), one in an email to BPM from DOC, and six records were found in online media (Table 1). None of the records found in online media included latitude and longitude data, and so these entanglement events are not included on the maps in this report although they are in statistical analyses.

Note that there are no documented entanglements between 1985 and 1991 in the available data; there may be data from this period available elsewhere (refer to Section 4.4), and therefore our summary will likely be an underrepresentation of the entanglements that have occurred overall. Furthermore, while there is a reporting process by which entanglement reports should be provided to DOC, there is no formal requirement for this nor is there any robust observer programme anywhere in New Zealand undertaking observations of entanglement. Therefore, all records should be considered as anecdotal with the possible exception of MPI observer data who do undertake systematic observations (although if a whale is entangled it is likely to swim off with the pot or net and so is unlikely to be reported by an observer aboard a vessel). As a result, reporting should be considered to be an absolute minimum estimate of entangled whales.

Three documented entanglements of killer whales were attributed to longlines. As these entanglements were not related to pot/trap lines or set nets as specified in the scope of works, they were excluded from further analyses but clearly represent an additional source of potential mortality.

Two Bryde's whales were entangled in gear associated with mussel farms; one in a mussel spat line and one in a mussel farm buoy. Both animals died and washed ashore, with the presumed cause of death being entanglement. These entanglements were also not related to pot/trap lines or set nets as specified in the scope of works, and were also excluded from further analyses but clearly represent an additional source of potential mortality.

Incidentally, one humpback whale entangled in rock lobster pot ropes then became secondarily entangled in mussel farm gear and was subsequently disentangled by mussel farmers; this whale is included in the analysis as the original entanglement involved rock lobster fishing gear.

The NZRLIC's *Whalesafe Identification Guide* states that, as at 2015, only 22 whales of all species had been recorded entangled in fishing gear since 1977 (about 0.6 whales/year[4]), and that 86% of all entanglements were in rock lobster pot buoylines (NZRLIC 2016). In this study, 39 whales were recorded in pot/trap, set net or unknown fishing gear since 1984, and (excluding the single whale entanglement in 1984 and the following 6 years of nil reports), the reported entanglement rate from 1991-2017 is 1.4 whales/year. 62% of entanglements involved rock lobster gear and 'likely' rock lobster gear, but this rose to 69% if 'unknown rope' is also assumed to be rock lobster pot-related, and then 80% if 'unknown gear' was included in addition to that (Table 2). Set nets accounted for 15% of entanglements and a further 5% attributed to set net ropes specifically. Again, given the lack of any systematic observation programme, all these values should considered to be minimum estimates.

Humpback whales were involved in 64% of entanglements, and 21% involved killer whales, with three records (8%) of southern right whale entanglements (Table 1 and Table 2).

[4] In their document, the NZRLIC state this as 1.6 whales/year. The calculation in this report is based on 22 entanglements over 39 years (i.e. 1977-2017), which equates to 0.6 whales entangled per year over this period.

The location of a documented entanglement event is generally the location where an individual whale was seen and reported as entangled. However, this location does not necessarily represent the location of the actual original entanglement event itself which could be considerably far removed in both time and or space. The reported position has been summarised here as it is the only data that is available. Furthermore, the location of a reported entanglement will reflect search effort. There is little or no dedicated search effort around most of the country with the exception of Kaikoura where most days there are a range of vessels, planes and helicopters out actively searching for whale and so it is no surprise that the bulk of reports come from that area. This is also important to keep in mind when reviewing summary data.

Eleven documented entanglements occurred in the North Island, of which seven (64%) involved killer whales (Table 1). Other than one entanglement near Wellington, all entanglements occurred in the upper North Island (Table 1, Figure 13). Entanglement in rock lobster or likely rock lobster fishing gear accounted for seven (64%) of the entanglements in the North Island, while set net fishery gear was attributed to 3 (27%) entanglement events (Figure 14).

Twenty-eight entanglements occurred in the South Island (Table 1, Figure 13), which were dominated by humpback whales (n=22, 79%). Of the humpback whale entanglement events, 18 (82%) occurred from Banks Peninsula north to the eastern edge of the Marlborough Sounds, with the Kaikoura region a hot spot (Table 1, Figure 13, Figure 15). Entanglements in the South Island involved set net and rock lobster fishing gear (Figure 14), but there was a predominance of entanglements in rock lobster fishing gear along the coast of the Kaikoura region (Figure 15).

The annual number of documented annual entanglements ranged from 0 to 4 (Figure 16). Almost one third (11 of 39) of all entanglements occurred in the month of June, and these were exclusively humpback whales (Figure 17). Of these eleven entanglements, eight occurred in the region of Kaikoura, two in Marlborough and one in the Banks Peninsula area. Eight of the entanglements were confirmed associated with rock lobster fishing gear, one was likely to be rock lobster fishing gear, one was set net gear and one unknown (Table 1). None of these eleven entanglements resulted in the known death of the animal, though the outcome in four cases is listed as unknown.

Table 1: Available documented large whale entanglement events in New Zealand waters associated with commercial fishing gear (1984-2017).

No.	Date	Data Source	Species	Region (District)[5]	Latitude	Longitude	Gear Involved	Outcome
1	1/02/1984	DOC incident database	Southern right whale *Eubalaena australis*	Canterbury (Christchurch)	-43.4872	172.7245	SN rope	Death - rope unlikely cause of death
2	25/04/1991	DOC incident database	Killer whale *Orcinus orca*	Northland (Kaipara)	-36.0826	173.8582	SN	Death - attacked by sharp implement?
3	22/10/1994	DOC sightings database	Humpback whale *Megaptera novaeangliae*	Canterbury (Christchurch)	-43.616667	172.93333	Unknown	Unknown
4	7/5/1996	DOC incident database	Bryde's whale *Balaenoptera edeni*	Auckland (Auckland)	-36.1987	175.3183	Mussel spat line	Death
5	10/5/1997	DOC incident database	Dwarf minke whale *Balaenoptera acutorostrata sp*	Canterbury (Timaru)	-44.3512	171.2682	SN	Death
6	7/6/2001	DOC sightings database	Humpback whale *Megaptera novaeangliae*	Canterbury (Kaikoura)	-42.401167	173.74133	RL pot	Disentangled - public
7	9/6/2001	DOC sightings database	Humpback whale *Megaptera novaeangliae*	Canterbury (Kaikoura)	-42.443833	173.75367	RL pot	Disentangled - public
8	29/6/2002	DOC sightings database	Humpback whale *Megaptera novaeangliae*	Canterbury (Kaikoura)	-42.300833	173.77433	RL pot x 2	Partially disentangled
9	26/11/2002	DOC incident database	Killer whale *Orcinus orca*	Bay of Plenty (Opotiki)	-37.5704	177.993	Commercial longline	Unknown
10	13/6/2003	DOC sightings database	Humpback whale *Megaptera novaeangliae*	Canterbury (Kaikoura)	-42.6175	173.47933	RL pot	Partially disentangled - public
11	16/6/2003	DOC sightings database	Humpback whale *Megaptera novaeangliae*	Canterbury (Kaikoura)	-42.436333	173.71983	RL pot	Partially disentangled
12	11/7/2003	DOC incident database	Killer whale *Orcinus orca*	Bay of Plenty (Whakatane)	-37.868	176.7019	SN	Stranded whale refloated but fate unknown
13	27/7/2003	DOC sightings database	Southern right whale *Eubalaena australis*	Southland (Stewart Island)	-47.166667	168.03333	RL pot	Unknown
14	29/11/2003	DOC incident database	Bryde's whale *Balaenoptera edeni*	Auckland (Auckland)	-36.417	175.0079	Mussel farm buoys	Death
15	25/1/2004	DOC incident database	Humpback whale *Megaptera novaeangliae*	Canterbury (Kaikoura)	-42.1242	173.9252	Unknown	Death

[5] https://en.wikipedia.org/wiki/Regions_of_New_Zealand

No.	Date	Data Source	Species	Region (District)[5]	Latitude	Longitude	Gear Involved	Outcome
16	9/6/2004	DOC sightings database	Humpback whale *Megaptera novaeangliae*	Canterbury (Kaikoura)	-42.458833	173.73017	Unknown	Unknown
17	2/7/2006	Internet - NZ Herald (Beston 2006)	Humpback whale *Megaptera novaeangliae*	Canterbury (Kaikoura)	Not available	Not available	RL pot	Unknown - not resighted
18	15/6/2007	Internet - NZ Herald (Booker 2007)	Humpback whale *Megaptera novaeangliae*	Canterbury (Kaikoura)	Not available	Not available	RL pot	Unknown - not resighted
19	26/05/2009	DOC incident database	Blue whale *Balaenoptera musculus*	Tasman (Tasman)	-40.605	172.494	Unknown rope	Death
20	14/6/2009	DOC sightings database	Humpback whale *Megaptera novaeangliae*	Canterbury (Kaikoura)	-42.40061	173.68647	SN	Unknown
21	17/10/2009	Internet - odt.co.nz (ODT 2009)	Humpback whale *Megaptera novaeangliae*	Otago (Dunedin)	Not available	Not available	RL pot	Disentangled - fisherman
22	27/09/2010	Internet - odt.co.nz (ODT 2010)	Humpback whale *Megaptera novaeangliae*	Northland (Far North)	Not available	Not available	Likely RL pot	Disentangled - DOC
23	29/09/2010	Internet - odt.co.nz (ODT 2010)	Humpback whale *Megaptera novaeangliae*	Northland (Far North)	Not available	Not available	Likely RL pot	Unknown
24	17/02/2011	DOC sightings database	Killer whale *Orcinus orca*	Canterbury (Kaikoura)	-42.46187	173.55884	RL pot	Disentangled - public
25	16/3/2011	DOC sightings database	Humpback whale *Megaptera novaeangliae*	Canterbury (Kaikoura)	-42.46349	173.68904	RL pot	Disentangled - DOC
26	27/6/2011	DOC sightings database	Humpback whale *Megaptera novaeangliae*	Canterbury (Christchurch)	-43.8281	172.7079	RL pot & mussel farm	Disentangled - mussel farmers
27	23/07/2011	Internet - odt.co.nz (Fox 2011)	Southern right whale *Eubalaena australis*	Otago (Dunedin)	Not available	Not available	RL pot	Unknown - not resighted
28	12/11/2011	DOC sightings database	Killer whale *Orcinus orca*	Gisborne (Gisborne)	-38.23618	178.32879	Longline	N/A - longline
29	07/02/2012	DOC sightings database	Killer whale *Orcinus orca*	Waikato (Thames-Coromandel)	-36.865133	175.82839	Likely RL pot	Disentangled- public
30	19/07/2012	DOC sightings database	Humpback whale *Megaptera novaeangliae*	Canterbury (Kaikoura)	-42.445133	173.76888	RL pot	Whale shed gear

No.	Date	Data Source	Species	Region (District)[5]	Latitude	Longitude	Gear Involved	Outcome
31	17/08/2012	DOC sightings database	Humpback whale *Megaptera novaeangliae*	Canterbury (Kaikoura)	-42.56452	173.51137	SN rope	Unknown - not resighted
32	27/11/2012	DOC incident database	Killer whale *Orcinus orca*	Bay of Plenty (Bay of Plenty)	-37.3048	176.2398	Unknown	Whale shed gear
33	08/04/2013	DOC sightings database	Killer whale *Orcinus orca*	Northland (Far North)	-34.553333	173.425	Longline-possible entanglement	N/A - longline
34	08/10/2013	Fisheries - Pot and set net cetacean NFPS	WHB-Baleen whales[6]	Bay of Plenty (Bay of Plenty)	Not available	Not available	SN	Unknown - fisheries database states 'caught alive uninjured' - assume disentangled
35	8/09/2014	DOC incident database	Killer whale *Orcinus orca*	Auckland (Auckland)	-36.3939	174.8649	RL pot	Disentangled – Orca Research Trust
36	30/10/2014	DOC incident database	Humpback whale *Megaptera novaeangliae*	Canterbury (Kaikoura)	-42.4366	173.6516	RL pot	Whale shed gear
37	5/11/2014	DOC incident database	Humpback whale *Megaptera novaeangliae*	Otago (Dunedin)	-45.7672	170.7527	Unknown rope	Unknown - not resighted
38	21/06/2015	DOC incident database	Humpback whale *Megaptera novaeangliae*	Marlborough (Marlborough)	-41.2507	174.2948	RL pot	Unknown - not resighted
39	24/06/2015	DOC incident database	Humpback whale *Megaptera novaeangliae*	Marlborough (Marlborough)	-41.7333	174.299	Likely RL pot	Partially disentangled - buoys cut free
40	13/09/2015	DOC incident database	Humpback whale *Megaptera novaeangliae*	Wellington (Lower Hutt)	-41.3861	174.8584	RL pot	Disentangled - DOC
41	18/11/2015	DOC incident database	Killer whale *Orcinus orca*	Waikato (Thames-Coromandel)	-36.6338	175.8633	RL pot	Death
42	14/03/2016	DOC incident database	Humpback whale *Megaptera novaeangliae*	Canterbury (Kaikoura)	-42.4775	173.5424	Unknown	Whale shed gear - severe trauma to fluke - both sides missing. Healing ok
43	14/12/2016	Internet - Stuff.co.nz (Yalden 2016)	Killer whale *Orcinus orca*	Waikato (Thames-Coromandel)	Not available	Not available	RL pot	Disentangled – harbourmaster
44	23/03/2017	DOC email directly to BPM	Humpback whale *Megaptera novaeangliae*	Canterbury (Kaikoura)	Not available	Not available	SN	Whale shed gear

[6] WHB-Baleen whales is a code used in NFPS forms issued by the Ministry For Primary Industries, it does not refer to a particular grouping of baleen whales.

Table 2: Percentage and number of documented large whale entanglement events by species common name and gear type (RL = rock lobster; SN = set net; n=39).

	Likely RL pot	RL pot	SN	SN rope	Unknown gear type	Unknown rope	Grand Total
Minke whale	0%	0%	2.6% (1)	0%	0%	0%	**2.6% (1)**
Blue whale	0%	0%	0%	0%	0%	2.6% (1)	**2.6% (1)**
Southern right whale	0%	5.1% (2)	0%	2.6% (1)	0%	0%	**7.7% (3)**
Humpback whale	7.7% (3)	35.9% (14)	5.1% (2)	2.6% (1)	7.7% (3)	5.1% (2)	**64.1% (25)**
Killer whale	2.6% (1)	10.3% (4)	5.1% (2)	0%	2.6% (1)	0%	**20.5% (8)**
Unknown baleen whale	0%	0%	2.6% (1)	0%	0%	0%	**2.6% (1)**
Grand Total	**10.3% (4)**	**51.3% (20)**	**15.4% (6)**	**5.1% (2)**	**10.3% (4)**	**7.7% (3)**	**100% (39)**

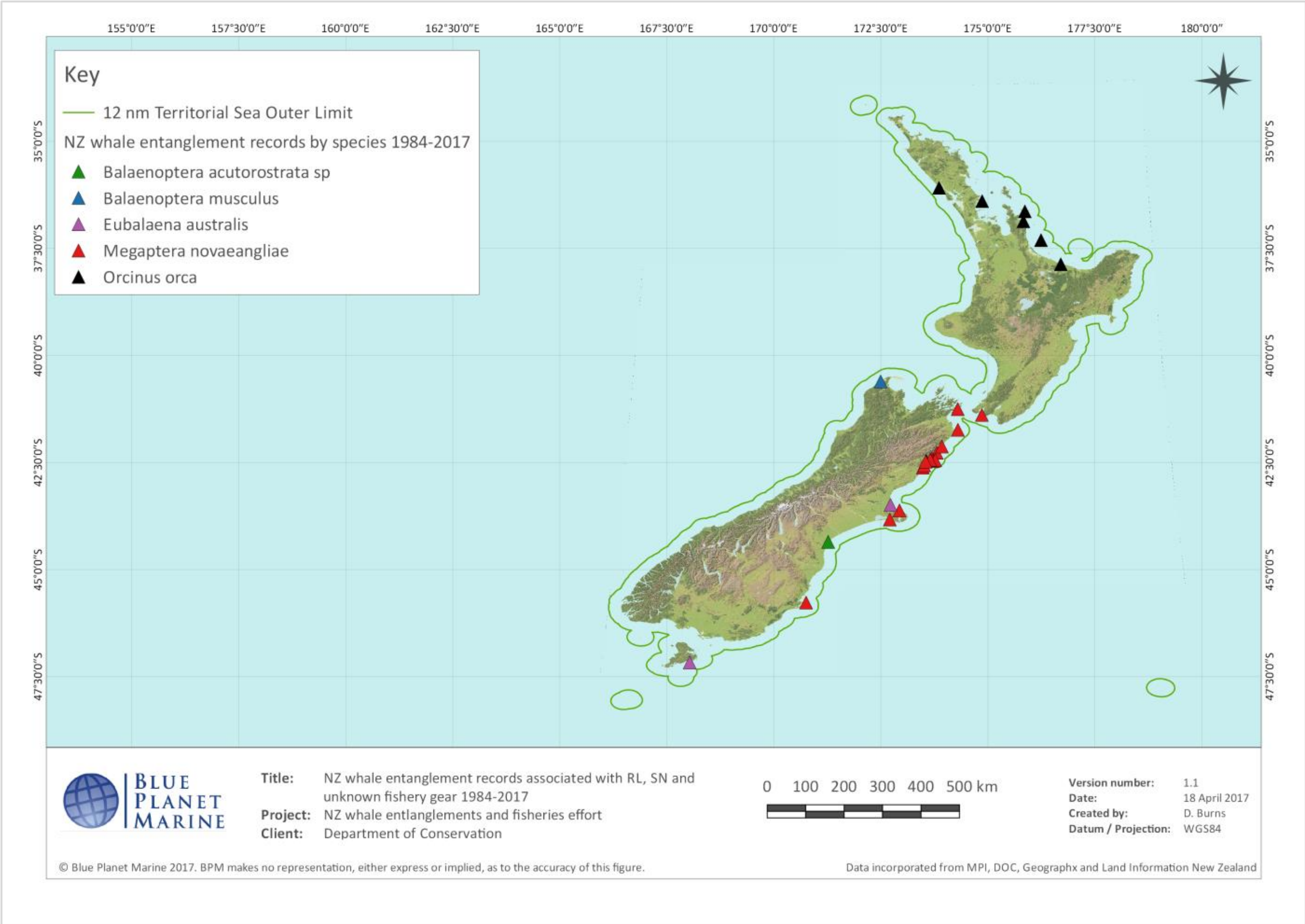


Figure 13: Location of documented large whale species entanglement events in New Zealand waters associated with rock lobster and set net fishery gear, or unknown fishery gear, 1984-2017 (n=30).

Note: figure includes only those records with associated latitude and longitude information. Also note that the reported location is the location where the whale was seen entangled and not necessarily the location where it was originally entangled.

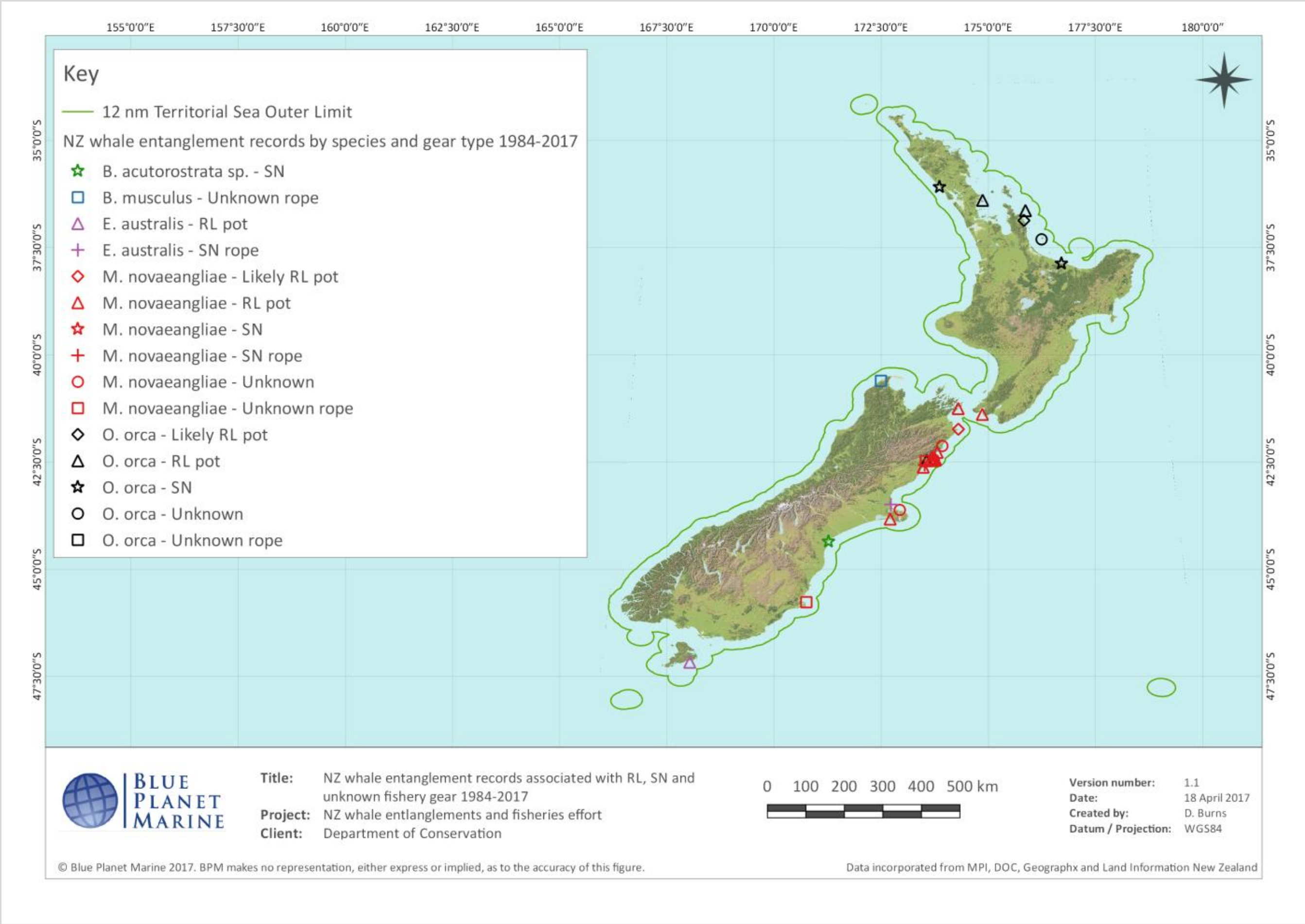


Figure 14: Location of documented large whale species entanglement events in New Zealand waters associated with rock lobster and set net fishery gear, or unknown fishery gear, 1984-2017 (n=30), by gear type.

Note: figure includes only those records with associated latitude and longitude information. Also note that the reported location is the location where the whale was seen entangled and not necessarily the location where it was entangled.

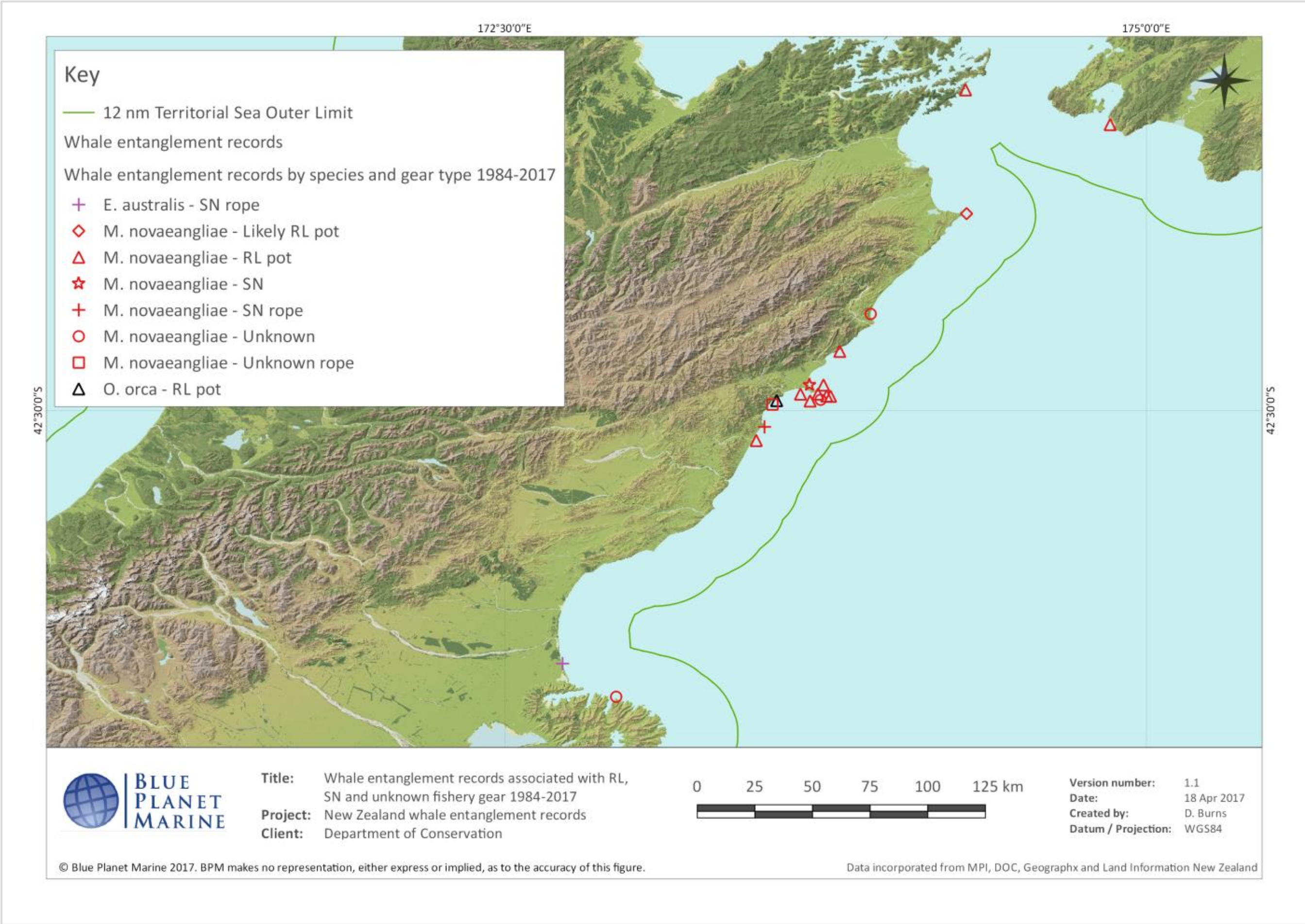


Figure 15: Location of documented large whale species entanglement events in the Kaikoura region associated with rock lobster and set net fishery gear, or unknown fishery gear, 1984-2017 (n=14), by gear type.

Note: figure includes only those records with associated latitude and longitude information. Also note that the reported location is the location where the whale was seen entangled and not necessarily the location where it was entangled.

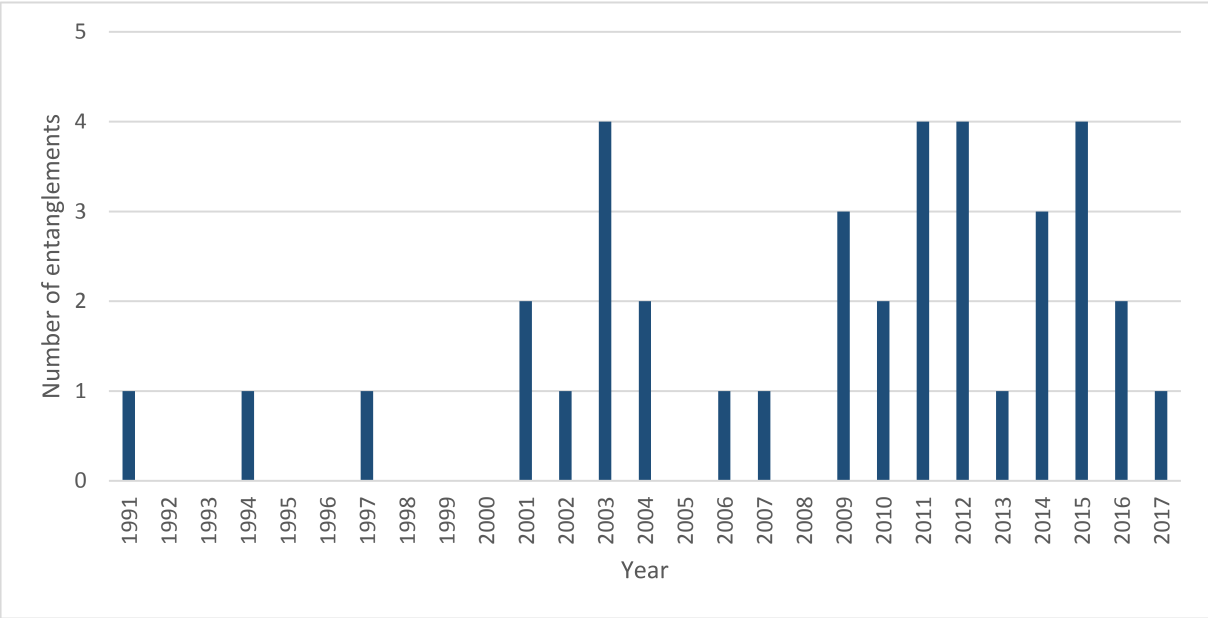


Figure 16: Number of documented large whale entanglement events by year (excluding the single record in 1984) (n=38).

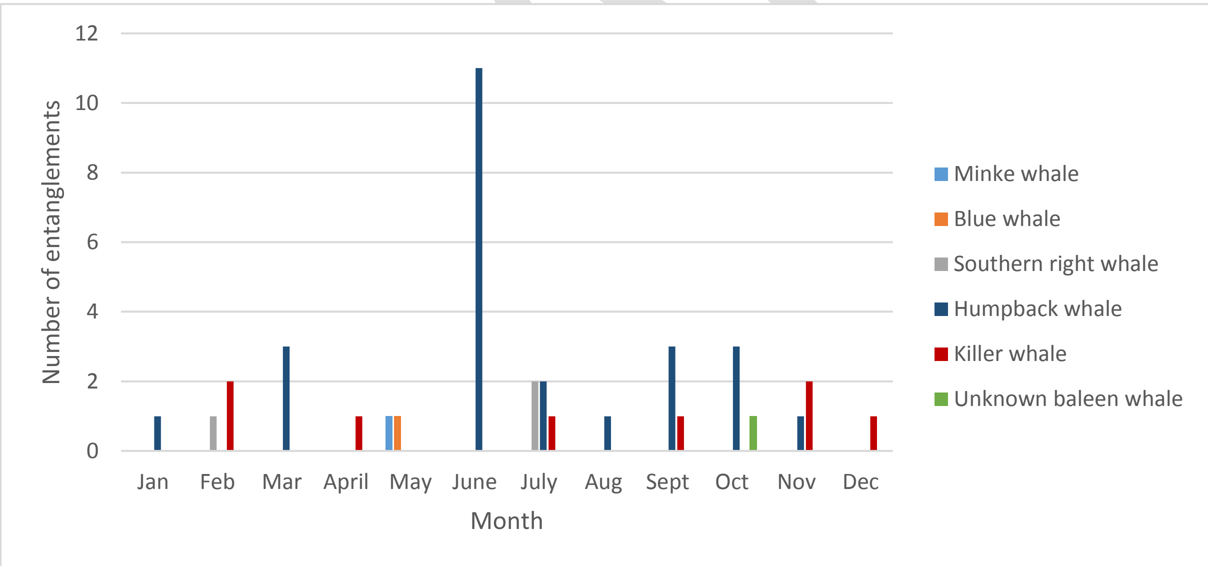


Figure 17: Number of documented entanglement events of large whales per month for each species affected (n=39).

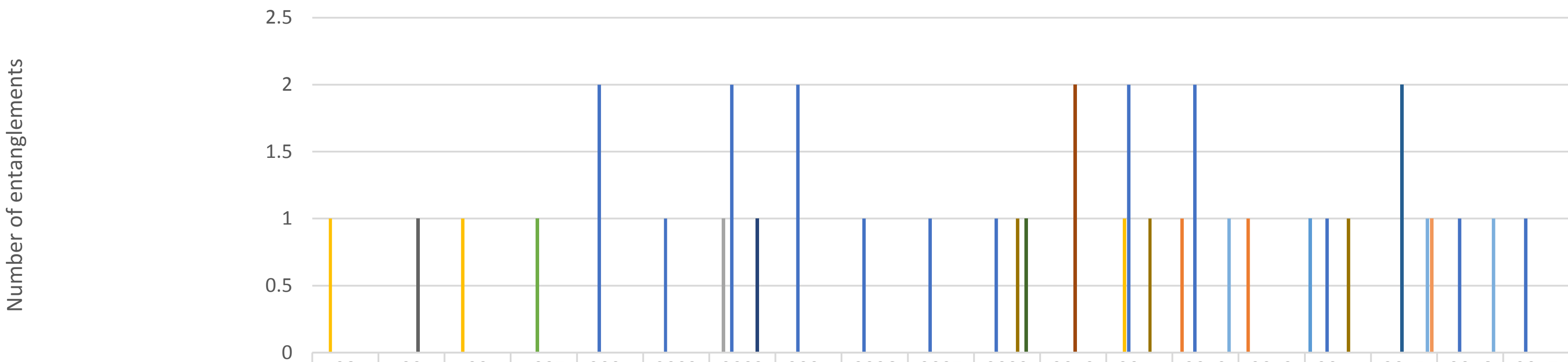
5.2.3 Temporal and spatial change in large whale entanglement associated with commercial rock lobster and set net fisheries

The data available regarding large whale entanglement over time and space allows analysis to be undertaken at a high level only.

In the last ten years (2008 onwards), large whale entanglements relating to rock lobster, set net and ‘unknown’ fisheries gear were recorded for the first time in nine regions and resulted in 15 entanglement events (Figure 18). These ‘new’ regions of entanglement represented 68% of the total number of documented entanglements from 2008. Over this same period, 36% of entanglements were documented from the region of Kaikoura (Figure 18).

Four species of large whale were represented in the entanglement records between 1984-2007, while four to five[7] were recorded from 2008-2017 (Figure 19). Humpback whales, killer whales and southern right whales were reported entangled during both periods, while a minke whale entanglement was reported in 1984-2007, and blue whale and ‘WHB Baleen whales’ were reported between 2008-2017 (Figure 19).

[7] ‘WHB-Baleen whales’ may or may not be one of the other baleen whale species represented in entanglement records over this period.



	1984	1991	1994	1997	2001	2002	2003	2004	2006	2007	2009	2010	2011	2012	2013	2014	2015	2016	2017
Auckland (Auckland)																1			
Bay of Plenty (Bay of Plenty)														1	1				
Bay of Plenty (Whakatane)							1												
Canterbury (Christchurch)	1		1										1						
Canterbury (Kaikoura)					2	1	2	2	1	1	1		2	2		1		1	1
Canterbury (Timaru)				1															
Marlborough (Marlborough)																	2		
Northland (Far North)												2							
Northland (Kaipara)		1																	
Otago (Dunedin)											1		1			1			
Southland (Stewart Island)							1												
Tasman (Tasman)											1								
Waikato (Thames-Coromandel)														1			1	1	
Wellington (Lower Hutt)																	1		

Year

Figure 18: Number of entanglement events of large whale species in rock lobster and set net fishery gear, or unknown fishing gear, per year (1984-2017) by region (n=39).

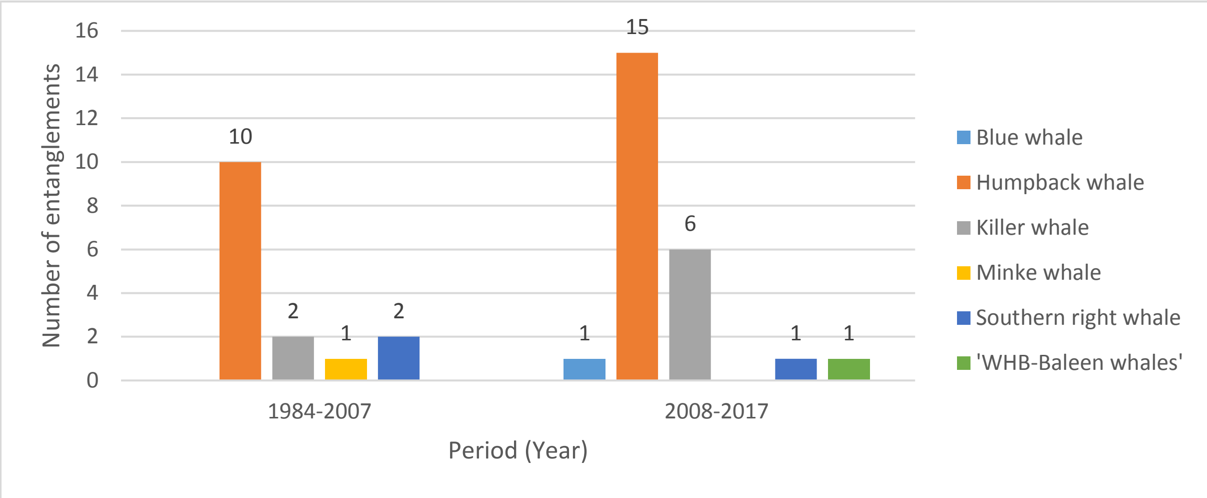


Figure 19: Number of entanglement events of large whale species in rock lobster and set net fishery gear, or 'unknown' fishery gear reported by species before and after 2007 (n=39).

5.2.4 Entanglements of large whale species and comparison to commercial rock lobster and set net fisheries effort

Fisheries effort data provided to BPM by MPI spanned the period 2005 to 2017. For the purposes of this study, however, these were considered as broadly representative of the fisheries' effort over the period for which we have documented entanglement events for large whale species (1984 to 2017, after entanglements with no definitive latitude and longitude location data are removed, n=9). Figure 20 to Figure 25, therefore, present entanglement events in set net and rock lobster fisheries from 1984 to 2017 against the fisheries effort data supplied by MPI (2005 to 2017).

As noted previously, the location of a documented entanglement event is generally the location where an individual whale was seen and reported as entangled. However, this location does not necessarily represent the location of the actual original entanglement event itself which could be considerably far removed in both time and or space. The reported position has been summarised here as it is the only data that is available.

Rock lobster fishery

There were 24 records of entanglements in rock lobster fisheries gear or unknown gear that could be mapped (Figure 20). This number rises to 31 recorded entanglements if those without latitude and longitude information are included (Table 1). These seven non-mapped entanglements all involved rock lobster or likely rock lobster fisheries gear and occurred in the regions of Kaikoura (n=2), Otago (n=2), Northland (n=2), and Coromandel Peninsula (n=1) (Table 1). When the 31 recorded events are considered, gear definitely or likely to be from the rock lobster fishery accounted for 77% of the entanglements.

The main cluster of recorded entanglement events occurs in the region of Kaikoura, which is also an area of relatively high fishing effort (Figure 20). Here eleven entanglements have been recorded, ten (91%) of which involved rock lobster or likely rock lobster gear, with one event associated with gear from an unknown fishery (Table 1). All documented entanglements in this cluster involved humpback whales, except for one entanglement of a killer whale (Table 1).

Rock lobster fishing effort in the Kaikoura region was higher for the period of the humpback whale northern migration between May-August (Figure 21) than the southern migration between

September-December (Figure 22). During these periods in the Kaikoura region, nine entanglements were recorded during the northern migration and one during the southern migration (Table 1, Figure 21, Figure 22).

Set net fishery

Entanglements in set net fisheries gear or unknown gear were recorded on 15 occasions, including two events that do not have associated latitude and longitude information (Figure 23, Table 1). These two non-mapped entanglements involved set net fishery gear and occurred in the Bay of Plenty and Kaikoura (Table 1). When all 15 recorded events are considered, gear from set net fisheries accounted for 53% of the entanglements (Table 1).

The main cluster of recorded entanglement events occurs in the region of Kaikoura, which is also an area of relatively high fishing effort (Figure 23). Six entanglements have been recorded this region, three (50%) of which involved set net fishery gear, while the remaining thee entanglements were due to gear from unknown fisheries (Figure 23, Table 1). All documented entanglements in this cluster involved humpback whales (Table 1).

Set net fishing effort in the Kaikoura region was similar during humpback whale northern and southern migration periods (Figure 24, Figure 25). During these periods in the Kaikoura region, three entanglements were recorded during the northern migration and zero during the southern migration (Table 1, Figure 24, Figure 25).

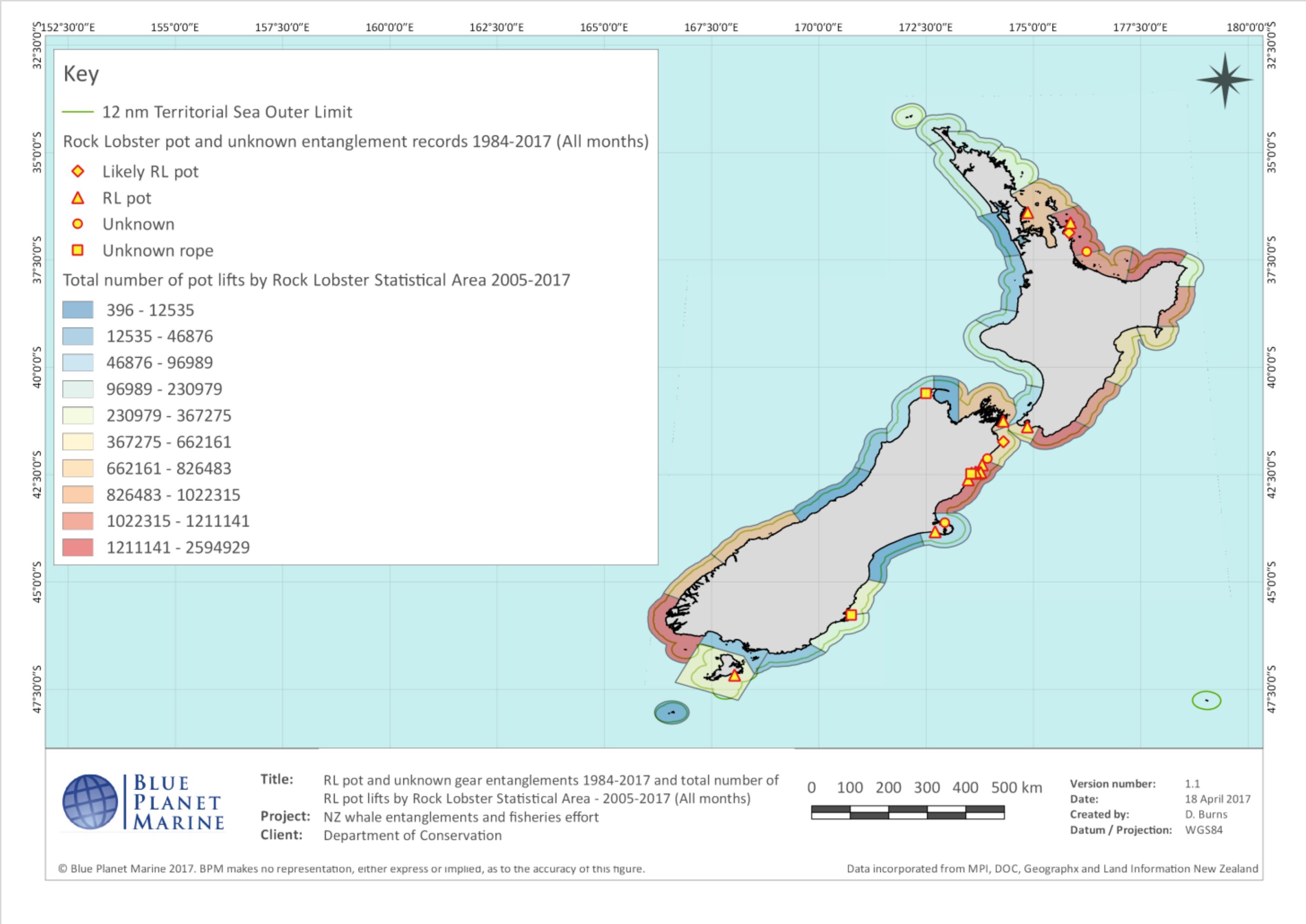


Figure 20: Rock lobster fishing effort (pot lifts between 2005-2017) and documented large whale entanglement events (1984-2017) in rock lobster fishing or unknown fishing gear.

Effort data provided by MPI 2017. n=24 whale entanglements in rock lobster/unknown fishing gear.

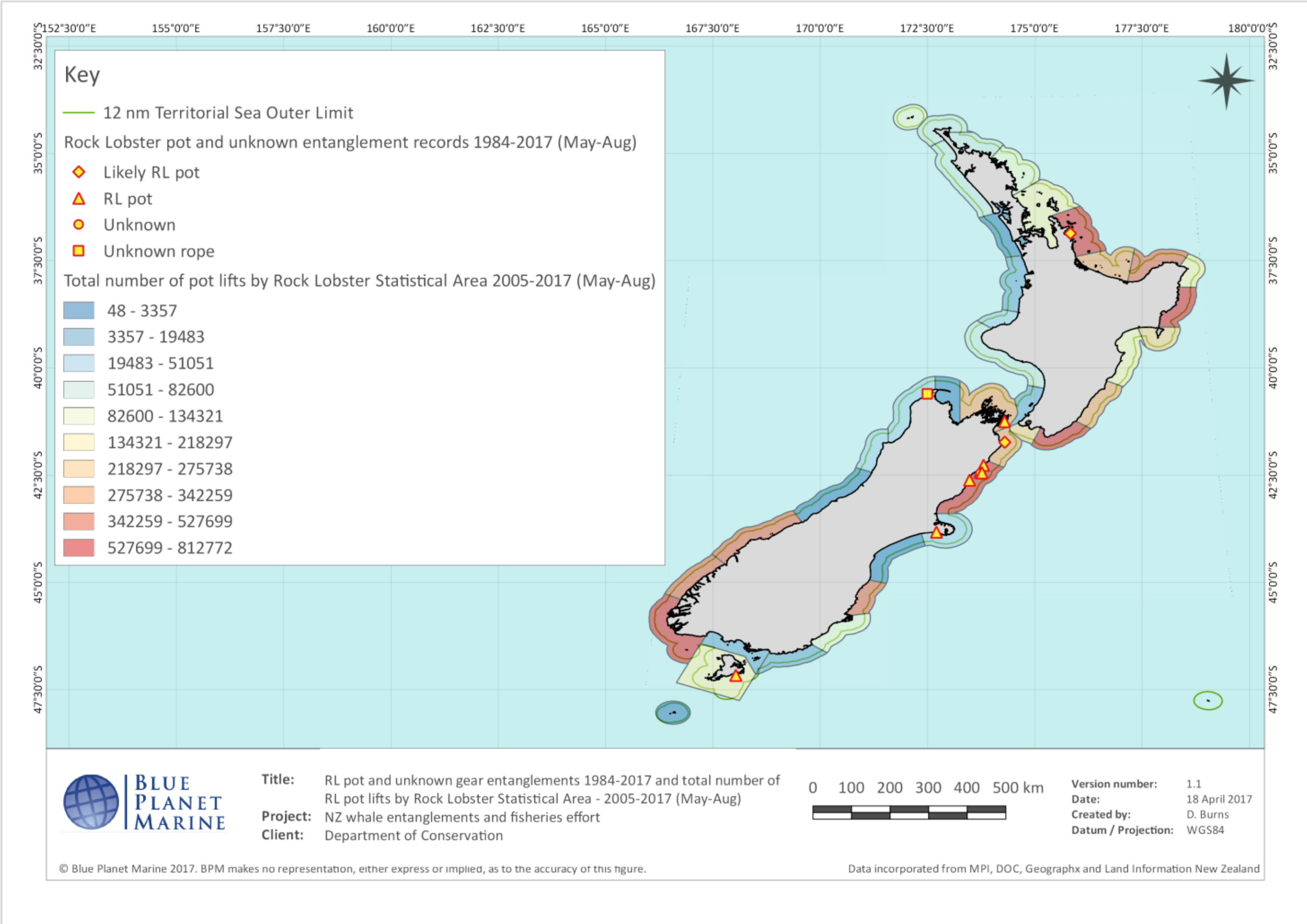


Figure 21: Rock lobster fishing effort (pot lifts between 2005-2017) and documented large whale entanglement events (1984-2017) in rock lobster fishing or unknown fishing gear during the humpback whale northern migration period.

Effort data provided by MPI 2017. n=12 whale entanglements in rock lobster/unknown fishing gear during May-Aug.

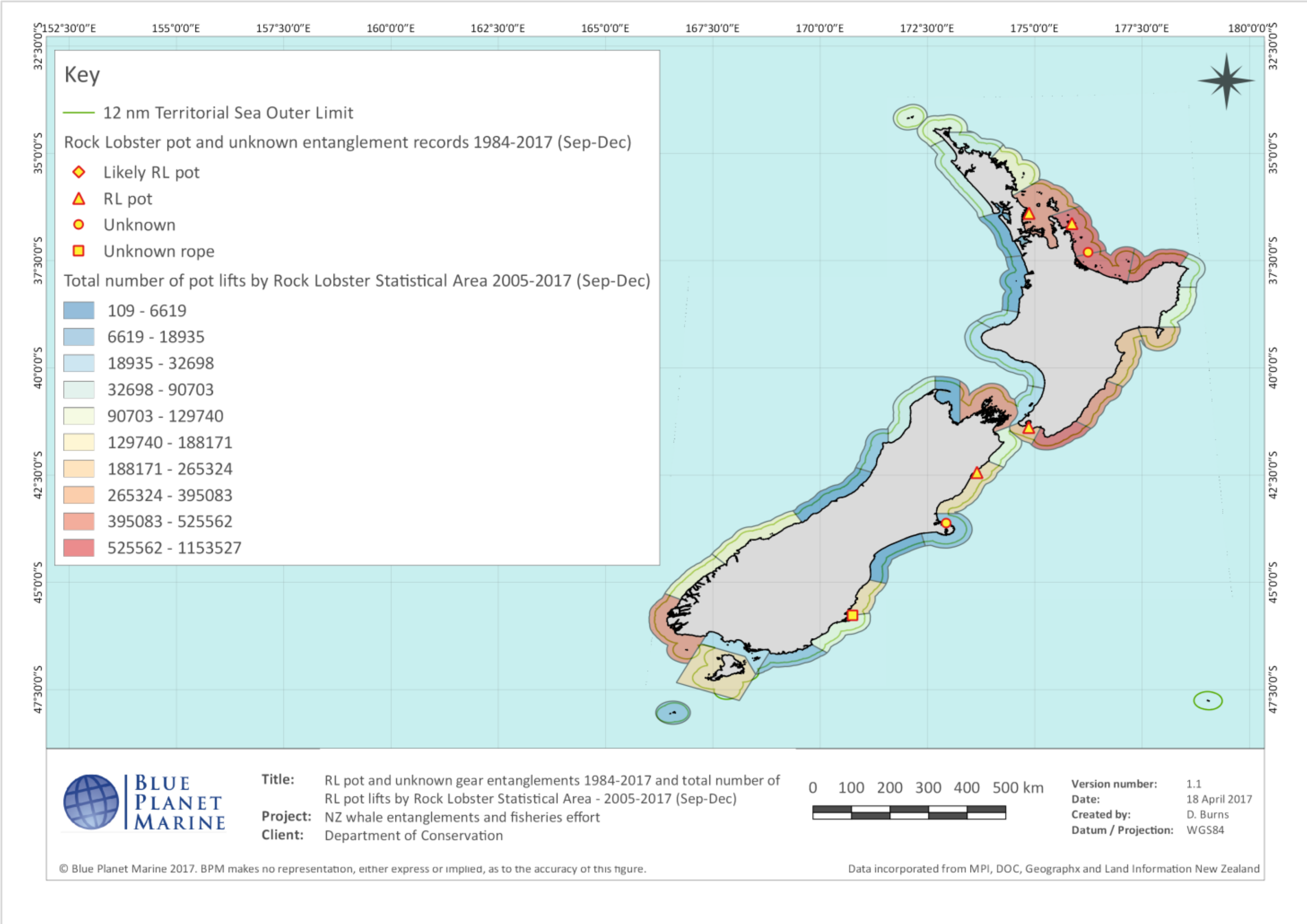


Figure 22: Rock lobster fishing effort (pot lifts between 2005-2017) and documented large whale entanglement events (1984-2017) in rock lobster fishing or unknown fishing gear during the humpback whale southern migration period.

Effort data provided by MPI 2017. n=7 whale entanglements in rock lobster/unknown fishing gear during Sep-Dec.

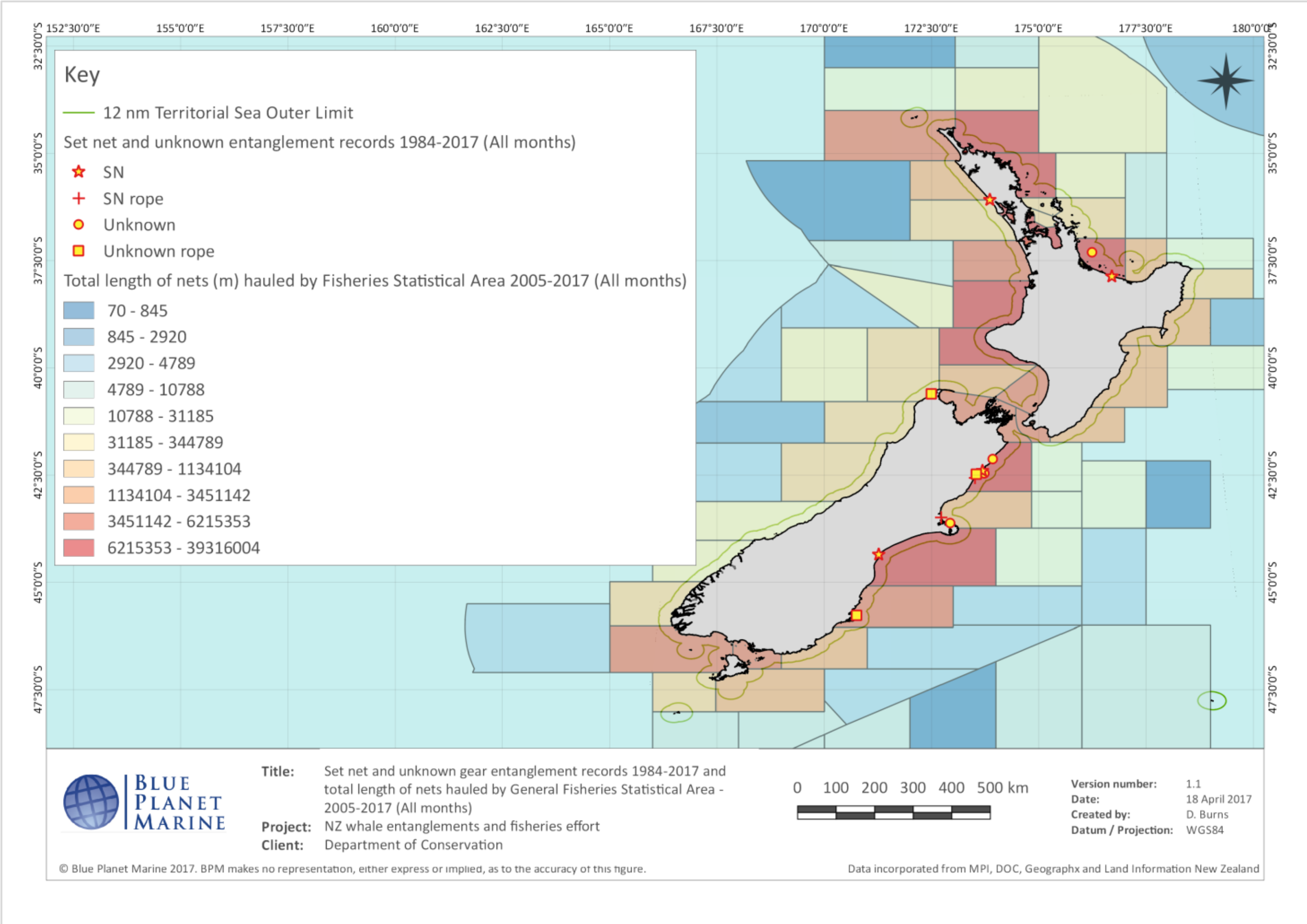


Figure 23: Set net fishing effort (net length (m) hauled between 2005-2017) and documented large whale entanglement events (1984-2017) in set net fishing or unknown fishing gear.

Effort data provided by MPI 2017. n=13 whale entanglements in set net/unknown fishing gear.

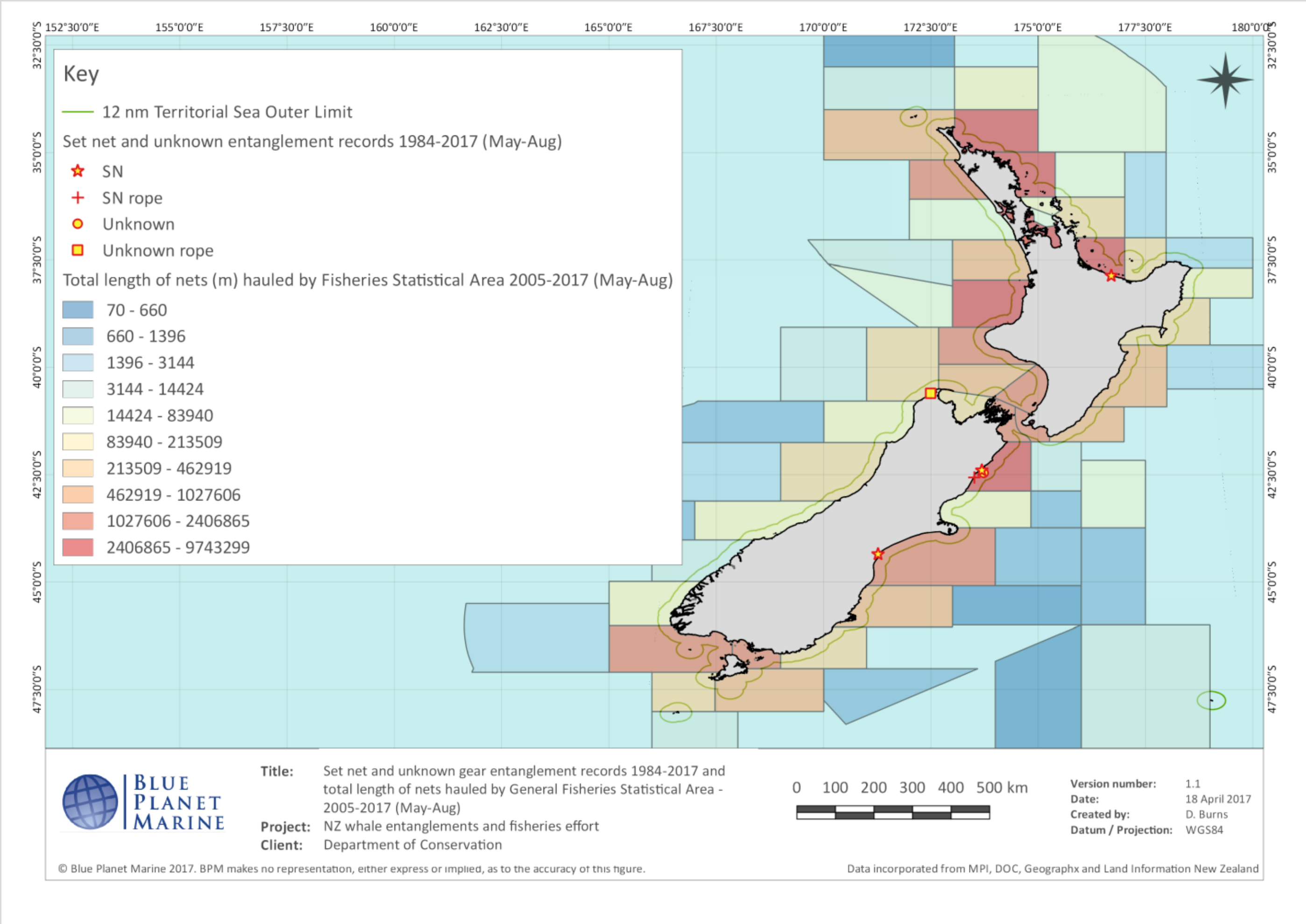


Figure 24: Set net fishing effort (net length (m) hauled between 2005-2017) and documented large whale entanglement events (1984-2017) in set net fishing or unknown fishing gear during the humpback whale northern migration period.

Effort data provided by MPI 2017. n=6 whale entanglements in set net/unknown fishing gear during May-Aug.

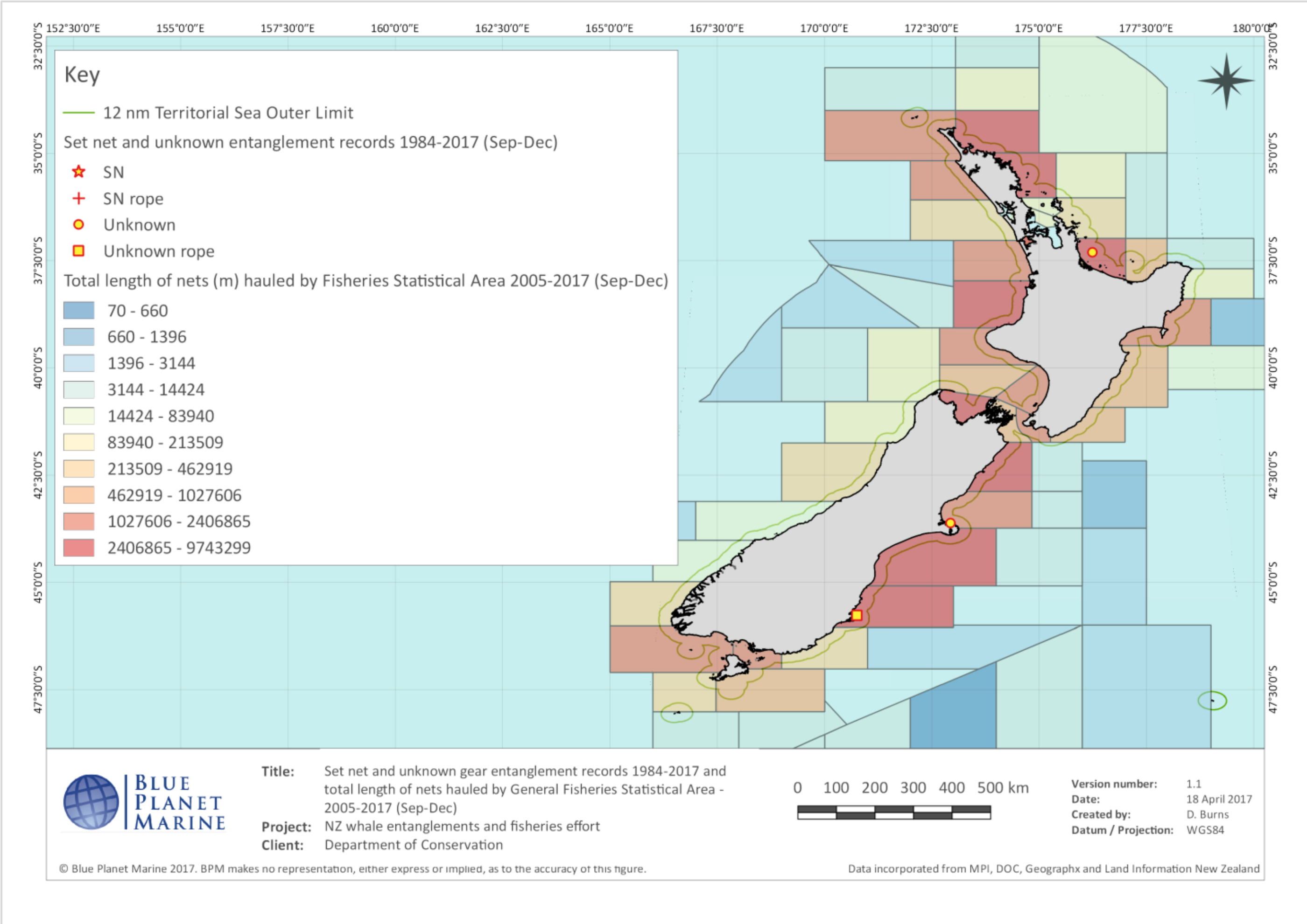


Figure 25: Set net fishing effort (net length (m) hauled between 2005-2017) and documented large whale entanglement events (1984-2017) in set net fishing or unknown fishing gear during the humpback whale southern migration period.

Effort data provided by MPI 2017. n=3 whale entanglements in set net/unknown fishing gear during Sep-Dec.

5.2.5 The effect of large whale entanglements on individual animals and populations

Calculating approximate annual entanglement rates for a species is possible if entanglement and sightings data are available for a given year. This is partly the case for New Zealand humpback whales, where the Cook Strait survey can be correlated with documented New Zealand entanglements in a given year. For example, the Cook Strait survey in 2004 reported observing 35 individual humpback whales and in that same year there were 2 documented humpback whale entanglements. Given that the Cook Strait Survey is conducted for 9 hours per day, the extrapolated sightings expected for a 24-hour period is 93 whales. Further, given there were 2 entangled humpback whales from a transiting population of approximately 93, the entanglement rate can be estimated to be 2% for 2004. In 2011 and 2015, the entanglement rate was calculated as 1% and 0.5% respectively. In some years, no entanglements were reported (Table 1). Notwithstanding these estimates of entanglement, it is important to note that (i) not all humpbacks migrate through Cook Strait and so the number migrating through NZ is likely to be larger and, (ii) the reported number of entangled whales is a minimum estimate and it is not clear how the reported rate corresponds to the true rate.

The outcome of entanglement events was variable. Whales were fully disentangled in 28% of all documented entanglement events, with 10% partially disentangled. 13% of whales shed gear on their own (without intervention). Conversely, 15% of entanglements were linked to the death of the individual, either directly or indirectly, and the fate of 33% of entangled whales remained unknown.

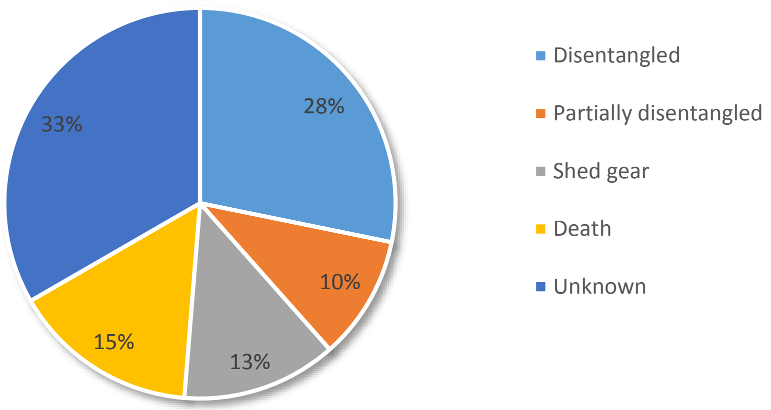


Figure 26: Outcome of documented large whale entanglement events in New Zealand, 1984-2017 (n=39).

5.3 Risk Analysis

BPM conducted a simple risk analysis of large whale entanglements for selected pressure groups[8] in

Likelihood of Occurrence	Description
Rare	Highly unlikely, but it may occur in exceptional circumstances. It could happen, but probably never will.

[8] In this context pressure group means the affected animal/population/organisation etc.

Unlikely	Not expected, but there is a slight possibility it may occur at some time.
Possible	The event might occur at some time as there is a history of casual occurrence in New Zealand waters.
Probable	There is a strong possibility the event will occur as there is a history of frequent occurrence in New Zealand waters.
Almost Certain	Very likely. The event is expected to occur in most circumstances as there is a history of regular occurrence in New Zealand waters.

Table 5) were used in conjunction in order to evaluate the current degree of severity and likelihood of entanglements occurring, then determine the level of risk.

Table 3: Consequence of entanglements to major pressure groups in New Zealand.

This table lists the possible consequences of whale entanglement – across various degrees of severity – for each pressure group involved.

Pressure Group	Degrees of Severity				
	Negligible	Low	Medium	High	Extreme
Whales- *individual level*	Behaviour is not modified (e.g. no avoidance of, or attraction to an activity or area), or immediately reversed when activity ceases. Whales are not entangled.	Behaviour is modified at a local scale (e.g. avoidance of, or attraction to an activity or area) - not immediately reversed when activity ceases, but reversed within three months. Whales are entangled with relatively 'simple' entanglements. Gear is shed independently in short timeframe without intervention (hours or days). Resulting in nil, negligible or strictly superficial injuries.	Behaviour is modified at a local scale (e.g. avoidance of, or attraction to an activity or area) - not reversed within three months. Entanglement requires intervention, or gear shed without intervention after a moderate timeframe (weeks). On disentanglement, injuries generally minor to moderate, resulting in temporary pain and injury, but animal will recover to pre-entanglement condition.	Temporary avoidance of entire migratory path or feeding/breeding habitat. Entanglement requires intervention, or whale carries gear for protracted periods (months) before being shed. On disentanglement, injuries generally moderate-severe. Will have either long-lasting effects involving protracted recovery times, or cause permanent physical trauma/debilitation (e.g. loss of flukes as documented in 2016).	Permanent avoidance of entire migratory path or feeding/breeding habitat. Whales entangled with simple or complex entanglements that remain on the whale as entanglements were ultimately: a) Never detected and not shed independently, b) Detected but unable to be disentangled, or c) Detected, disentangled but whale experienced unrecoverable, severe loss of condition or injury. Will result in either quick death via drowning, or protracted death from

Pressure Group	Degrees of Severity				
	Negligible	Low	Medium	High	Extreme
					starvation, infection, exhaustion or predation.
Whales- *population level*	Population continues to recover well to pre-exploitation level. Any individual's death will not affect future population status.	Population increasing to pre-exploitation level, but reduced rate of increase. Any individual's death will not affect future population status.	Population stable but not increasing. Any individual's death may have a small effect on population status.	Population begins to decline slowly: numbers sighted on migratory path and/or breeding grounds showing slow rates of decline. Any individual's death will affect current and future population status.	Population severely affected; any anthropogenic event could affect population recovery: numbers sighted on migratory path and/or breeding grounds in serious decline, population 'at risk'. Any individual's death has a detrimental effect on current and future population status.
Fisheries (New Zealand rock lobster and set net)	Nil or very little gear lost due to interactions with whales. No financial cost to fishers.	Gear occasionally damaged/lost due to interactions with whales. Gear easily repaired or replaced without significant financial loss. Catch levels unaffected. Gear occasionally sighted on live entangled whales. Some public awareness of fisheries/whale interactions.	Gear regularly lost/damaged due to interactions with whales. Financial loss due to replacement. Catch levels affected, reducing profitability. Gear regularly sighted on live entangled whales. Increasing public awareness of fisheries/whale interactions; public pressure for fisheries to respond. Relationships with other pressure groups affected.	Lost/damaged gear regularly sighted on dead entangled whales. Public and/or government pressure to modify or close industry. Some public boycott of products causing loss of income and financial instability. Seasonal closures of fishery causing financial loss. Relationships with other pressure groups affected.	Lost/damaged gear frequently sighted on dead entangled whales. Significant public and/or government pressure to modify or close industry. Temporary or permanent closure of fishery and significant financial loss. Public boycott of products causing loss of income and financial instability. Seasonal closures of fishery causing financial loss. Relationships with other pressure groups strongly affected.

Pressure Group	Degrees of Severity				
	Negligible	Low	Medium	High	Extreme
Whale watching operators	Whales seen on tours continue to be behaving normally, with nil to very few entangled whales sighted per annum. No financial cost to operators.	Entangled whales increasingly sighted on tours. No financial cost to operators. Minor effect on the perceived 'naturalness' of the whale watching experience.	Entangled whales commonly sighted on tours. Minor financial cost to operators due to reduced patronage. Effect on the perceived 'naturalness' of the whale watching experience. Increasing public awareness including negative publicity of the whale watching experience. Time/financial cost to operators from management of issue with government/fisheries. Relationships with other pressure groups affected.	Reduced numbers of whales (either entangled or not entangled) sighted on tours. Financial cost to operators due to reduced patronage. Strong effect on the perceived 'naturalness' of the whale watching experience. Increasing public awareness including strong and sustained negative publicity of the whale watching experience. Increased time/financial cost to operators from management of issue with government/fisheries. Relationships with other pressure groups strongly affected.	Whales rarely sighted- unsustainable loss of business and income. Significant financial cost to operators due to reduced patronage. Loss of employment. Significant time/financial cost to operators from management of issue with government/fisheries. Relationships with other pressure groups severely affected.
Department of Conservation	Occasional entanglements reported: DOC disentanglement teams have capacity to attend all events in a timely fashion, and successfully and safely disentangle all whales.	Occasional entanglements reported: DOC disentanglement teams have capacity to attend most events in a timely fashion but unable to successfully disentangle all whales. DOC disentanglements undertaken safely.	Regular entanglements reported: DOC disentanglement teams don't have capacity to attend increasing number of events in a timely fashion. Unable to successfully disentangle all whales. DOC	Regular entanglements reported: DOC disentanglement teams don't have capacity to attend increasing number of events. Unable to successfully disentangle all whales. Most DOC disentanglements undertaken safely.	Frequent entanglements reported: DOC disentanglement teams don't have capacity to attend to many events. Unable to successfully disentangle all whales. Most DOC disentanglements undertaken safely.

Pressure Group	Degrees of Severity				
	Negligible	Low	Medium	High	Extreme
			disentanglements undertaken safely.		
	Minimal financial/time cost to DOC.	Minimal financial/time cost to DOC. Some negative publicity regarding DOC's ability to respond quickly to an event. Public occasionally responding independently of DOC to disentangle whales. Potential for injury.	Increased financial/time cost to DOC. Increasing negative publicity regarding DOC's ability to respond quickly to an event. Public pressure to respond to increasing entanglement rates. Increased potential for injury. Public responding independently of DOC to disentangle whales.	Increased financial/time cost to DOC. High level of negative publicity regarding DOC's ability to respond quickly to an event. Public pressure to respond to increasing entanglement rates. Public increasingly responding independently of DOC to disentangle whales. Increased potential for injury. Pressure on DOC personnel may result is lower adherence with safety protocols. Increased potential for injury. Potential DOC not fulfilling requirements of Marine Mammals Protection Act, Health and Safety at Work Act 2015 etc.	High financial/time cost to DOC. High level of negative publicity regarding DOC's ability to respond quickly to an event. High public pressure to respond to increasing entanglement rates. Public frequently responding independently of DOC to disentangle whales. Increased potential for injury or loss of live/lives. Pressure on DOC personnel resulting in lower adherence with safety protocols. Increased potential for injury or loss of life/lives. Increased potential DOC not fulfilling requirements of Marine Mammals Protection Act, Health and Safety at Work Act etc.

Table 4: Risk Likelihood Descriptors.

Likelihood of Occurrence	Description
Rare	Highly unlikely, but it may occur in exceptional circumstances. It could happen, but probably never will.
Unlikely	Not expected, but there is a slight possibility it may occur at some time.
Possible	The event might occur at some time as there is a history of casual occurrence in New Zealand waters.
Probable	There is a strong possibility the event will occur as there is a history of frequent occurrence in New Zealand waters.
Almost Certain	Very likely. The event is expected to occur in most circumstances as there is a history of regular occurrence in New Zealand waters.

Table 5: Risk Assessment Matrix. Use Table 3 and Table 4 for reference.

LIKELIHOOD		CONSEQUENCE				
		1	2	3	4	5
		Negligible	Low	Medium	High	Extreme
5	Almost Certain	Medium	High	High	Extreme	Extreme
4	Probable	Medium	High	High	Extreme	Extreme
3	Possible	Low	Medium	High	Extreme	Extreme
2	Unlikely	Low	Low	Medium	High	High
1	Rare	Low	Low	Low	Medium	Medium

5.3.1 Likelihood of entanglement

Based on the 1-4 documented entanglements of large whales in New Zealand waters per annum (IWC 2012, NZRLIC 2016, Morrissey, pers. comm. 2017, this study), and that large whale populations each number in just a few thousand (or less), we determine the likelihood of entanglements occurring in New Zealand waters as 'Unlikely' (Table 4). Note that, as whale populations (and/or fishing effort) increase, so will the likelihood of entanglement.

5.3.2 Risk to individual whales

The consequence of entanglement to individual whales is dependent on the configuration and severity of each entanglement. Based on the data available on New Zealand entanglements between 1994-2017, most entanglements would be rated as 'Medium' to 'Extreme' consequence to individual whales (Table 3). Assigning a conservative 'Medium' consequence rating to an individual whale entanglement event, with a 'Unlikely' likelihood of entanglement occurring, correlates to a 'Medium' risk to individual whales (Table 4. Risk Likelihood Descriptors

Likelihood of Occurrence	Description

Rare	Highly unlikely, but it may occur in exceptional circumstances. It could happen, but probably never will.
Unlikely	Not expected, but there is a slight possibility it may occur at some time.
Possible	The event might occur at some time as there is a history of casual occurrence in New Zealand waters.
Probable	There is a strong possibility the event will occur as there is a history of frequent occurrence in New Zealand waters.
Almost Certain	Very likely. The event is expected to occur in most circumstances as there is a history of regular occurrence in New Zealand waters.

Table 5).

5.3.3 Risk to whale populations

Since their populations appear to be slowly increasing in number, the current consequence of entanglement to humpback whales and southern right whales at the population level is 'Low' (Table 3). A 'Low' consequence rating and 'Unlikely' likelihood of entanglement occurring, results in a 'Low' risk to the populations of humpback and southern right whales in New Zealand waters (Table 4: Risk Likelihood Descriptors

Likelihood of Occurrence	Description
Rare	Highly unlikely, but it may occur in exceptional circumstances. It could happen, but probably never will.
Unlikely	Not expected, but there is a slight possibility it may occur at some time.
Possible	The event might occur at some time as there is a history of casual occurrence in New Zealand waters.
Probable	There is a strong possibility the event will occur as there is a history of frequent occurrence in New Zealand waters.
Almost Certain	Very likely. The event is expected to occur in most circumstances as there is a history of regular occurrence in New Zealand waters.

Table 5).

The consequence of entanglements to the New Zealand population of killer whales is considered 'Medium' based on their small population size and resulting New Zealand Threat Classification of '*Nationally Critical*' (Table 3). Accordingly, the risk of entanglement to the killer whale population, given a 'Unlikely' likelihood of entanglement occurring, is 'Medium' (Table 4: Risk Likelihood Descriptors

Likelihood of Occurrence	Description
Rare	Highly unlikely, but it may occur in exceptional circumstances. It could happen, but probably never will.
Unlikely	Not expected, but there is a slight possibility it may occur at some time.
Possible	The event might occur at some time as there is a history of casual occurrence in New Zealand waters.

Probable	There is a strong possibility the event will occur as there is a history of frequent occurrence in New Zealand waters.
Almost Certain	Very likely. The event is expected to occur in most circumstances as there is a history of regular occurrence in New Zealand waters.

Table 5).

5.3.4 Risk to commercial fisheries

With 1-4 documented entanglements of large whales per annum, the current consequence of entanglements to fisheries is 'Low' (Table 3), and the likelihood 'Unlikely' means that the risk to fisheries is currently 'Low' (Table 4: Risk Likelihood Descriptors.

Likelihood of Occurrence	Description
Rare	Highly unlikely, but it may occur in exceptional circumstances. It could happen, but probably never will.
Unlikely	Not expected, but there is a slight possibility it may occur at some time.
Possible	The event might occur at some time as there is a history of casual occurrence in New Zealand waters.
Probable	There is a strong possibility the event will occur as there is a history of frequent occurrence in New Zealand waters.
Almost Certain	Very likely. The event is expected to occur in most circumstances as there is a history of regular occurrence in New Zealand waters.

Table 5).

5.3.5 Risk to whale watching operators

With 1-4 documented entanglements of large whales per annum, the current consequence of entanglements to whale watching operators is 'Negligible' (Table 3), and the likelihood 'Unlikely' entanglement events, means that the risk to operators is currently 'Low' (Table 4: Risk Likelihood Descriptors.

Likelihood of Occurrence	Description
Rare	Highly unlikely, but it may occur in exceptional circumstances. It could happen, but probably never will.
Unlikely	Not expected, but there is a slight possibility it may occur at some time.
Possible	The event might occur at some time as there is a history of casual occurrence in New Zealand waters.
Probable	There is a strong possibility the event will occur as there is a history of frequent occurrence in New Zealand waters.
Almost Certain	Very likely. The event is expected to occur in most circumstances as there is a history of regular occurrence in New Zealand waters.

Table 5). Also, given that sperm whales are the focal species of Whale Watch Kaikoura, and no records of entanglement in set net or rock lobster pot fisheries were located for this species, the risk to this specific operator is in practical terms negligible.

5.3.6 Risk to DOC

DOC has responded to most entanglement events in a timely fashion and has undertaken disentanglement work safely, though not all whales could be disentangled. The current consequence of entanglements to DOC, therefore, is 'Low' (Table 3). With the likelihood of entanglement rated as [illegible]

Likelihood of Occurrence	Description
Rare	Highly unlikely, but it may occur in exceptional circumstances. It could happen, but probably never will.
Unlikely	Not expected, but there is a slight possibility it may occur at some time.
Possible	The event might occur at some time as there is a history of casual occurrence in New Zealand waters.
Probable	There is a strong possibility the event will occur as there is a history of frequent occurrence in New Zealand waters.
Almost Certain	Very likely. The event is expected to occur in most circumstances as there is a history of regular occurrence in New Zealand waters.

Table 5).

Given the level of risk posed by entanglement to individual whales is Medium, and there is a Low to Medium risk of entanglements to whale populations (and associated Low risk to fisheries and DOC), it is appropriate to assess current levels of entanglement mitigation in New Zealand, examine mitigation worldwide and comment upon the applicability of current mitigation techniques to the New Zealand market.

5.4 Summary of mitigation literature reviewed

Eighty-four papers and reports relevant to large whale entanglement were identified. Many of these were published scientific reports (45%), with a number of government reports (18%), on topics such as status of whale populations or fisheries; as well as relevant legislation relating to whale entanglements (United States) (13%) and a number of published reports, generally from International Whaling Commission meetings (13%). The remainder of literature were technical reports, describing the development of new mitigation techniques (4%), media reports of the entanglement issue (4%) and safety guidelines for disentanglement teams (2%) (Figure 27). All documents were deemed relevant in understanding and characterising the issues of entanglement and mitigation practices, locally and worldwide.

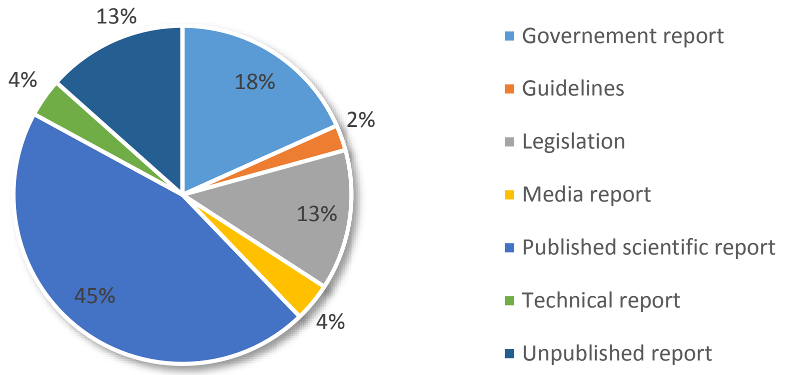


Figure 27: Type of literature reviewed (n=84 total papers relevant to large whale entanglement).

5.5 Detailed analysis of mitigation literature

Of the 84 reports and papers reviewed, only 26 (31%) contained information specifically relevant to the development, testing and implementation of mitigation techniques. A summary of these specific papers, and the nature of the information contained within each is provided in Appendix 1. The remainder of the reports provided some information relevant to bycatch mitigation but were mainly focused on other issues such as determining and describing the issue and extent of large whale entanglements in various areas, or providing a description of specific bycatch interactions in pot/trap and/or set net fisheries. While all of these references have been used to inform the final analysis, they contained insufficient relevant information to warrant the detailed assessment that was applied to the 26 key papers and reports listed in Appendix 1. Most of the literature was directly related to the efforts of the United States Government to mitigate against large whale entanglements in the North Atlantic (Figure 28).

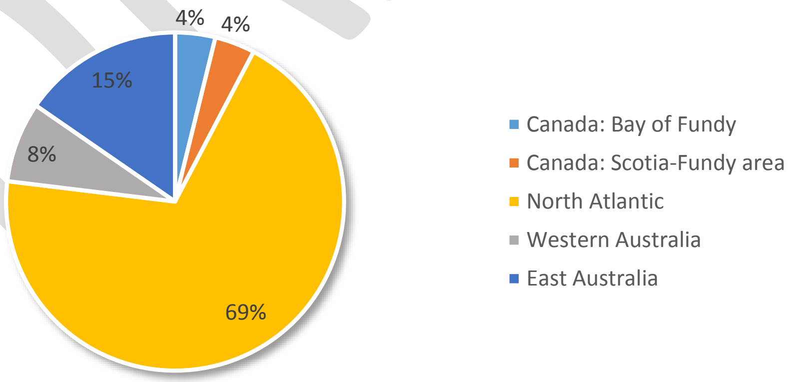


Figure 28: Location of mitigation effort outlined in key literature.

n=26 papers containing information specifically relevant to the development, testing and implementation of mitigation techniques.

Mitigation can generally be characterised as one of three main categories: acoustic deterrents, gear modifications and management modifications. Many papers addressed a combination of these. A breakdown of the literature by category showed that 77% of the literature were related to gear modification, 66% were related to management modification and 15% focused on acoustic deterrents relating to large whale entanglement (Figure 29).

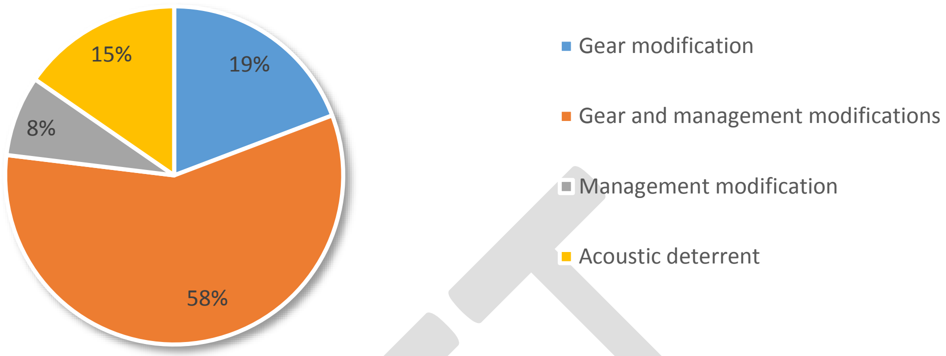


Figure 29: Mitigation type of literature reviewed.

n=26 papers containing information specifically relevant to the development, testing and implementation of mitigation techniques.

5.6 Mitigation techniques

To date, most evaluations of the effectiveness of mitigation techniques have focused on the efforts of the United States Government to reduce human-induced injuries and mortalities (caused by fisheries and vessel-strikes) on North Atlantic right whales, Gulf of Maine humpback whales and western North Atlantic fin whales via a suite of legally-binding regulations stipulated in the Atlantic Large Whale Take Reduction Plan (ALWTRP). In 2007, the United States Government finalised an amendment to the ALWTRP, which implemented a broad-based gear modification strategy that included expanded weak link and sinking groundline requirements, additional gear marking requirements as well as additional regulated fisheries, changes in boundaries, seasonal restrictions for gear modifications and expanded exempted areas (NMFS 2008). The gear modifications stipulated in these measures were designed to reduce the probability of an entanglement and increase the likelihood of self-disentanglement (Vanderlaan et al. 2011). Management responses such as fishing closures and reduction of effort aimed to reduce whale mortality by reducing the probability of whales encountering gear, and thus becoming entangled (Vanderlaan et al. 2011).

Entanglement of humpback whales has increased on the West Australian Coast in recent years, due to whale interactions with the expanded, year-round season of the Western Rock Lobster Fishery (How et al. 2015). Several gear modifications have been trialled with the cooperation of this industry in an effort to reduce entanglements (How et al. 2015, How, pers. comm. 2017), and these are also reported here.

The effectiveness of specific gear modifications, however, is difficult to determine. While many components of fishing gear have been shown to be involved in whale entanglements (Johnson et al. 2005, Knowlton et al. 2012), most gear-based mitigation methods trialled worldwide have been applied without any real understanding of the dynamics of whale entanglement: whether entanglements tend to happen at the surface, seabed or in the water column, and in turn what component of the gear poses the greatest risk. In addition, gear modifications have often been implemented as part of a suite of other mitigation methods, confounding the understanding of individual modification effectiveness.

Following is a summary of the mitigation measures trialled and used world-wide, under the categories of: 1) gear modifications, 2) acoustic deterrents and 3) management response. Each of these categories may be employed to either reduce risk of contact with gear and thus avoid entanglement events, or to reduce risk of injury or mortality to those whales that do become entangled.

5.6.1 Gear modification – weak links and rope strength

The following gear modifications are used to reduce the risk of mortality to whales that become entangled in gear.

Weak links

In the United States, one of the primary measures implemented by the United States Government to reduce human-induced whale mortality was the introduction of weak links in fishing gear. These weak links connect lines to buoys and are designed to break under certain maximum pressure, which is greater than encountered under normal fishing operations but still breaks over a certain threshold such as when a whale entangles. First implemented in 1997 (NFMS 1997), the breakage strength specification of weak links has been incrementally lowered over time, as load cell assessments calculated the initial breakage strengths were higher than needed for successful fishing operations. Currently, a weak link with a maximum breaking strength of 272.4 kg must be placed at all buoys for lobster trap/pot gear in inshore waters, and weak links with maximum breaking strength of 680.4 kg placed at all buoys in offshore areas (NMFS 2007, 2008).

For anchored gill net gear, the breaking strength of each net panel weak link must currently not exceed 498.8 kg, regardless of net panel size. One weak link must be placed in the centre of the floatline and one weak link must be placed in the centre of each of the up and down lines at both ends of the net panel. In addition, one weak link must be placed as close as possible to each end of the net panels on the floatline; or, one weak link must be placed between floatline tie-loops between net panels and one weak link must be placed where the floatline tie-loops attached to the bridle, buoy line, or groundline at each end of a net string. A weak link with a maximum of 498.8 kg must be placed at all buoys (NMFS 2007, 2008).

After years of implementation, weak links (along with other ALWTRP measures) have not appeared to reduce the incidence or severity of entanglements (Knowlton et al. 2012, Knowlton et al. 2016, Van der hoop 2013). An inherent flaw of this approach is that the break-away link is located where the buoy and rope are connected- and often the buoy is not involved with the entanglement itself, but drags behind the whale and entangled line (Moore 2009). In addition, disentanglements are more successful when the whale is anchored so it can be disentangled without being free-swimming (Groom and Coughran 2012, How 2015). During the disentanglement process, teams attach more floats to the trailing gear in order to slow down the whale: a practice known as 'kegging' (Groom and Coughran 2012). Removing the float also makes an entanglement less visible/obvious to detection. In Western Australia, the use of weak links is not a preferred mitigation measure of the Fisheries Department to manage fisheries interaction (How 2015).

Rope strength

Knowlton et al. (2016) examined historical incidents of entanglements and rope strength in a desk-top study on previously retrieved entanglement gear, to analyse the properties of ropes removed from entangled right whales, humpback whales and minke whales. Their study also aimed to identify trends in entanglement configurations and injury severity from 1980 to 2009 relative to changes in rope manufacturing practices used in United States and Canadian fisheries.

They found that rope strength was correlated with entangled species and animal age. Minke whales (the smallest species) were found in significantly lower breaking strength ropes than both humpback and right whales. Adult right whales were found in significantly stronger ropes than juvenile right whales. Adult right whales were also found in significantly stronger ropes than juvenile and adult humpback whales; a species the authors state as having less strength than right whales. The absence of juvenile right whales found in strong ropes suggests that they either evade stronger ropes or, more likely, may die in stronger gear, sink and remain undetected (Knowlton et al. 2016).

Knowlton et al. (2016) reported that adult right whales were only found entangled in rope over 20.02 kiloNewtons (kN), which suggests they can break free from weaker ropes and thereby avoid a life-threatening entanglement.

For right whales, injury severity was related to rope strength. Knowlton et al. (2016) suggest that rope strength may influence entanglement severity in right whales, and that using reduced breakage strength (RBS) ropes could lead to a reduction of whale mortality and serious injury from entanglement in fishing gear.

The benefit of RBS ropes is that they would give a whale a better chance of breaking free regardless of where it makes contact with the line, as the whole length of the rope is weaker, rather than specific points such as weak links. However, Knowlton et al. (2016) also point out that the implementation of RBS ropes would not reduce the number of encounters between whales and gear, and may not prevent lethal entanglements in some areas such as right whale calving grounds, where neonates have less strength than adult right whales and even minke whales.

Preliminary trials of RBS ropes were undertaken in 2006 and 2007, using RBS ropes of 2.67 and 5.34 kN respectively. The ropes were fishable in some areas and fishers were receptive to the concept. As an aside, using RBS ropes may reduce the chance that gear would be dragged if snagged by a whale, or indeed a passing vessel (one of the main reasons gear is lost in the United States fishery). This would make retrieval location easier to estimate, in all likelihood being close to the deployment location.

However, they concede that RBS ropes may not be feasible for fishing in some areas, and recommend that other mitigation techniques such as rope-less fishing, should be considered in these areas.

In 2014, the United States Government announced a vertical line rule as part of the ALWTRP, which specified a maximum breaking strength of vertical line in some areas (998 kg or 680 kg depending on the area) and that vertical lines be made of negatively buoyant line (NFMS 2014a). As this rule only came into effect in 2015, it is too soon to definitively tell whether it has had any effect on entanglement rates. Experts report there continue to be serious and lethal entanglements of large whales since 2014, and possibly no reduction in those numbers (Robbins, pers. comm. 2017).

5.6.2 Gear modification – reduction of vertical line

Pot and set net fisheries currently require a certain amount of rope in the water column, between the submerged fishing gear and surface buoys, or at the surface. This part of the line remains a serious entanglement risk to all large whales (Johnson et al. 2005; Knowlton et al. 2012). The reduction of slack rope in the water column is a measure employed to decrease the risk of contact and entanglement (Leaper 2016).

Negatively buoyant line/sinking groundline

Negatively buoyant groundline is a primary mitigation measure used in United States fisheries. The purpose behind the use of negatively buoyant line is to reduce rope slack in the water column, in which whales may become entangled.

In the United States, the 'ground line rule' was a contentious rule introduced in 2009, mandating all ground lines (joining strings of pots or gillnets together) must be negatively buoyant, effectively removing them from the water column (NMFS 2009).

A subsequent study of pot-setting in Canada (where fisheries used 'regular' buoyant line) found that groundlines were generally found <3 metres from the sea bed (Brilliant and Trippel 2010). This height was deemed as a conservative threshold to entanglement for northern right whales. The results of this study suggest that reducing the buoyancy of groundlines would have a small, but likely insignificant effect in reducing entanglement rates of northern right whales, but that more research into right whale behaviour/proximity to sea bed was required before a definitive assessment could be made. A limitation to this study is that the 3-metre height considered a 'threat' to northern right whales (which they deem conservative) requires further behavioural research to be substantiated. However, Brilliant and Trippel's (2010) suggestion that making groundlines negatively buoyant might have little to no effect on entanglement rates is consistent with the reports that mitigation measures in the United States have been largely ineffective at reducing entanglement rates, and rather the severity of entanglements is increasing (Knowlton et al. 2012).

Negatively buoyant line has more recently been mandated in vertical lines as well as groundlines (NFMS 2014b). As this rule only came into effect in 2015, it is too soon to definitively tell whether it has had any effect on entanglement rates. Experts report there continue to be serious and lethal entanglements of large whales since 2014, and possibly no reduction in those numbers (Robbins, pers. comm. 2017).

Western Australia Code of Practice for Reducing Whale Entanglements

In Australia, the West Coast Rock Lobster Managed Fishery's Code of Practice focuses on gear modifications that reduce the amount of rope at the water's surface. These modifications are compulsory between 1 May to 31 October every year, which coincides with the peak migration period of humpback whales along the coast. Most entanglements of humpback whales off the West Coast of Australia occur during the northern migration, when whales migrate in deeper offshore waters than the more coastal route of the southern migration (Groom and Coughran 2012, How et al. 2015).

The Code of Practice requires ropes greater than 32.9 m to be negatively buoyant at the top 1/3 of the pot line (WRLC 2016), which reduces slack line at the surface similar to the method of 'dog boning' excess line (coiling and tying the excess line at the surface). The float rig at the surface must be less than 9.1 m in length, and the maximum length of pot line must be no more than twice the water depth.

When the line is less than 32.9 m total length, surface rope is permitted with no maximum float rig length, although the gear may only have a maximum number of two surface floats (WRLC 2016). A reduction of slack rope at the surface may be done voluntarily via 'dog boning'.

Anecdotal reports are that the Code of Practice has successfully reduced the incidence of whale entanglements since 2013 (How, pers. comm. 2017), but the effect of the Code of Practice over multiple, varying migration seasons is yet to be determined.

The NZRLIC has published a set of recommendations to New Zealand rock lobster fishers, suggesting practices that reduce the risk of whale entanglement (NZRLIC 2016). These recommendations are a replicate of the West Coast Rock Lobster Industry's Code of Practice (WCRLF 2016).

Rope-less fishing (remote releases)

Another way of reducing slack rope in the water column is to eliminate it entirely while fishing pots are in situ.

The use of acoustic or anode releases has been proposed and trialled on a very limited basis in Australian fishers in Western Australian and New South Wales (How et al. 2015 and FRDC 2012/504 (unpublished), respectively). While promising in theory, field trials of remote releases in Western Australia have been limited to a small number of pots deployed, despite remotely-released pots being made available for fishers to trial. Uptake was low with fishers due to fears of gear loss, as well as the expense associated with this type of gear (How et al. 2015). Further trials in New South Wales may also shed some light on the feasibility of using acoustic releases to achieve rope-less fishing. The FRDC Project 2012/504 "*Tactical Research Fund: industry-extension of acoustic release technology for at-call access to submerged head-gear in the New South Wales rock lobster fishery*" is expected to be published mid-2017. However, it is important to note the fishing gear used in New South Wales is likely to vary to that used currently in New Zealand waters.

Recent developments in rope-less fishing technology have also been undertaken in the United States, by the Consortium for Wildlife Bycatch Reduction. A final report on rope-less fishing technology development submitted by Partan and Ball (2016), details the trails of three prototype systems intended as a contribution towards evaluating the potential of rope-less fishing in the Gulf of Maine offshore lobster fishery. The prototypes were designed to be compatible with existing setups and equipment aboard offshore fishing vessels. These prototypes all used a timer with a release time set by the user, aiming to be more cost-effective than acoustic releases, and more reliable than anode releases. Partan and Ball (2016) also conducted preliminary investigations into passive acoustic detectability of the gear, as without buoys at the surface, gear conflicts with other gear in the water may occur. The prototypes were produced at a cost of approximately US$13,000 each, however this cost is expected to significantly reduce under larger-scale production (Partan and Ball 2016). The next phase of the project is dock testing, followed by sea trials (Partan and Ball 2016).

5.6.3 Gear modification – coloured rope

Some recent effort has focussed on assessing the visibility of fishing gear to large whales. Kraus et al. (2014) have been examining the feasibility of enhancing the visibility of ropes and nets to improve their detection by feeding whales. They conducted laboratory trials, which showed the visual sensitivity of right whales is tuned to perceive red and orange as high contrast 'black' against the ambient blue/green oceanic background (Kraus et al. 2014). They then constructed rope 'mimics' (1-inch PVC pipes designed to look like vertical rope but shatter if a whale comes into contact with them), in four colours: green, black (green and black ropes are commonly used for fishing in that area), red and orange.

Kraus et al. (2014) found right whales detected red and orange coloured rope mimics at greater distances than the black and green mimics. The authors acknowledged that further research was required in order to examine the effect of different rope colours while considering potential confounding variables such as distance and underwater visibility (Kraus et al. 2014), and the applicability to other whale species. Preliminary gear trials with local fishermen (in partnership with the Maine Lobstermen's Community Alliance), were to be undertaken to test the feasibility of changing rope colours, by examining the rope handling and fishing characteristics of the red/orange gear (Kraus et al. 2014). Work on the feasibility of this mitigation measure is ongoing (Robbins, pers. comm. 2017).

5.6.4 Acoustic deterrents

Another approach to reducing entanglement occurrence is to change the behaviour of bycatch species around fishing traps/pots or nets. The use of acoustic deterrents, particularly 'pingers', has become a common mitigation technique in several fisheries to deter small cetaceans. Dawson *et al.* (2013) reviewed the use and effectiveness of pingers on small cetaceans and found varying levels of success. Results for different species, areas and potentially even different individuals can be variable and difficult to predict (Childerhouse et al. 2013). Erbe and McPherson (2012) modelled the acoustic output and sound propagation of pingers in Queensland, Australia, and found that the pingers tested would be detectable by all species examined. They noted, however, that detection of pingers would not necessary result in a behavioural response.

Few studies have investigated the behavioural effects of acoustic deterrents on large whale species. Studies conducted on the east coast of Australia on migrating humpback whales have had mixed results. Dunlop et al. (2013) reported that humpback whales showed a behavioural change in response to a broadcasted tonal stimulus; where groups of whales were found to move offshore and surface more often, suggesting an aversion to the sound. However, more recent studies conducted by Harcourt et al. (2014) and Pirotta et al. (2016) suggest that the whales in their studies were not deterred by either an 'off-the-shelf' whale alarm producing a simple tone of 3 kHz for 400 milliseconds every 5 seconds, nor by more complex 'upswept' acoustic signals that were well within the acoustic range of the species. Further, they found that neither acoustic signal was an effective deterrent for humpback whales (Harcourt et al. 2014, Pirotta et al. 2016). The humpback whales in Dunlop et al.'s 2013 study were, however, on their southbound migration while Harcourt et al. (2014) and Pirotta et al. (2016) studied humpback whales during the northbound migration. Whales on each migration may display different behaviour: southbound new mothers with calves may be more cautious than mature, competing animals on route to the breeding grounds (Pirotta et al. 2016). Preliminary analysis of the effectiveness of pingers in Western Australian waters on southbound humpback whales also found no difference in the proportion of whale pods interacting with a pinger array due to pinger status (on or off) (How 2015).

A study currently underway in Alaska by Kate Wynne aims to evaluate the potential effectiveness of pingers for reducing net entanglements of large whales (IWC 2015). The results of this study will likely provide further information into pinger effectiveness for large whales.

As well as the uncertainty of pingers causing an avoidance response in large whales, one of the main issues involved with the use of acoustic deterrents for any marine mammal is the chance of habituation, where the behavioural response of animals lessens over long-term exposure. There are concerns that for some species, acoustic deterrents may act as a 'dinner bell', where the deterrents are associated with an easy source of food (Berggren et al. 2009, Carretta and Barlow 2011).

There is also potential for pingers to increase noise pollution in the marine environment. Testing and determining the minimum number and spacing of pingers needed to reduce bycatch should assist in reducing noise from pingers insofar as possible. Using more pingers than required will not only increase noise pollution unnecessarily, but could greatly increase overhead costs to fisheries and affect practicality (Northridge et al. 2011, Larsen et al. 2013). Tests of a louder acoustic device on small cetacean bycatch in the UK (Northridge et al. 2011) have appeared effective in terms of reducing the number of devices needed, however, whether overall noise pollution has been decreased remains unclear.

Pingers also come with associated costs for fisheries, particularly when used extensively. These devices are relatively expensive to initially setup and maintain, and even trials of devices can be cost prohibitive. This is particularly the case for fisheries with relatively low bycatch rates, as a large number of sets would be required in order to gain sufficient statistical power to determine effectiveness (Dawson et al. 2013).

Acoustic deterrents show promise for small cetaceans that are neophobic and have large home-ranges (Dawson et al. 2013), however, their effectiveness has not yet been demonstrated for large whales and there are many potential risks and costs associated with their long-term use that have not been fully explored.

5.6.5 Management response – reduction of vertical lines in the water column

As part of the ALWTRP, from 2015 the National Marine Fisheries Service (NMFS) in the United States restricted the number of vertical lines in the water by prohibiting single trap/pots and requiring fishermen to increase the number of traps per trawl (NMFS 2014a). NMFS acknowledged in some areas this may represent a change from current fishing methods.

This mitigation measure is only feasible for industries that fish with more than one pot/trap per line. As this rule only came into effect in 2015, it is too soon to determine whether it has had any effect on entanglement rates. Experts report there continue to be serious and lethal entanglements of large whales since 2014 and possibly no reduction in those numbers (Robbins, pers. comm. 2017). Assessments are ongoing (Robbins, pers. comm. 2017).

5.6.6 Management response – spatial or temporal closures

In Australia, the Western Australian rock lobster fishery season was expanded first by a reduction in the period of the closed season in 2010/11 and then in 2013 by opening the fishery to a year-round operational period. These actions corresponded with a measured increase in entanglement incidents from 2011 (How et al. 2015). In their assessment, How et al. (2015) acknowledge this increased interaction between whales and the fishery, and suggest that temporal and seasonal closures would be highly effective in completely eliminating whale entanglements. They also stated that such closures would cause a significant economic impact on the commercial fishery (~$50-100 million Australian dollars). This conflict between socio-economic concerns and ethical and environmental impacts represents the crux of the issue facing policy-makers on whale-fisheries interactions (Moore, 2009). How et al. (2015) suggest that, given whales do not occupy the entire Western Australian coast for the duration of the migration season, that there is the potential to institute closures (temporal and spatial) during the migration that protect areas and times of higher potential interaction and permit fishing during low risk times or areas, reducing the cost of closures to fishers.

Others, however, have hypothesised that temporary fishery closures may have the opposite socio-economic effect than one would initially expect. Myers et al. (2007) compared the effort and take of two fisheries in adjoining areas of the Gulf of Maine: the United States side (state of Maine) and Canadian side (Lobster Fishing Area 34). While the Maine fishery had approximately 30% higher catches than LFA 34, it has a year-round season (compared to LFA34's 185 days), and 8-9 times more traps in the water at any given time. The greater fisheries take in Maine is not, therefore, in proportion to the relative effort expended by the Maine fishery compared to RLA 34, which was calculated by Myers et al. (2007) to be four times greater than required in order to obtain maximum biological yield. They assert that a reduction in effort in these fisheries would allow for a build-up of biomass and greatly reduced operating costs. Reducing the season would deliver savings in fuel, bait and labour; and these savings, in addition to the negligible difference in yield, would actually increase net economic returns while reducing risk to whales (Moore 2009).

In situations where whales are only present in an area for a limited and predictable period each year, planned seasonal closures can be effective (Leaper 2016). For example, in New England (United States), the National Oceanic and Atmospheric Administration (NOAA), introduced a seasonal closure for all trap/pot fisheries for the Massachusetts Restricted Area from January 1 to April 30, which is the main feeding season for North Atlantic right whales in the area (Leaper 2016). However, given that crude whale entanglement numbers have not decreased, seasonal restrictions and closures in the western North Atlantic region, instigated as part of the ALWTRP, have shown no great sign of effectiveness in that region (van der Hoop et al. 2012, Pace et al. 2014, Knowlton et al. 2015). More recently, the Massachusetts Restricted Area was modified, to begin later, on February 1 2015, but the area was expanded by 912 square miles (NFMS 2014b). The action aimed to decrease the number of affected vessels, resulting in reductions in compliance costs while maintaining the same entanglement risk reduction (NFMS 2014b).

When implemented in a manner that adequately covers the times and locations of importance to a whale species (e.g. timing of migration, calving grounds etc.), temporal and spatial closures may be very effective tools. Failure to properly assess a species' use of an area will likely undermine the capacity of temporal and spatial tools to mitigate against entanglement.

5.6.7 Management response – disentanglement

Disentanglement is a valuable mitigation tool for documented entanglement events, proving effective in Australia, Canada, South Africa, Mexico, New Zealand and the United States. In 2011, the International Whaling Commission established an Expert Advisory Panel on Entanglement Response, followed by the establishment of the Global Whale Entanglement Response Network.

The South African entanglement response network has successfully disentangled 23% of confirmed entangled individuals, with the Sharks Board managing to release 81% of entangled whales (Meyer et al. 2011). The Mexican disentanglement network has successfully disentangled 38% of reported entangled whales (RABEN 2017). In Western Australia, between 1995 and 2010, over a third of reported entanglements were successfully disentangled (Groom and Coughran 2012). However, over a third of disentanglement efforts in Western Australia were not successful due to: rough seas making efforts too dangerous or impeding sightings; the reporting vessel not standing to maintain observations of the whale; and an inability to respond fast enough (Groom and Coughran 2012). The fate of the whales in such circumstances remains unknown (Groom and Coughran 2012).

In recent years, disentanglement teams in New Zealand have been trained to the highest international standard of safety and best practice. Australian and New Zealand members/responders are trained by Doug Coughran, whom after retirement from the Western Australia Government, continues to work with the IWC on entanglement issues. The results in New Zealand are similar to those of South African and Australian disentanglement networks, with 28% of reported entanglements successfully disentangled, and 33% of whales with fate unknown (see Section 5.2.5).

The disentanglement process

The initial phase of disentanglement involves assessing the whale's condition and entanglement as well as other factors such as environmental conditions and potential obstacles to disentanglement operation (Coughran 2016; IWC 2016).

The principal disentanglement technique used worldwide is a modification of an old whaling practice called kegging. This involves attaching large floats, or kegs, to the gear entangling the animal. The floats add buoyancy and drag to the animal, making it difficult for it to dive, eventually tiring it out. The aim of kegging is to tire the whale such that it becomes relatively immobile, remaining close to the surface enabling responders to safely and effectively remove the entanglement (Coughran 2016, CCS 2017). An additional benefit of kegging is that it may increase drag on the entangled gear, and under some circumstances even free the whale of the entanglement (Coughran 2016).

Another technique used increasingly is the use of telemetry buoys on entangled whales (AMMC 2017). The telemetry buoy is designed primarily to allow operational personnel to track an entangled whale if conditions are not ideal to attempt an immediate disentanglement response, such as during poor weather or light. The telemetry buoy can also be deployed to allow time for a disentanglement strategy to be developed or if there are multiple incidents at the same time. The buoys are equipped with a satellite tag and VHF transmitter, to allow remote tracking of the entangled animal. The use of these buoys gives the disentanglement team greater opportunities to intercept and disentangle the affected whale, with the added bonus of giving gear increased drag, which may help the animal shed the gear without further intervention. It should be noted, however, that the use of these buoys is very much a short-term strategy.

Pros and cons

The primary benefit of disentanglement is the obvious one – the implicit benefit of saving lives of individual whales of any species. Disentanglement is particularly valuable as a conservation tool when disentangling/saving the lives of critical members of a threatened population. There are also ethical/animal welfare considerations of reducing the suffering and distress of wild animals incurred by anthropogenic causes – indeed some governments are legally obligated to reduce the impact of permitted activities on non-target species (e.g. Australia and United States). In addition, there are public relations benefits for government and industry in having a pro-active approach to the issue of entanglement.

Disentanglement also assists in gathering information that may help to minimise future entanglements. Gear collection and analysis is a critical part of identifying entanglement causal effects, and through analysis, contributing to the development or enhancement of entanglement mitigation measures. In addition, for many countries, part of the rationale behind entanglement response is to prevent fishers and/or members of the public from harming themselves by intervening when an entanglement event is observed (IWC 2011).

While the efforts of disentanglement teams have saved the lives of many whales around the world, in terms of a mitigation option, it should be noted that this technique is reactionary, rather than preventative (Knowlton and Kraus 2001). Successful disentanglement should not be assumed to result in certainty of a whale's survival (Robbins and Mattila 2004). Disentanglement should not be considered a long-term solution to the issue of entanglement (Knowlton and Kraus 2001; Knowlton et al. 2012, IWC 2014), but rather as a stop-gap solution until effective preventative measures are developed (Moore et al. 2013).

Disentanglement activity is also extremely dangerous for the people involved. In the 2000s, many human deaths were associated with disentanglement activity or proximity to whales, including in New Zealand (IWC 2012). These tragic events led to the establishment of Standard Operating Procedures and best practice guidelines for trained entanglement teams (Coughran 2004; Coughran 2016; IWC 2012), which stress that, at all times, human safety is paramount in any disentanglement operation.

6. Discussion

Whale entanglement in pot/trap lines and set nets is a problem facing governments and fisheries worldwide. In some areas, such as the North Atlantic, whale entanglements are a significant threat to whale populations; while in others, such as South Africa and Western Australia, whale entanglement currently has little to no impact on population recovery. In all cases, however, the ethics surrounding the humane treatment of animals warrants management response: an issue of heightened importance when those animals are protected species.

Underreporting of entanglements has been documented and recognised as a major issue facing whale entanglement management and mitigation practices worldwide (IWC 2011, 2012, Groom and Coughran 2012). There are several factors that may influence the reporting rate of entanglements, including:

1) An entanglement not being observed: due to lack of observer/whale overlap; whales' cryptic behaviour; or gear sightability (e.g. buoys tend to be more visible than other fishing gear) (Robbins and Mattila 2004, IWC 2011, Knowlton et al. 2102; Moore 2014);
2) Perceived dis-incentive by fisheries to report entanglements in some areas due to potential regulatory action (IWC 2011); and
3) Death and loss of the carcass prior to observation and documentation (Knowlton and Kraus 2001, IWC 2011, Groom and Coughran 2012, Knowlton et al. 2012, Berkenbusch et al. 2013). There are many reasons (besides whale/observer overlap) why unobserved live whales are not subsequently observed after death. Some whales, such as blue and fin whales, are negatively buoyant and so will sink quickly after death. Alternatively, positively-buoyant whales, such as right whales, become emaciated after long entanglements and so are

generally lipid depleted, meaning that when they do die, they too are negatively buoyant and sink below the surface (Moore 2014). Smaller whales are more at risk of becoming anchored in gear and drowning due to lack of strength or body mass (Cassoff et al. 2011). It follows that some smaller whales may never be discovered and that fishery gear is simply reported as 'lost' (as initially occurred in New Zealand with a juvenile killer whale in 2015).

Knowlton et al. (2012) highlight that entangled whales sighted with gear attached represent only those entanglements in which either: the animal survived the initial encounter with gear and was later sighted still carrying it; or a whale carcass was found, reported and accessible for examination. In addition, many whales that become entangled clear themselves of the gear and may be left with only physical scars to indicate an entanglement ever took place (Knowlton et al. 2012, this report). One study has shown that northern right whale entanglement rates based on both scarring analysis and presence of fishing gear on the whales are up to 10 times higher than those calculated by counting only whales observed carrying fishing gear (Knowlton et al. 2012).

Any analysis of entanglement rate, therefore, inherently relies on whales being detected and reported. Results from such studies must be considered as highly conservative; with actual rates of entanglement potentially ten times higher than detected. In management situations where there are uncertainties relating to reporting as well as the potential conservation effects, a precautionary approach to risk management is advisable.

Entanglement data for this report were collected from several sources including DOC, MPI and online media. These data currently represent the best contemporary record of New Zealand large whale entanglements. Online media reports included entanglement events that were attended by DOC or contained direct comment by DOC personnel, but which were not recorded in the DOC sightings or incident databases.

Historical entanglement records of large whale species not held by DOC (reaching back to 1977), were cited in the NZRLIC's '*Whalesafe Identification Guide'* but were not able to be located at the time of publication of this report. While all efforts were made to gather and analyse all documented entanglement events involving large whale species in New Zealand waters, this report is likely an underrepresentation of the incidence of said events. This potential underrepresentation is compounded further by the finding of Knowlton et al. (2012), that actual entanglement events are possibly ten times higher than those observed. Consequently, the entanglement results listed in this report are likely to be highly conservative.

6.1 Entanglement of large whale species in commercial pot/trap and set net fisheries in New Zealand waters

The annual mean number of reported large whale entanglements in New Zealand waters calculated in this report is 1.4 and is most likely to be an underestimate of the actual annual rate of entanglement.

Humpback whales were the species most often entangled in pot/traps or set nets in New Zealand waters, comprising 64% of all documented entanglements. More than half of humpback whale entanglements involved rock lobster pot gear, with set net-related gear comprising a lower, but still significant risk (8% of humpback whale entanglements). The reporting of entanglement events of humpback whales occurred predominantly along the east coast of the South Island, with the vast majority occurring in the Kaikoura region during the month of June. This coincides with the timing and location of the humpback whale northern migration (Gibbs and Childerhouse 2000). Fishing effort data from 2005-2017 also suggests that rock lobster fishing effort along the east coast of New Zealand is higher during the humpback whale northern migration period than during the southbound migration. It is important to note that the location of the entanglement event is where the whale is sighted but that the actual location of the entanglement itself may be far away in time and/or space. For the purposes of this report we have assessed each event around where it has been reported as it the location of entanglement is unknown for most events.

It is important to note that the DOC sightings and incident databases do not specifically identify whether 'rock lobster' or 'likely rock lobster' gear is from a commercial or recreational fishery. While the possible source of gear may be inferred from notes in the 'comments' field of the databases, none of the entanglement records used in this report specifically stated that the gear was commercial. It is a legal requirement that rock lobster gear be marked with sufficient information so that the owner can be identified. It seems feasible that if the rock lobster gear involved in an entanglement includes the contact details of the owner that this information can be recorded at the time and added to the DOC databases in order to at least identify whether a commercial or recreational fishery was involved.

For the purposes of this study all entanglements associated with 'rock lobster' or 'likely rock lobster' gear have been assumed to relate to commercial fisheries as no information from each event has suggested that non-commercial gear has been involved but it will still represent a risk for whales.

Set net fishing effort along the east coast of the North and South Islands does not appear to change greatly across the year. This stretch of coastline is an area of significant overlap with the paths taken by humpback whales during their northern and southern migrations. Given this overlap, it is perhaps surprising that set nets and set net ropes were involved in only 12% (3 of 25) of all humpback whale entanglements. One possible explanation might involve the overlap between whales and set net fisheries in New Zealand. Along some parts of the east coast of the South Island there are commercial and recreational set net prohibition extending out to 4 nm. It may well be that either whales are migrating close to the shore and not encountering nets, or alternatively that whales encounter set nets offshore and are not observed as entangled, or a combination of both.

When combined with entanglement data, the annual humpback whale sightings data collected during surveys in the Cook Strait region suggest that entanglements may affect 0.5-2% of humpback whales migrating past New Zealand annually. This estimate must be viewed with caution. It is based on a likely underestimate of actual entanglement rate. It is also likely that sightings surveys in Cook Strait underestimate the number of humpback whales migrating past New Zealand, since whales migrating north may either travel past the east coast of the North Island or through Cook Strait where the sightings survey takes place (Gibbs and Childerhouse 2000).

Killer whales were also commonly entangled in pot/traps or set nets in New Zealand waters, comprising 21% of all documented entanglements. Killer whales were generally entangled along the north coast of the North Island, an area with a moderate to high amount of rock lobster and set net fishing effort. The entanglement of killer whales was spread more evenly across the year, which is to be expected for a resident rather than migratory population, which 'peaks' at certain times of year. Most (5 of 8) documented killer whale entanglements involved rock lobster or 'likely rock lobster' fishery gear, with 2 entanglements involving set nets. Given the small population size of killer whales in New Zealand, the regularity and commonness of killer whale entanglements is of concern. While eight documented entanglements between 1991-2017 may seem low, Read (2008) suggests that in small populations, bycatches (in this case entanglements), are rare events. The rarity of such events hampers the ability to prevent them and it may even be difficult to persuade stakeholders that entanglements take place (Read 2008).

The behaviour of killer whales likely plays a role in their entanglement. Anecdotally, killer whales are known to rub themselves against rock lobster buoylines (Morrissey, pers. comm. 2017), a behaviour which would significantly increase their risk of entanglement. Once entangled, younger and smaller individuals would likely succumb sooner than stronger, larger adults. In one documented entanglement in New Zealand, a fisherman failed to locate a lobster pot while fishing, assuming the float to have been cut off by a passing boat. Five days later he relocated the pot, which was securely fixed to the tail stock of a dead and decaying juvenile or young male killer whale. The killer whale likely drowned shortly after becoming entangled.

Other whales, such as southern right, blue and minke, were rarely documented as entangled in New Zealand between 1984-2017, with 3 (1 x set net rope and 2 x RL pot), 1 (unknown rope) and 1 (set net) entanglements recorded respectively. There was also a single 'unknown baleen' whale documented in MPI fisheries observer data as entangled in a set net, but there was no corresponding information on species or location. It does appear from the data that the whale was released from the net, but the extent of the entanglement, and how this animal was released, was not documented. Little is known about the abundance and distribution of most of these species in New Zealand waters.

In terms of risk management, while New Zealand populations of humpback whales and southern right whales are smaller than those found elsewhere in their global distribution, the risk to each of these populations from entanglement events is currently Low. Due to their smaller population size, however, the risk of entanglement to the killer whale population in New Zealand waters is determined to be Medium. The risk of entanglement to an individual whale is Medium, and when it occurs, often results in severe injury or death. The individual animals at greatest risk of entanglement are humpback whales on their northern migration along the east coast of the South Island, especially in the region of Kaikoura and during the month of June. This timing and location coincides with a high level of rock lobster fishery effort.

The recovery of whale populations is likely to lead to more frequent interactions with fisheries and heighten the need for adequate mitigation methods (Meyer et al. 2011). New Zealand's populations of southern right whales are slowly increasing (Carroll 2013a), while humpback whale populations have also recently begun to show signs of increase (Bott, pers. comm. 2017) from having no trend in abundance in 1999-2005 (Constantine et al. 2012). With increasing interactions between whales and fisheries, there is increasing risk, not only to individual whales but to stakeholders such as DOC, fisheries, and whale watching operators.

The level of risk to New Zealand stakeholders associated with the entanglement of large whale species is currently Low. Risk level may increase, however, if the incidence of whale entanglements, particularly lethal entanglements, increases.

Risks to fisheries currently relate to public perception and public relations at the lower levels of consequence. If the severity level of entanglements increases, however, this may lead to some financial risk.

The current risk to DOC is similarly focussed around public perception and public relations, but also on the safety of individuals responding to entanglements. Recent media reports have suggested the public are becoming increasingly frustrated with seemingly delayed responses by DOC to reported entanglements (Flahive 2016, Yalden 2016). Regardless of whether this delay in response time is real or perceived, it is causing people to take matters into their own hands and put their own lives at risk. This will likely continue to occur and may be assuaged by some form of public awareness campaign. Should entanglement rates increase, the risk to DOC potentially shifts to become an increasing financial/personnel burden, as well as increased public scrutiny and potential for injury. At the worst-case scenario, there is increased potential for injury or loss of life/lives.

The current risk to whale watching operators around New Zealand is deemed to be Low and is unlikely to change markedly unless entanglements increase significantly. Whale Watch Kaikoura is perhaps the operation with the greatest geographical overlap and observation of entanglements involving large whales. Given that sperm whales are the focal species of Whale Watch Kaikoura, and no records of entanglement in set net or rock lobster pot fisheries were located for this species, the risk to this operator is negligible.

6.2 Mitigation

The most preferable mitigation options are those that prevent or reduce the incidence of entanglement (IWC 2014). The current absence of proven mitigation techniques, however, means that monitoring incidences of entanglement and developing solutions to the issue (such as releasing entangled whales), goes some way to serving both animal welfare and conservation management concerns (Meyer et al. 2011).

The efforts of the ALWTP have failed to reduce entanglement incidence or severity for humpback and right whales in the North Atlantic, with several studies asserting that these changes have had little to no effect at the population level (Moore 2009, Knowlton et al. 2012, Pace et al. 2014, Knowlton et al. 2016). In fact, some evidence suggests that incidents of entanglement have increased over the last decade while these measures have been in place (Knowlton et al. 2012, Pace et al. 2014). Since multiple measures were implemented concurrently, it is difficult to determine the relative effectiveness of individual gear modifications such as weak links or sinking groundline. When taken together, it appears that the measures of the ALWTRP (weak links, sinking groundline, temporal and spatial restrictions etc.), have not been effective, and have been implemented at great cost to fisheries (Moore 2009). Moore (2009) suggests that the government mitigation methods were undertaken without adequate attempts to scientifically model proposed changes in the laboratory and in the field before they were implemented.

Decreasing rope strength and decreasing the number of lines in the water column were promising developments implemented by the ALWTRP, but it is too soon to establish whether these measures have been effective (Robbins, pers. comm. 2017).

More recently, there has been promising research on rope colour providing a visual cue to whales to avoid entanglements (Kraus et al. 2014). It appears that northern right whales have a 'black and white' visual scale with peak visual sensitivity in the blue range; they see the oceanic background as bright, and colours they are not sensitive to (such as red or orange) appear as high-contrast 'black' objects. Kraus et al.'s (2014) field trials indicated that changes in colour can affect the distance at which right whales can detect ropes under water. Whether these results would translate to other baleen whale species remains to be seen. Also, it is still uncertain whether entanglement occurs because animals fail to detect gear, or whether they simply do not regard fishing gear as a threat (Childerhouse et al. 2013). For instance, both killer whales and humpback whales are known to rub themselves against pot lines (Morrissey, pers. comm. 2017), and increasing the distance at which these animals can see lines may not reduce entanglement rates for that species.

The strength of a rope has been correlated with entangled species and age (Knowlton et al. 2016). Stronger ropes are found more frequently on larger and older whales. Reduced breaking strength ropes have been used as a mitigation tool in some fisheries in the United States since 2015, their efficacy is yet to be determined.

Rope-less fishing is also a mitigation method currently under development, but at this stage there are no published results of the logistical- and cost-effectiveness of the broad application of this technique. The prototype units used to date, regardless of whether they utilise acoustic or timed releases, are currently expensive and have been deemed as cost prohibitive in at least one fishery (How et al. 2015).

The IWC Global Whale Entanglement Response network is well organised, and partnering countries share research, new techniques and training freely. Disentangling whales is generally successful once operations begin, however there are limitations to initiating operations: whales are often not relocated after an initial sighting, or weather or environmental factors such as darkness often prohibit operations (Groom and Coughran 2012, RABEN 2017). Disentanglement also comes with inherent risks to personnel as well as costs to local governments.

Disentanglement is an effective tool for mitigating documented entanglements. It is, however, an ambulance at the bottom of the cliff'. While efforts to disentangle whales are admirable and undoubtedly beneficial for a majority of the individual whales involved and populations considered 'at-risk', they do not reduce the incidence of interactions between whales and fishing gear. Without other mitigation measures in place, whales will continue to become entangled, gear (and catch) will continue to be lost. Some studies have shown the daily energetic costs of entanglement are comparable to energy demands during life-history stages such as pregnancy and migration (van der Hoop et al. 2016), meaning that even if successfully disentangled, these whales carry energetic costs of entanglement for some time, even after short-term entanglements.

6.2.1 Applicability to New Zealand fisheries

In terms of preventing entanglements in New Zealand, the single most effective mitigation measure would be seasonal closures of some fisheries during the humpback whale migration period. The financial cost to fisheries and the New Zealand economy, however, would be significant. The New Zealand rock lobster fishery is well-managed, with stocks performing well (with one exception in the Bay of Plenty). In addition, the periods of highest market/consumer demand correspond to the migratory seasons of whales. The set net fishery targets a variety of species around the entire coast of mainland New Zealand, including within harbours. The peak season for set netting and the fishing methodology used varies depending on the target species. Without data identifying a particular set netting fishery as responsible for a significant proportion of entanglements (which the DOC and MPI data sets supplied for this report do not do), seasonal closures to set netting would likely be a blunt instrument. To close a fishery when there are on average 1-4 reported entanglement events per year (IWC 2012, Morrissey, pers. comm., this study) is, at this stage, an extreme measure.

Should the incidence of entanglements increase, seasonal closures in areas of high incidence may need to be considered. For instance, from 1984-2017, 28% (11 of 39) of documented entanglements occurred in the area around Kaikoura during the humpback whale northern migration period (May-August). If this continues to be an area of relatively high entanglement incidence, and crude entanglement numbers increase due to population recovery, seasonal restrictions covering the peak entanglement period (June from this study's data, n=8 entanglements), may significantly reduce entanglement rates. However, while most reports are from the Kaikoura area (as there is a high search effort), it is not clear if most entanglements actually occur in this area and therefore any closures in the region may be ineffective. For now, seasonal, mandatory gear modifications, or seasonal effort restrictions would be a more measured approach, and one that the fisheries may be more open to, considering many such measures are already recommended by the NZRLIC.

The gear modifications put in place in Western Australia by Western Australia Fisheries and the West Coast Rock Lobster Council are highly applicable to the New Zealand market, especially given that the NZRLIC's '*Whalesafe Identification Guide'* has already recommended these measures to their fishers (Section 5.1.4). The results of the Western Australia mitigation measures, whilst anecdotally promising, have not yet been quantified.

Interestingly, one of the outcomes of the '*Whalesafe Identification Guide'* is a sightings application called 'OceanSnap', which aims to compile marine mammal and seabird sightings information, but also provide a tool by which fishers may be alerted to whales in their area of operations (Sykes, pers. comm. 2017). The uptake and effectiveness of the application as a mitigation tool has yet to be determined. Similarly, the uptake and effectiveness of the recommendations given to fishers to minimise risk of entanglement remains to be seen. Regardless, it is commendable that the fishery has taken a pro-active approach aiming to increase awareness of its members and potentially minimise whale entanglements.

Mitigation measures proposed in New Zealand will have the best chance of success if relevant stakeholders are engaged and involved from the outset. It is important to note that without the assistance and input of fisheries, gear modifications cannot (or will not) be trialled and rolled out to fishers. Mitigation methods must be financially viable either in outright costs to fishers, or through government subsidies (such as gear buy-back schemes). The Bycatch Reduction Engineering Program in the United States is a good example of government agencies and fisheries working together, aiming to achieve a positive outcome for both the whales and the fishery.

Disentanglement efforts are highly effective in New Zealand, and will continue to be a vital mitigation measure until effective preventative measures are developed. In addition, the collection of entanglement gear by the disentanglement network is invaluable; analysis of the gear collected from entangled whales provides vital information regarding the nature of the entanglement process and help identify the fisheries involved. All disentanglement events inherently include an element of risk to personnel. Safety of people must always be paramount.

6.3 Recommendations

While there is no proven single method for mitigating large whale entanglements that is appropriate for all locations and at all times, there are ways to reduce risk in practical, cost-effective terms until effective measures are developed. These include:

- Minimising slack rope likely reduces the risk of entanglement and is an appropriate interim mitigation method until other methods are further developed and ground-truthed.
- Conducting observations of the use of NZRLC's 'OceanSnap' application and if/how this consequently results in fishers moving/removing gear in instances when whales are sighted.
- Developing or purchasing entanglement buoys similar to those used in Western Australia may help relocate entangled animals when weather, logistics or availability hamper the disentanglement effort.
- Conducting public education campaigns about the New Zealand disentanglement network to decrease likelihood of people taking matters into their own hands. Similarly, increased funding or training for DOC's phone operators to reassure callers their call has been attended to and that DOC is responding.
- Training of additional personnel (within and outside of DOC) as part of the New Zealand disentanglement network. Ideally such personnel will have existing sufficient vessel and whale experience so that they understand both the marine environment and animal behaviour.

While a seasonal closure seems like a blunt tool, a more appropriate mitigation tool might be a advocacy campaign that targets fishers around the Kaikoura region and along the south east coast of the South Island during the months of May-August. This would coincide with the northern migration of humpback whales and encompasses the peak period of large whale entanglements. Any mitigation will require early and genuine consultation with commercial fisheries, especially rock lobster.

The limited data available on large whale entanglements and interactions with fisheries has necessarily resulted in a high-level analysis of information. In compiling this report, many knowledge-gaps have been identified. The following recommendations are made in order to increase New Zealand's knowledge and ability to appropriately mitigate the entanglement of large whale species in commercial pot/trap lines and set nets:

- Conduct an audit of all internal DOC entanglement-related records and collate the results. This study found evidence of data gaps in the DOC databases. It is generally accepted that entanglements are inherently underreported, but having data of identified incidents missing adds an additional layer of uncertainty to fundamentally conservative data. In order to adequately assess the extent, or trends of, entanglement in New Zealand in the future it is vital that entanglement records be as accurate as possible.
- Enhance data reporting protocols for entanglement events. At least 21% of documented large whale entanglements were associated with gear from an unknown source (i.e. 'unknown rope,' or 'unknown' gear), but for over half of these incidences, the gear type (such as rope or net) was never actually recorded in the databases. It is suggested that in all instances of entanglement, DOC should develop and instigate a clear, consistent classification system whereby gear type is specifically listed (including differentiating between commercial and recreational gear, where possible). For example, if the gear was viewed/collected and unable to be identified to a source, a classification such as 'unknown net- source unidentifiable' may be appropriate. Similarly, if gear was never definitively sighted, enter a term such as 'unknown gear- not sighted'. This would allow more robust examination and assessment of entanglement causal sources in the future.
- Conducting scar-based studies would help quantify the extent of the entanglement problem for whales migrating past New Zealand. Studies such as those conducted by Jooke Robbins in the Gulf of Maine have documented the incidence and long-term trends of humpback whale entanglements in that area. The caudal peduncle has been shown to be often involved with entanglements for humpback whales in New Zealand and elsewhere (Robbins and Mattila 2004, Johnson et al. 2005, Morrissey, pers. comm. 2017) and it is a relatively easy part of the whale to photograph consistently (Robbins and Mattila 1999, Neilson et al. 2009). A similar scar-based detection technique has also been used to successfully assess entanglement rates for northern right whales (Kraus 1990, Knowlton et al. 2012). While the known population of New Zealand humpback whales is small, with few resights between years, even a single year of data would be useful in order to assess the prevalence of entanglement (similar to Neilson et al.'s 2009 study), and would provide a baseline for any future studies examining trends in entanglement rates.
- Determining sex via DNA analysis may be useful in order to help inform impact on particular demographics, or particular risk, as well as add to the data informing population dynamics of other genetic collections. The logistics and ethics of collecting a biopsy sample from an already stressed animal requires careful consideration.
- Monitor (or assist with), the global development of fisheries gear modifications focused on lowering the rate of whale interactions with fisheries.

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Appendix 1: Summary table of large whale entanglement mitigation literature

No	Mitigation Measure	Source	Region of Interaction	Gear configuration	Target fish species	Bycatch species	Outcome	Level of efficacy	Level of scientific rigour	Caveats or uncertainties in methods
1	Reducing rope strength	Knowlton, Robbins et al. 2015	North Atlantic	Various	Various	Baleen whales	Asserts that reducing rope strength to that which is still practicable for fisheries operations but allows entangled whales a better chance of breaking free.	Theoretical / feasibility study	Theoretical / feasibility study	Reduced break strength ropes would not reduce the number of encounters between whales and gear and may not prevent lethal entanglements in some areas such as calving grounds.
2	ALWTRP	Pace, Cole and Henry 2014	North Atlantic	Pot	Various	Large whales	Asserts that the ALWRP were generally ineffective in abating whale deaths from entanglements in fishing gear. Entanglement rates increased between 1999-2009, but evidence for increased rates of entanglement-related mortality were equivocal.	Modelling entanglement rates	Model	Limited observations for some species.
3	ALWTRP	Van Der Hoop et al. 2012	North Atlantic	Various fisheries and including ship strike	Various	Large whales	Shows increasing mortality trends associated with entanglement and vessel strikes despite regulatory efforts to reduce these risks.	N/A - is analysis of cause of mortality		
4	Reduced fishing effort- seasonal closure	Myers et al. 2007	North Atlantic	Effort	Lobster	Right whales	Suggests seasonal closures would reduce CPUE, and allow biological build-up of target species. Operational costs would also be reduced.	N/A - theoretical study	Theoretical study	Doesn't say how they come up with the numbers for reduced effort=more lobster catch
5	Acoustic deterrent	Harcourt et al. 2014	East Australia	Fixed mooring with surface float 1.3 km offshore East Australia during peak migration in June-Aug	N/A	Large whales	No evidence of effective deterrence of northerly migrating humpback whales.	Off-the-shelf-pinger used-single tone 3 kHz, 400 ms repeated every 5s.	No evidence of effective deterrence	These were adults and near-term pregnant females on northward migration.

No	Mitigation Measure	Source	Region of Interaction	Gear configuration	Target fish species	Bycatch species	Outcome	Level of efficacy	Level of scientific rigour	Caveats or uncertainties in methods
6	Acoustic deterrent	Pirotta et al. 2016	East Australia	Fixed mooring with surface float 1.3 km offshore East Australia.	N/A	Large whales	No evidence of effective deterrence of northerly migrating humpback whales.	Used a higher frequency tone than the 2014 study (5.3 kHz) and a more complex, upswept tone (2.0-2.1 kHz)	No evidence of effective deterrence	These were adults and near-term pregnant females on northward migration.
7	Acoustic deterrent	Erbe and McPherson 2012	East Australia	Modelled efficacy of pingers on shark nets.	Shark	Various – humpback whales, dolphins, dugongs	This was a feasibility study modelling outputs and feasibility of pingers as bycatch mitigation of shark nets.	Fumunda pingers were detectable by all target species and were installed at an appropriate depth (6 m) and spacing (every 67-100 m) to highlight the net to all animals travelling either parallel or perpendicular to the net.	Feasibility study of pinger performance and audibility.	No prediction of animal behaviour.
8	Acoustic deterrent	Dunlop et al. 2013	East Australia	J11 acoustic projector used as underwater loudspeaker.	N/A	Humpback whales	Groups showed a consistent response to tones, moving offshore and surfacing more often (suggesting an aversion to the stimulus).	Swept tones from 2-2.1 kHz over a period of 1.5s, repeated every 8s for 20 min.	Behavioural response experiment of social (whale) sounds vs tonal sounds.	Southward migrating animals.
9	Reducing line in water column	Johnson et al. 2005	North Atlantic	Various fishing	N/A	North Atlantic right whales and humpback whales	Examined the incidence of different types of gear in entanglements.	Buoy line present in 33% of entanglements when both species combined, Groundline	Good. Some of the percentages are a little unclear.	Published 2005 - before ALRTRP was amended in 2007.

No	Mitigation Measure	Source	Region of Interaction	Gear configuration	Target fish species	Bycatch species	Outcome	Level of efficacy	Level of scientific rigour	Caveats or uncertainties in methods
								16%. 85.7% of groundline entanglements involved floating line.		
10	ALWTRP	Knowlton, Hamilton et al. 2012.	North Atlantic	Pot and set net	Various	North Atlantic right whales	Used photographic evidence to track trends in annual entanglement rate and serious entanglement rate, over 30 years (between 1980-2009). Found that crude and annual entanglement rates did not show an increasing trend, but that serious entanglements showed an increasing trend. Hypothesised that changes in gear type, fishing methods or RW distribution have altered the impact of entanglements without changing the rates.	ALWTP measures from 1997-2009 ineffective.	Good. Discusses the effectiveness of the early stages of the ALWTRP. Considers detection bias.	
11	Area-specific closures	Vanderlaan et al. 2011	Canada: Scotia-Fundy area	Groundfish and pelagic hook and line; groundfish gillnet; crab-hagfish- and inshore and offshore lobster-trap hear.	Ground fish, crab, hagfish and lobster.	North Atlantic right whales.	During the summer -resident period in Critical habitat, groundfish and hook-and-line gear pose the greatest threat than other gear types. During spring and autumn, when whales are migrating to and from critical habitat, gear from lobster fisheries poses the greatest threat. Suggest that area-specific seasonal closures of some fisheries would reduce threat and risk to whales without unduly compromising fishing interests	Nil - only suggests closures would be a management option.		Is more an assessment of threat and recommendation for mitigation rather than an assessment of the mitigation technique.
12	WARLF Code of Practice (shorter ropes, avoiding clusters regularly	Groom and Coughran 2010	Western Australia	Crayfish pots	Rock lobster	Humpback whales	Increased awareness of the entanglement issue, and greater trust of the fishery (not afraid of penalties if report an entanglement), which	Reduction in fishing effort also limits whale entanglements	Reporting rate is assumed to be an underestimate; entanglements	Data to 2010, prior to the peak in 2011-2013

No	Mitigation Measure	Source	Region of Interaction	Gear configuration	Target fish species	Bycatch species	Outcome	Level of efficacy	Level of scientific rigour	Caveats or uncertainties in methods
	checking pots); fishing effort; disentanglement						increases chance of successful disentanglement. Reduction in fishing effort happened where the fishery limited the number of pot-lifts used (=# of pots x length of fishing season) to reduce the catch to maintain sustainability and increase economic efficiency. Kegging technique has a 100% disentanglement success rate. One-third of reported entanglements were successfully disentangled. A vessel standing by the entangled whale (until response team arrived) was highly important to success-88% of whales that evaded disentanglement did not have a vessel tracking their movements.	by limiting amount of gear, and time it is in the water. Reasons for whales evading disentanglement involved rough seas (too dangerous or hampering resights), reporter vessel not standing by and whale not relocated, and inability to respond quick enough due to the remoteness of the entanglement, or lateness of report, concurrent entanglements or limited staff and resources.	unable to be verified are not recorded in the database, and some entangled whales are likely to be undetected.	
13	Negatively buoyant groundlines	Brilliant and Trippel 2009	Canada, Bay of Fundy	Pot strings	American lobster	North Atlantic right whale	The proportion of groundlines <3 m from the seabed was 0.92, and <1 m was 0.32, which given these lines are floating, is a good result. They comment that by making lines negatively buoyant may reduce entanglement rates further, but likely, these reductions would be minimal. Given that most (92%) of the elevations studied were within one body-height of a right whale from the seabed (3 m) and the	Maximum elevation of regular groundline was 7 m, and of sinking groundline was 0.4 m.	This study used a threshold height from seabed of >3 m to be considered a threat to right whales, although noted that more research into the behaviour of RW in proximity to the	Canada use floating groundlines, so neg. buoyant groundlines in the US should be even less of an issue.

No	Mitigation Measure	Source	Region of Interaction	Gear configuration	Target fish species	Bycatch species	Outcome	Level of efficacy	Level of scientific rigour	Caveats or uncertainties in methods
							apparent infrequency that right whales come within this distance of the seabed (and diet sp distribution), the absolute reduction in risk may be small.		sea bed is required to make a definitive assessment of risk. They say 3 m is conservative, but not sure if it is.	
14	WARLF Code of Practice (shorter ropes, avoiding clusters regularly checking pots- also mentions coloured ropes)	How et al 2015	Western Australia	Crayfish pots	West Australian Rock lobster	Humpback whales	Code of practice used across fishery.	Unknown - report due 2017		
15	Rope-less fishing	Partan and Ball 2016	North Atlantic	Pots	Lobster	Large whales	3 prototypes built, using timed (not acoustic or anode) released.	Under development	technical development - prototype	
16	Coloured rope	Kraus and Hagbloom 2016	North Atlantic	Pots	Lobster	Right whales	Red and orange ropes detected by whales at greater distances.	Under development	Research ongoing	Water quality, distance to whales may be confounding; will do future experiments to test.
17	ALWTRP-Fed Reg	NFMS 1997	North Atlantic	Pot and set net	Various fixed fisheries (trap/net)	Large whales	fishers may choose from a list of mitigation options.	Ineffective	N/A	
18	ALWTRP-Fed Reg	NFMS 1999	North Atlantic	Pot and set net	Various fixed fisheries (trap/net)	Large whales	Gear marking, decreased weak link breaking strength (in some areas only), seasonal closure of crayfish areas, seasonal closures on gillnets (some areas) lobster restricted	Ineffective	N/A	
19	ALWTRP-Fed Reg	NFMS 2000	North Atlantic	Pot and set net	Various fixed fisheries (trap/net)	Large whales	Mandatory requirements (not a 'pick list') in some areas	Ineffective	N/A	

No	Mitigation Measure	Source	Region of Interaction	Gear configuration	Target fish species	Bycatch species	Outcome	Level of efficacy	Level of scientific rigour	Caveats or uncertainties in methods
20	ALWTRP-Fed Reg	NFMS 2002a	North Atlantic	Pot and set net	Various fixed fisheries (trap/net)	Large whales	Dynamic Area Management (DAM) now applicable	Ineffective	N/A	
21	ALWTRP-Fed Reg	NFMS 2002b	North Atlantic	Pot and set net	Various fixed fisheries (trap/net)	Large whales	Seasonal Area Management (SAM) effective	Ineffective	N/A	
22	ALWTRP-Fed Reg	NFMS 2002c	North Atlantic	Pot and set net	Various fixed fisheries (trap/net)	Large whales	Expands gear modifications to other areas.	Ineffective	N/A	
23	ALWTRP-Fed Reg	NFMS 2007	North Atlantic	Pot and set net	Various fixed fisheries (trap/net)	Large whales	Brad-based gear modifications - universal modifications includes all other potting fisheries as well as lobster: modifications include (but not limited to) borders expanded, mandatory gear mods in some areas year-round, groundline must be negatively buoyant, weak links on all flotation devices. Gillnets: weak links mandatory, number per net panel.	Ineffective	N/A	On adoption of most gear mods the DAM management program is eliminated. On adoption of the sinking groundline rule (6 months later) SAM will be eliminated
24	ALWTRP-Fed Reg	NFMS 2008	North Atlantic	Pot and set net	Various fixed fisheries (trap/net)	Large whales	Additional time given for adoption of sinking groundline.	Ineffective	N/A	
25	ALWTRP-Fed Reg	NFMS 2014	North Atlantic	Pot and set net	Various fixed fisheries (trap/net)	Large whales	Vertical line reduction (prohibiting single trap/pots, minimum number of traps per trawl), one endline for trawls of less than or equal to 5 traps, expansion of some areas. MAXIMUM breaking strength of vertical line itself is stipulated.	Unknown	N/A	
26	ALWTRP-Fed Reg	NFMS 2015	North Atlantic	Pot and set net	Various fixed fisheries (trap/net)	Large whales	Reduces the single pot restrictions in some areas.	Unknown	N/A	