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Potential climate change effects on New Zealand marine mammals: a review

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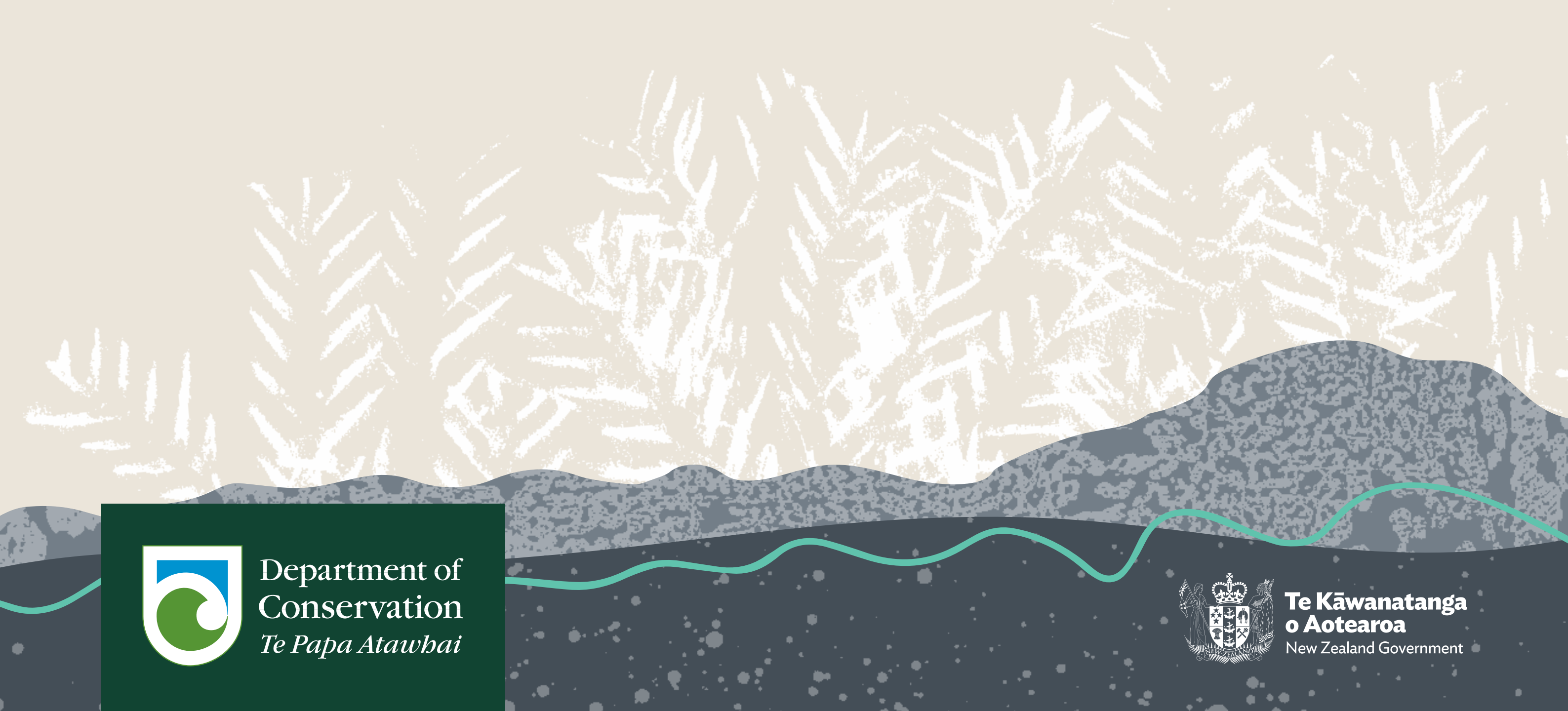

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Potential climate change effects on New Zealand marine mammals: a review

Jim O. Roberts[1] and Hannah R. Hendriks[2]

[1] Anemone, Wellington, New Zealand.
Email: jimoroberts@gmail.com

[2] Department of Conservation, PO Box 10-420, Wellington 6143, New Zealand.

Abstract

We describe a qualitative, first-pass risk assessment of selected climate hazards for marine mammals around New Zealand. Under a business-as-usual emissions mitigation scenario, projected changes to the New Zealand environment by the end of this century include: a greater than 3°C increase in sea surface temperatures relative to pre-industrial levels, changes in atmospheric and oceanographic circulation, rising sea level, and widespread ocean acidification. Together, these changes could affect New Zealand marine mammals directly via modifications to their physical environment, or indirectly via modifications to regional productivity and food web structure impacting on the local abundance of prey or predator species. Our literature review suggests that climate change impacts would be worst for species and/or independent populations that have a narrow habitat tolerance, are already close to tolerance thresholds, or have a limited ability to adapt to predicted changes. New Zealand marine mammal taxa or populations that appear relatively vulnerable include the Westland population of New Zealand fur seal (*Arctocephalus forsteri*), Māui dolphin (*Cephalorhynchus hectori maui*), and multiple baleen whale species (Mysticeti). In response to increasing sea temperature, poleward range shifts are expected for sufficiently mobile species, causing subtropical migrant/vagrant species to become more common around New Zealand and subantarctic species to become scarcer. We highlight some information gaps for future assessments of climate change impacts on New Zealand marine mammals, and suggest some possible avenues for managing risks, emphasising the benefits of a collaborative approach.

Keywords: New Zealand, marine mammals, climate change, conservation, risk assessment, cetaceans

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1. Introduction

1.1 Background

Human-caused climate change has modified the global marine environment in several ways, including: warming and acidification of the global oceans, shrinking the extent of sea-ice, and increased sea level. Near-surface air temperature over the global oceans has increased by c. 0.6°C since the pre-industrial period (IPCC 2019), and warming of the upper ocean (<2000m depth) appears to have accelerated in recent years – five of the six calendar years from 2015 to 2020 were ranked in the top-five hottest years on record since 1955, and the two most recent of these years were the hottest (Cheng et al. 2021). Sea temperatures were projected to continue increasing throughout this century under most fossil fuel emission mitigation scenarios, even under Representative Concentration Pathway 4.5 (RCP 4.5) – the 'intermediate' mitigation scenario used by the Intergovernmental Panel on Climate Change (IPCC) (IPCC 2019). This would be accompanied by further ocean warming, shrinkage of sea-ice cover, continued ocean acidification, and probable changes in ocean circulation patterns across varying spatial scales.

The projected changes under most mitigation scenarios used by the IPCC are likely to significantly alter the distributions and productivity of marine mammal species globally (Albouy et al. 2020; Learmonth et al. 2006; Schumann et al. 2013; Simmonds 2016). To date, the literature has mainly focused on the marine ecosystem of the Arctic region, which appears particularly vulnerable (e.g., Wassmann et al. 2011; Nunny & Simmonds 2019; Albouy et al. 2020).

Recently observed climate variability and climatic shifts have already been implicated in the shifting productivity of several of New Zealand's charismatic marine megafauna species, including New Zealand sea lion (rāpoka/whakahao, *Phocarctos hookeri*), New Zealand fur seal (kekeno, *Arctocephalus forsteri*), southern elephant seal (ihu koropuku, *Mirounga leonina*), yellow-eyed penguin (hoiho, *Megadyptes antipodes*) and southern rockhopper penguin (*Eudyptes chrysocome*); as well as of commonly important prey species, e.g., red cod (*Pseudophycis bachus*), hoki (*Macruronus novaezelandiae*), southern arrow squid (*Nototodarus sloanii*) and sprat (*Sprattus* spp.) (Taylor & Taylor 1989; Beentjes & Renwick 2001; Bull & Livingston 2001; Taylor & Marriot 2004; Hilton et al. 2006; Best et al. 2008; Hurst et al. 2012; Roberts & Doonan 2016; Mattern et al. 2017). Other studies have found evidence for climate-mediated changes in the seasonal spatial distribution of megafauna species (Hartel et al. 2015; Barlow et al. 2020). These studies provide us with some of the information needed for predicting the direction (but not necessarily the magnitude) of changes in the distribution and productivity of marine mammal species that might occur in response to various climate change hazards.

Previous reviews of climate change effects on the New Zealand marine environment have given limited consideration of marine mammals (Willis et al. 2007; Boyd & Law 2011; Foley & Carbines 2018). To date, there has been no dedicated review of the potential impacts of climate change on marine mammals occurring around New Zealand.

1.2 Purpose of this assessment

The purpose of this assessment is to review the potential impacts of projected climate change effects on New Zealand marine mammals. This is not a quantitative risk assessment of the vulnerability of each marine mammal species to climate change hazards. Instead, this analysis summarises the current knowledge of relevant changes to the New Zealand climate by the end of this century (under RCP 8.5 – the IPCC's least stringent mitigation and highest emission pathway) and uses a review of the global literature to identify specific climate change hazards that are most likely to impact on marine mammals around New Zealand.

The specific research objectives of this review were to provide:

- a summary of projected changes to the physical environment of New Zealand that will be most relevant to marine mammals
- a review of the state of knowledge of current and future climate change impacts on marine mammals within the New Zealand Exclusive Economic Zone (EEZ)
- a first-pass risk assessment of selected, relevant climate change hazards for New Zealand marine mammal species
- an indication of significant information gaps that can be prioritised for monitoring and management.

There are considerable uncertainties with respect to the nature and degree of projected climate change effects on the physical environment and biological responses. As such, this assessment should be considered as a first step, identifying key climate change hazards and priority species that can then be addressed by second- and third-pass risk assessments of climate change effects.

1.3 Literature review and first-pass risk assessment

For a first-pass assessment, it is normally only necessary to establish the relevance and presence / absence of a climate hazard for each respective marine mammal species. Our approach was based on the four-step methodology outlined by Tonmoy et al. (2019):

1. Establish the scope (e.g., the assessment objective, time frame, and climate change scenario).
2. Identify *existing* climate risks.
3. Identify *future* climate risks and opportunities, based on projected changes to the existing New Zealand environment and marine mammal responses, identified in step 2.
4. Based on steps 2 and 3, evaluate risks to identify information gaps and priority hazards / species for management.

The scope for this review was specified by the New Zealand Department of Conservation (DOC). Climate change hazards considered by this assessment included:

- increased sea temperature
- oceanographic changes
- ocean acidification
- rising sea level
- ecosystem responses to climate change (i.e., changes in primary production, trophic interactions etc.).

Marine mammal species that were in scope for this assessment included all species listed in the latest New Zealand Threat Classification (NZTC) assessment for marine mammals (Baker et al. 2019), and vagrant species that may have a more consistent presence in New Zealand under future climate change scenarios. For some species, sub-population effects were considered. Climate change effects on marine mammals occurring in the Southern Ocean (some of which are included in NZTC assessments; see Appendix 1) were not in the scope of this review, though have been reviewed by others (e.g., Constable et al. 2014; Bestley et al. 2020)

For the purposes of this assessment, and consistent with the *Climate Change Adaptation Action Plan* (Department of Conservation 2020a), projected changes to the New Zealand environment at the end of this century were derived from the outputs of climatic/oceanographic models under the RCP 8.5 mitigation scenario. RCP 8.5 assumes a continuation of increasing emissions (i.e., 'business-as-usual') and is the worst-case of four mitigation scenarios regularly assessed by the IPCC (IPCC 2019).

To inform the reviews under Steps 2 and 3, we first reviewed the latest information with respect to changes in the marine environment up to the present day (i.e., since the pre-industrial period), and predicted changes by the end of this century under RCP 8.5. Under Step 2, we then reviewed the domestic and international evidence for changes to the distribution or productivity of marine mammal species in response to the assessed climate change hazards, and how these findings could be applied to New Zealand species/populations. Under Step 3, we then used the outputs of Step 2 to summarise the possible effects of projected climate change on New Zealand marine mammals up to the end of this century, under RCP 8.5. The analysis under Step 3 was essentially qualitative, e.g., assuming a continuation of observed relationships up to the present day.

In Step 4, we summarised the qualitative information gathered under Steps 2 and 3 and identified priority climate change hazards and marine mammal species for future assessment. We conclude with a discussion of key information gaps for science to address and identify some management recommendations based on the outputs of this analysis.

2. Probable climate impacts for marine mammals

The projected effects of human-caused climate change have been summarised by the IPCC under multiple scenarios, ranging from stringent to business-as-usual emission mitigation regimes (IPCC 2019). Associated climate change hazards of relevance to marine mammals globally include (but are not limited to): increasing sea temperature, rising sea levels, ocean acidification, decreasing sea-ice cover and changes in ocean circulation patterns (IPCC 2019). Several studies have now reviewed the potential impacts of these changes on marine mammal species and other marine vertebrates (e.g., Learmonth et al. 2006; Schumann et al. 2013; Simmonds 2016; Sydeman et al. 2015) (summarised in Figure 1). While the precise effects of any one climate change hazard are difficult to predict for any marine mammal species, some common themes emerge from these reviews, which we summarise in this section.

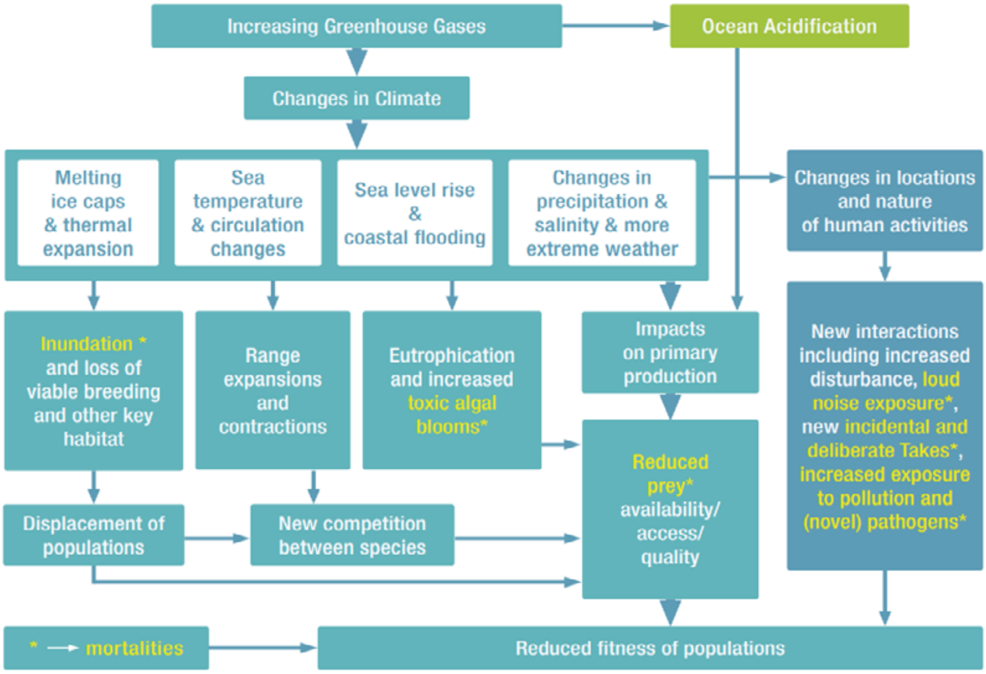

Figure 1. Potential impacts of climate change on marine mammal populations. Predicted physical changes (in white boxes) are linked to habitat effects relevant to marine mammals. Effects in yellow with asterisks indicate where mass mortalities may occur. The dark blue boxes show 'tertiary effects' where interactions may occur with human activity. Figure reproduced from Simmonds (2016).

Increasing sea temperature

Increasing sea temperatures can affect marine mammals directly, e.g., via changes in ambient temperature that might be problematic for species already close to a thermal tolerance threshold, or indirectly, e.g., via changes in mixed layer depth and other oceanographic features such as upwellings that impact on the productivity or distributions of their preferred prey species (reviewed by Learmonth et al. 2006; Sydeman et al. 2015).

For an optimally foraging population of marine mammals, their fine-scale spatial distribution will largely be driven by the local environmental features that define their physical habitat, such as bathymetry and oceanography, which can also determine the spatial distribution of available prey (Torres et al. 2008; Bailey & Thompson 2010), whereas their broader distributional range may often best be predicted best by water temperature (e.g., Stephenson et al. 2020). As such, sustained changes in sea temperature should result in distributional range shifts, contingent on a species' ability to disperse to newly optimal habitat (Poloczanska et al. 2016). Marine mammal species/populations that comprise few individuals, have a narrow thermal niche, are already close to their thermal tolerance thresholds, or are characterised by restricted dispersal ability (due to biology or geography) are likely to be most vulnerable to the effects of increasing sea temperature (Slatyer et al. 2013; Albouy et al. 2020). Conversely, adult baleen whales appear relatively well-adapted to locating alternative feeding grounds due to their high mobility and broad thermal tolerance (IWC 1997), although may be vulnerable to environmental changes at multiple locations along their migratory paths (Derville et al. 2019; Tulloch et al. 2019).

For warmer water species, increasing sea temperatures may present an opportunity to colonise new regions at higher latitudes. For example, tropical species that were previously constrained by their ability to thermoregulate in colder water or a lack of potential prey species.

An analysis of global marine mammal species by Albouy et al. (2020) found that North Pacific and Arctic marine mammals were most at-risk from predicted oceanic warming up to the end of this century, under alternative mitigation scenarios (Figure 2).

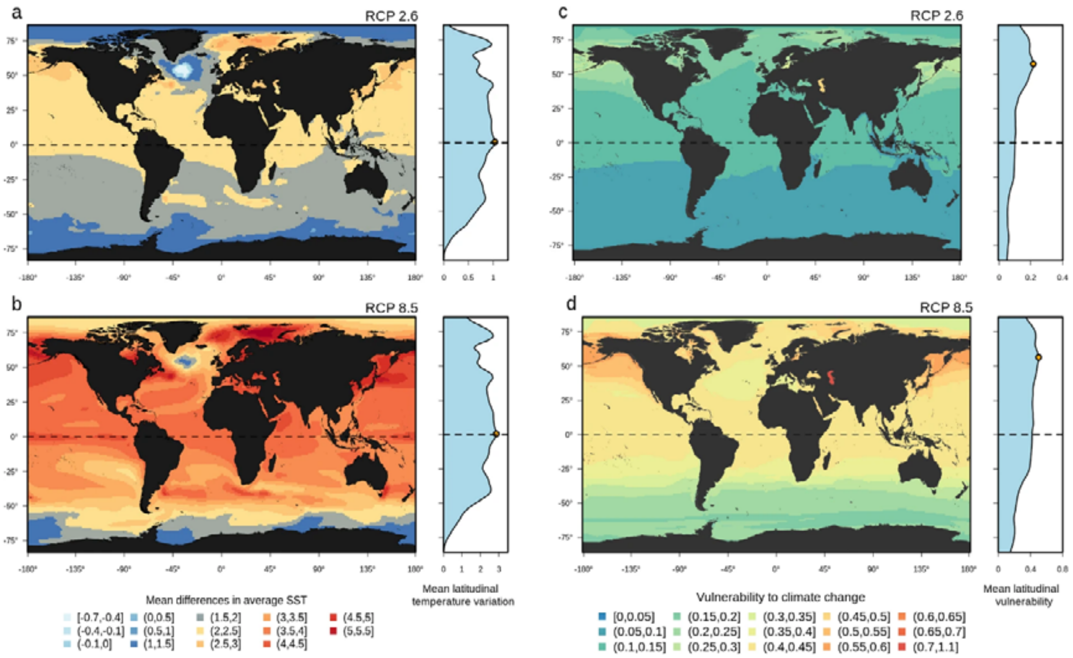

Figure 2. Projected changes in sea surface temperatures and estimated vulnerabilities of marine mammal species. Projected changes in the sea surface temperature between the recent period (1971–2000) and the end of the century (2070–2099) following the RCP 2.6 (a) and RCP 8.5 (b) scenarios. Local assemblage-level vulnerability of marine mammals to climate change by the end of this Century based on (c) the RCP 2.6 scenario and (d) the RCP 8.5 scenario.
Figure reproduced from Albouy et al. (2020), http://creativecommons.org/licenses/by/4.0/.

The relative vulnerability of each species was determined from model-predicted warming within each species' range and the intrinsic vulnerability of each species, based on biological traits and biological/behavioural plasticity. Notably, the estimated vulnerability across marine mammal assemblages was much reduced under the RCP 2.6 mitigation scenario (which limits the increase temperature to 2°C) compared with under RCP 8.5. This was true of all global regions, including around New Zealand.

To date, the evidence for ocean warming-mediated range shifts is limited for marine mammal species relative to fish and other marine organisms (Poloczanska et al. 2016). However, Evans and Waggit (2020) concluded that range shifts may already appear to be occurring around the United Kingdom in response to oceanic warming, with a northward shift of warmer-water species including striped dolphin (*Stenella coeruleoalba*), common dolphin (*Delphinus delphis*), and Cuvier's beaked whale (*Ziphius cavirostris*), and possible range contractions of cold-water species, such as white-beaked dolphin (*Lagenorhynchus albirostris*).

Oceanic warming may also affect the migratory patterns of certain marine mammals, although this may have a greater effect on their presence at regular feeding grounds than on the migratory paths taken to reach them. For example, the migratory corridor used by southwest Atlantic humpback whales (*Megaptera novaeangliae*) appears to have changed little since the 1960s (Horton et al. 2020), although their use of Southern Ocean feeding grounds appears to be much reduced in strong El Niño years, when the extent of sea ice is typically reduced around the Western Antarctic Peninsula (Schall et al. 2021). Increasing sea temperature could also exacerbate other existing threats to a species, e.g., via changes in predation pressure or of the abundance of competitors (Romero et al. 2018). There is also some evidence that increasing sea temperature could increase the prevalence of infectious disease outbreaks (e.g., Harvell et al. 2002; Sanderson & Alexander 2020).

Changes in ocean circulation

The ecological niches of many marine mammal species are at least partially defined by oceanographic features. This is evidenced by the utility of oceanographic covariates for predicting the spatial distribution of certain marine mammal species (reviewed by Cox et al. 2018). For example, blue whales (*Balaenoptera musculus*) are known to congregate on upwelling regions supporting dense patches of krill (Euphausiacea) (Gill et al. 2011; Barlow et al. 2020), and many marine mammal species will typically associate with hydrographic fronts of different types (Cox et al. 2018).

Based on extensive empirical evidence, as well as model simulation, we know that projected climate change is likely to alter global oceanographic patterns (Boyd & Law 2011). Some of these changes, e.g., in the strength of surface mixing or of coastal upwelling, will impact on marine ecosystems (Boyd & Law 2011), with probable flow-on affects for marine mammals via changes in the availability of plankton, fish, and cephalopod prey species (Walther et al. 2002). For example, El Niño events are associated with delayed maturation and low breeding rate of mature female California sea lions (*Zalophus californianus*) (Melin et al. 2012), which appears to be driven by changes in the distribution of key fish prey during periods of reduced upwelling and surface warming (Robinson et al. 2018). Changes in the circulation of the northwest Atlantic have driven warming near the seafloor, impacting on the availability of the main copepod prey species (*Calanus finmarchicus*) of the North Atlantic right whale (*Eubalaena glacialis*), influencing changes in their seasonal foraging patterns and increasing overlap with other human threats (Meyer-Gutbrod et al. 2021; Record et al. 2019).

Many of the recently observed shifts in oceanographic patterns have occurred during years of anomalously warm sea temperatures, also termed 'marine heatwaves' (MHWs) (Schlegel et al. 2017; Salinger et al. 2019).

In addition to effects on species' distribution and key vital rates, oceanic warming has also been associated with changes in the breeding phenology of grey seals (*Halichoerus grypus*) (Bull et al. 2021). Proximally, this is caused by changes in the balance of older and younger breeders and is, ultimately, speculated to relate to changes in prey availability, although the precise mechanisms of this are not well understood (Bull et al. 2021).

Changes in atmospheric climate

Changes in atmospheric and sea surface climate patterns such as rainfall intensity, storm frequency and wave conditions are predicted in many global regions including New Zealand (Ministry for the Environment 2018). Small-bodied marine mammals, e.g., pinnipeds, dolphins and porpoises, may be more affected than other taxa by changes in atmospheric weather patterns. Offspring may be most vulnerable, e.g., mortality rates can be high for Australian fur seal (*Arctocephalus pusillus doriferus*) pups drowning in high swell and storms (Pemberton & Kirkwood 1994; Pemberton and Gales 2004). Mass stranding events of marine mammal species have been linked to anomalous climate conditions, e.g., Australian dugongs (*Dugong dugon*) stranded by a storm surge associated with a cyclone (Marsh 1989) and mass strandings of multiple species around Japan that were attributed to stormy conditions (Honma et al. 1993).

More intense precipitation can increase the nutrient loading of coastal waters and, in conjunction with increased sea temperatures, this is expected to increase the frequency of harmful algal bloom (HAB) events at certain locations (Gambaiani et al. 2009; Doney et al. 2012). Fatal poisonings from HABs have been recorded in numerous marine mammal species including cetaceans, pinnipeds, and manatees (Scholin et al. 2000; Flewelling et al. 2005).

An elevated risk of exposure of coastal marine mammals to novel diseases has been linked to increased freshwater runoff during flood events (see Schumann et al. 2013). For example, Indo-Pacific humpback dolphins (*Sousa chinensis*) in the Townsville region of Australia may be more prone to toxoplasmosis (a disease caused by infection with *Toxoplasma gondii,* a parasite shed by cats) during periods of heavy runoff (Bowater et al. 2003). Increased rainfall and flooding associated with more intense cyclones may also increase the flow of pollutants/pathogens into coastal waters, thereby increasing the exposure of coastal marine mammals to these contaminants (Lawler et al. 2007).

Ocean acidification

The direct effects of ocean acidification on marine mammals are mostly unknown, although are assumed to be minimal (Learmonth et al. 2006; Schumann et al. 2013). However, ocean acidification may have indirect effects on marine mammals via adverse effects on calcifying organisms, e.g., impacting on coral reef formation, plankton community structure, the growth of fish larvae, and productivity of crustaceans and other shellfish prey species of marine mammals (Poloczanska et al. 2016; Law 2020). It had been suggested that ocean acidification could interfere with the normal metabolic function or growth of certain key marine mammal prey including krill and squid (e.g., Kaplan et al. 2013; Rosa et al. 2014), although recent laboratory-based simulations indicate these taxa may not be as badly affected as previously thought (Birk et al. 2018; Ericson et al. 2018).

Rising sea level

Rising sea level may reduce the extent of suitable breeding and haul-out habitat for pinnipeds and affect cetaceans that require coastal bays and lagoons for breeding, although there is limited evidence of any effects up to the present day (IWC 1997, and reviewed for Australian marine mammals by Schumann et al. 2013). Potential indirect threats arising from sea-level rise include the release of refuse and pollutants in leachates from coastal dump sites and increased coastal erosion and changes to sediment loads (Pierdomenico et al. 2019).

The human response to sea-level rise, particularly in urban areas, may also have adverse effects on marine mammals. For example, the construction of seawalls and other defensive structures could potentially impair the access of some marine mammals to coastal habitat and can modify near shore habitat, e.g., via wave reflection (summarised by Learmonth et al. 2006).

Changes in ecosystem structure

Changes in prey availability are often deemed the greatest climate change threat for marine mammal species (Learmonth et al. 2006; Schumann et al. 2013; Simmonds 2016). Climate change effects on marine mammals will generally be indirect, driven by changes in ocean productivity and food web structure (Sydeman et al. 2015). The spatial density and movements of some marine mammals appear to be at least partially driven by variation in prey availability, which may be associated with periods of warming and cooling (Kenney et al. 1996; Bjørge & Tolley 2002). Theoretically, this may be a greater issue for marine mammals that depend on a narrow array of prey species, or on prey that are short-lived and/or prone to high recruitment variability through time.

Multiple studies have described the marine ecosystem roles of marine mammals (e.g., Bowen 1997; Croll et al. 2006). Comparatively few have assessed the potential indirect effects of climate change on marine mammals via broadscale and long-lasting changes to the structure of marine ecosystems, also termed ecosystem regime shifts. Caveats to this include independent assessments developing simple multispecies models to assess the effects of climate change on Southern Ocean whales, principally mediated by changes in krill abundance (Klein et al. 2018; Tulloch et al. 2019). The protracted decline of Steller sea lions (*Eumetopias jubatus*) in the North Pacific has been attributed to a multi-decadal ecosystem regime shift, affecting some of their main prey species (Trites et al. 2007). There are likely to be many more incidences of marine mammal populations affected by changes in ecosystem structure, although this linkage is typically difficult to determine.

Summary

In summary, the various climate change hazards are likely to have a multitude of effects on marine mammals, including changes in: spatial distribution, migration patterns, the timing of breeding, ecosystem processes affecting prey availability or predation pressure and, ultimately, changes in the demographic rates driving population change. For some marine mammal species, climate change driven modifications to the marine environment will be positive, allowing the colonisation of new areas (potentially excluding native species). For the more vulnerable species – those that have a narrow habitat tolerance, that are already close to tolerance thresholds, or have a limited ability to adapt to predicted changes – climate change hazards may increase the risk of population decline and extinction.

3. Review of climate change effects on New Zealand marine mammals

3.1 Effects on the marine environment of New Zealand

Under RCP 8.5, climate models predict a c. 3°C increase in sea surface temperature across the New Zealand region by the year 2100 relative to the 1986–2005 'baseline' period (Figure 3), which is c. 1°C below the global average increase (Ministry for the Environment 2018). Note that New Zealand land air temperatures increased by approximately 1°C since the year 1909 (Mullan et al. 2010) and it is likely that there was an associated increase in sea surface temperature prior to 1986–2005 that would not be included in the projected increase above the specified baseline (Ministry for the Environment 2018).

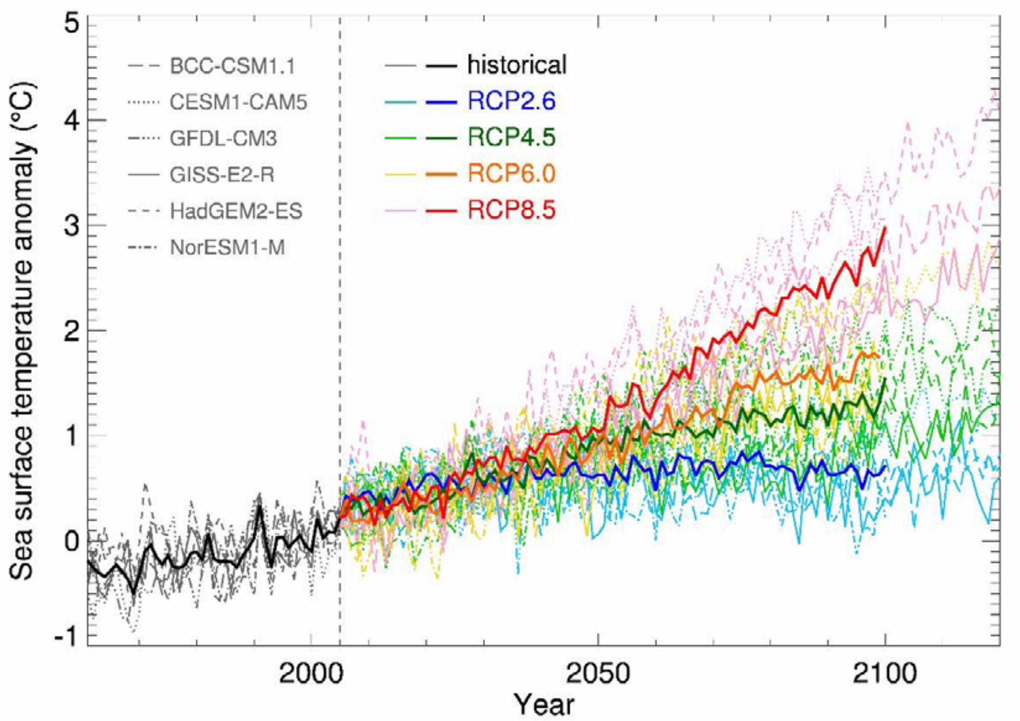

Figure 3. Predicted sea surface temperatures averaged over the model domain around New Zealand (33–48° S, 160–190° E) from six global climate models. Historical simulations (here 1960–2005) are in grey, and four future simulations (RCPs 2.6, 4.5, 6.0 and 8.5) are shown in different colours. Figure reproduced from a report by the Ministry for the Environment (2018).

The projected seawater temperatures around New Zealand are similar across the four assessed IPCC climate scenarios (i.e., also RCP 2.6, RCP 4.5, RCP 6.0) up until the year 2050, after which there would be an acceleration in the rate of increase under RCP 8.5 that was not estimated by any of the other RCP scenarios (which simulate alternative reductions in the levels of emissions) (Ministry for the Environment 2018). The warming of sea surface temperatures would be greatest in summer/autumn and least in winter/spring (Ministry for the Environment 2018). Earth System Models (ESMs) predict the increase in sea surface temperatures to be greatest around the north of New Zealand and least in the south, although the precise spatial distribution of the predicted increase remains highly uncertain, particularly in the subantarctic region to the south and south-east of New Zealand (Law et al. 2018).

Changes in the regional climatology and oceanography of New Zealand are also anticipated up to the year 2100. The general effects of warming on the marine ecosystem were summarised by Boyd and Law (2011). Across the New Zealand region, it is predicted (on average) that:

- surface waters will warm and freshen, increasing the density gradient between surface and deeper waters. This will reduce the supply of nutrients that encourage algal growth in surface waters. This would negatively impact primary production, although this will not be true everywhere (see below)
- phytoplankton will receive more light as the surface layer narrows
- ocean warming will reduce the dissolved oxygen concentration, increasing the volume of mid-water column oxygen-deficient zones
- increasing carbon dioxide will make the ocean more acidic
- there will be large-scale changes in wind fields, i.e., more north-easterly airflow in summer and strengthened westerlies in winter (Ministry for the Environment 2018), affecting ocean currents and vertical mixing
- there will be increases in storm frequency and dust deposition, affecting nutrient supply.

While warming is predicted to negatively affect marine primary production across the New Zealand region, the empirical evidence suggests this is likely to be specific to subtropical waters around the North Island, and the west coast of the South Island (Chiswell & Sutton 2020). Along the subtropical front and in parts of the New Zealand subantarctic region, sea surface temperature and chlorophyll-a concentration were *positively* correlated in the period 2002–2018 (Chiswell & Sutton 2020) (Figure 4).

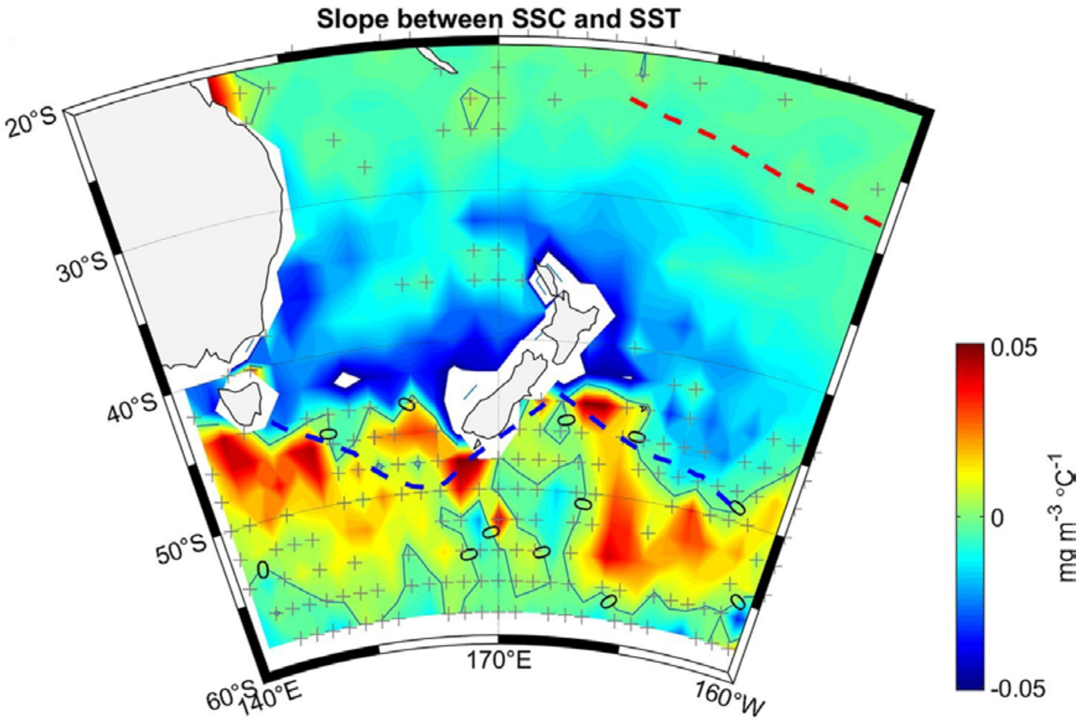

Figure 4. Slope of the linear regression between sea surface chlorophyll-a concentration (SSC) and sea surface temperature (SST) across the period 2002–2018. Figure reproduced with permission from Chiswell and Sutton (2020).

Earth system model-based predictions indicate a reduction in global net marine primary production of approximately 8.5% under RCP 8.5 (Bopp et al. 2013). A much smaller reduction of 4.5% was predicted across the New Zealand region, although the magnitude of this reduction varied considerably by ESM model (Law et al. 2018). Also, alternative ESMs produce differing spatial patterns in the change in primary production, although the two best-performing models both predicted a decrease to the north of New Zealand (Law et al. 2018).

Changes in phytoplankton communities are anticipated in response to increasing atmospheric CO_2, warming sea temperatures, and ocean acidification, which should favour the growth of nitrogen fixers in the waters north of New Zealand and have a detrimental effect on coccolithophore blooms (Boyd & Law 2011). These changes are likely to alter the nature of productivity at the base of marine food webs.

Harmful algal bloom events may have increased in frequency and intensity in recent global history. This appears to have been caused by a combination of warming, changes to nutrients in upwelling areas, and coastal eutrophication (Bindoff et al. 2019). There is limited support for future climate change effects on HABs at the global level (Bindoff et al. 2019), although HAB events become more likely when the water column is more strongly stratified, e.g., as driven by projected warming (summarised by Ministry for the Environment and Stats New Zealand 2020).

Ocean wave patterns have been changing around New Zealand, affecting the coastal environment (Ministry for the Environment 2019). Over the past decade, the prevalence of extreme wave events increased to the south and east of New Zealand and decreased off the west coast of the North Island (Figure 5).

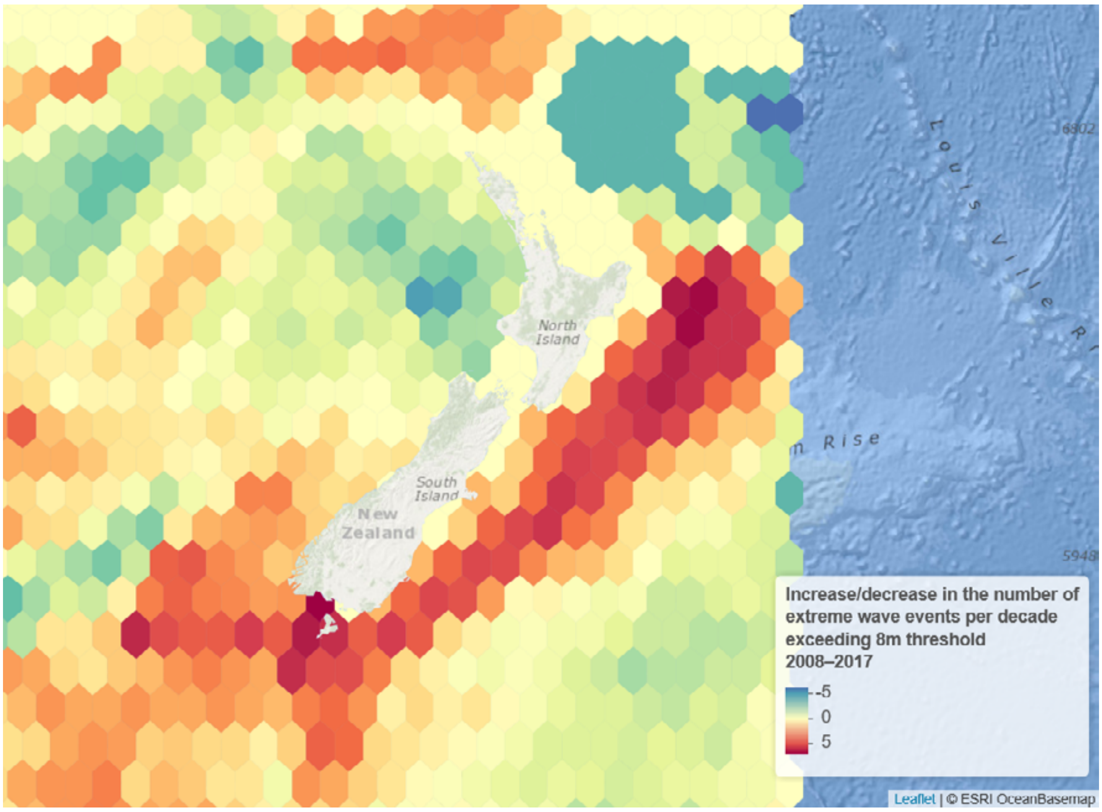

Figure 5. Trend in extreme wave events at the 8-metre threshold, 2008–2017 (defined as a continuous 12-hour period when the wave height equalled or exceeding 8 metres). Plot produced via a mapping tool by Statistics New Zealand (2021), using data produced by NIWA.

Due to the observed and projected decline of sea ice extent in the Arctic (IPCC 2019), species with dependence on the sea ice are predicted to be highly sensitive to climate change effects (Laidre et al. 2008; Moore & Huntington 2008; Silber et al. 2017). Many of the migrant or vagrant species listed in New Zealand's Threat Classification are associated with or dependent on sea ice, e.g., humpback whale, Antarctic blue whale (*Balaenoptera musculus intermedia*), crabeater seal (*Lobodon carcinophaga*) and other phocids, so changes in this habitat could potentially impact on how these species associate with New Zealand's waters and the threats associated with that.

The sea-ice extent around Antarctica once appeared more stable than in the Arctic region, with a gradual increase in the overall extent of sea-ice from the late-1970s up to 2014, although this was followed by a period of comparatively rapid decrease (Parkinson 2019; Vaughan et al. 2013).

Alterations to marine fish and invertebrate communities are anticipated with all the projected changes to the New Zealand marine environment. Mechanisms of change include shifts in species' distributions with warming, changes in mean recruitment, and changes to predator and prey densities. For example, the annual spawning or recruitment strengths of various major marine mammal prey species, e.g., hoki, southern arrow squid, red cod, and sprats are variously thought to be responsive to changes in oceanography, sea temperature, or phytoplankton productivity (Beentjes & Renwick 2001; Bull & Livingston 2001; Taylor & Marriot 2004; Hurst 2012). Projected environmental changes are also likely to impact on mesopelagic fish and crustaceans, although changes to non-fishery species are more challenging to monitor through time.

In summary, projected changes in climate under RPC 8.5 that could impact on marine mammals around New Zealand are not just restricted to modifications of their physical environment, such as warming sea temperatures. There will also be changes in oceanographic features used by various species, including the intensity of upwellings (e.g., a probable decrease in the strength of upwelling off the west coast of the South Island) and the locations of surface currents and fronts between water bodies. We are currently unable to predict the spatial variability in changes to primary production by the end of this century to a high spatial resolution. However, based on the empirical evidence, we expect a decrease in productivity around the North Island and west coast of the South Island with increasing sea temperatures, and increasing productivity in the subantarctic region to the south of New Zealand (Figure 4). A decrease of c. 0.3 pH units is predicted by the end of this century under RCP 8.5; that is forecast to alter plankton communities and may adversely affect the larvae of bony fish, with potential down-stream effects on marine mammals (Boyd & Law 2011; Ministry for the Environment 2018). Warming is also predicted to cause sea level to rise by 51–92 cm by the year 2100 (IPCC 2019), in addition to the c. 20 cm rise that has already occurred since 1900. Changes in New Zealand weather patterns are predicted, including an increase in extreme winds and rainfall events, and a likely poleward shift of storms (Ministry for the Environment 2018).

The relative importance of the various changes predicted under RCP 8.5 for New Zealand marine mammals will vary by species and at the sub-population level.

3.2 Observed climate effects on New Zealand marine mammals

The scientific literature is predominantly focused on monitoring or estimating changes in response to long-term climate trends or inter-annual variability up to the present day. Comparatively few studies have predicted impacts to New Zealand marine mammals occurring under future climate change scenarios (e.g., Torres et al. 2013). Hence, although still quite uncertain, changes up to the present day are better understood than future changes. This section describes historical rather than future changes, noting that backwards-looking studies can still help us to predict the future.

The scientific literature on climate change effects on New Zealand marine mammals can broadly be categorised into studies that describe:

- Changes in spatial distribution in time in response to climate variability, e.g., how this varies comparing warm and cold years, or shifts under longer-term warming (e.g., Torres et al. 2013; Hartel et al. 2015);

- Changes in population productivity rates through time, e.g., measured as changes in population trajectory or shifts in responsive demographic rates (e.g., Best et al. 2008; Roberts & Doonan 2016); or
- Variation in biology and behaviour (Best et al. 2008; Roberts et al. 2020).

Of the various threats posed by long-term climate change, the scientific literature is dominated by studies assessing New Zealand marine mammal responses to variability in sea temperature and oceanography.

3.2.1 Changes in sea temperature, oceanography, and ecosystem structure

Because pronounced changes in ocean circulation tend to occur during MHW events (Schlegel et al. 2017; Salinger et al. 2019) the effects of oceanic warming and changing ocean circulation on New Zealand marine mammals were reviewed together, along with effects on ecosystem structure.

Large cetaceans

Southern right whales (tohorā, *Eubalaena australis*) are a migratory balaenid species of the southern hemisphere. Multiple international studies have obtained strong correlations between environmental conditions at high latitude feeding grounds and reproductive success at lower latitude breeding grounds (e.g., Leaper et al. 2006; Seyboth et al. 2016) and, hence, this species is considered by some to be a sentinel species for climate change. Around New Zealand, southern right whales are most frequently observed around the subantarctic islands, including their only known New Zealand breeding site at Port Ross, Auckland Islands (Rayment et al. 2012; Torres et al. 2017), although, historically, they were frequently captured by commercial whalers off the east coast of the South Island and to the north-east of the North Island (Torres et al. 2013). Torres et al. (2013) used boosted regression tree (BRT) habitat models fitted to the historical commercial whaling records to predict a southward shift in southern right whale distribution, mostly driven by projected surface warming up to end of this century. However, Torres et al. (2013) acknowledge that the responses of the whales' copepod prey to projected changes in ocean temperature and oceanography remain poorly understood.

Krill are the main prey of migratory blue whales and are known to be sensitive to changes in the distribution of upwelling regions, mediated by changes in temperature (Klein et al. 2018). A genetically-distinct population of pygmy blue whale (*B. m. brevicauda*) is thought to be present in New Zealand waters throughout the year (Barlow et al. 2018). Barlow et al. (2020) explored a potential mechanistic relationship between changes in sea temperature and oceanography at an upwelling system located in the Southern Taranaki Bight region. This research found fewer and less dense aggregations of southern krill (*Nyctiphanes australis)* during the warm regime. Furthermore, the distribution of blue whales was different comparing years of warm versus average temperature and this appeared to relate to the number and density of krill aggregations. This is one of few New Zealand studies exploring the mechanistic effects of warming on marine mammals via changes in their preferred prey, as opposed to indirectly via changes in climate indices.

Humpback whales are transient visitors to New Zealand along their migratory route between the Southern Ocean and their breeding grounds in the Pacific Islands. We found no studies with evidence of changes in their distribution or behaviour around New Zealand.

An ongoing study of sperm whales (*Physeter macrocephalus*) at Kaikōura tentatively found that a long-term decline in their abundance there was partly correlated with a long-term increase in temperatures in the preceding winter (Guerra Bobo 2018). For many other large, migratory whales and the numerous beaked whale species occurring around New Zealand, the available information for assessing climate effects on these species is extremely limited.

Small cetaceans

Changes in ocean climate also appear to affect the fine-scale seasonal distribution of a number of smaller cetacean species around New Zealand, including bottlenose dolphin (*Tursiops truncatus*) and common dolphin populations in the north of the North Island (Constantine & Baker 1997; Hartel et al. 2015). In the Bay of Islands, bottlenose dolphins are found over deeper waters in months and years of warmer sea temperature (Hartel et al. 2015). This pattern is more likely to be a response to seasonal movements of prey and predators mediated by changes in the warm East Auckland Current than a direct response to changes in ambient sea temperature, which were well-within the thermal tolerance range for this species (Hamilton, unpublished research). Ongoing research has also found a marked change in the use of the Hauraki Gulf / Tīkapa Moana by common dolphins (as well as Bryde's whale, *Balaenoptera edeni brydei*) through time, with an increased density of individuals in the outer Gulf and top of the Coromandel Peninsula in warmer periods (Colbert 2019).

To date, long-term studies at the Bay of Islands and Hauraki Gulf / Tīkapa Moana have not reported any long-term demographic effects of changing climate that might indicate a population response, although a sustained shift in the survival of bottlenose dolphin calves was estimated for the Doubtful Sound/Patea population (Henderson 2013). The causes of this shift are unknown, although it was speculated that large rainfall events might affect the availability of prey there via a deepening of a surface low salinity layer, in addition to potential anthropogenic factors (Henderson 2013).

Māui dolphin (*Cephalorhynchus hectori maui*) are a subspecies of the endemic Hector's dolphin (*C. hectori*), which are generalist predators of small-bodied fish, predominantly found in turbid waters close to the shore (Miller et al. 2013; Roberts et al. 2019). Roberts et al. (2019) used trawl survey catch rate information to infer a much lower availability of key prey species within the range of Māui dolphin (relative to South Island Hector's dolphin), which could render them particularly vulnerable to climate-mediated changes in prey availability. In the MHW summer of 2017/18, during an ongoing boat-based photo ID survey, it was noted that Māui dolphin were absent from areas that they were typically expected to be found (Scott Baker, Oregon State University, pers. comm.). Derville et al. (2016) estimated a narrow thermal range for this subspecies using a BRT model fit to spatial sightings, although it is likely that temperature was proxying for other correlated habitat variables that were not included in the model (e.g., prey distribution), based on results from more spatially comprehensive studies across both subspecies (e.g., Roberts et al. 2019).

Pinnipeds

The recent history of southern elephant seal breeding inside the New Zealand EEZ is consistent with the paradigm of a poleward shift in marine mammal species' ranges with global warming. Annual pup production at Campbell Island/Motu Ihupuku (considered part of the Macquarie Island population) declined by c. 97% between 1947 and 1986 (Taylor & Taylor 1989) and has remained low since. This decline mirrors the decline in rockhopper penguins there, which was accompanied by a shift in tissue isotopes, indicative of climate/prey-mediated population decline (Hilton et al. 2006). A comparable decline was also observed in the Gough Island population of southern elephant seals at the species' northernmost breeding location, in the South Atlantic Ocean (Jones et al. 2020). Contrary to the poleward shift paradigm, leopard seals (*Hydrurga leptonyx*), which primarily occur in the Southern Ocean, appear to have become more frequent visitors to the New Zealand mainland in recent years, with evidence of pupping on the mainland (Hupman et al. 2020), noting that it is difficult to disentangle a potential northward range shift from changes in reporting rate and awareness. The distributional ranges of the New Zealand sea lion and New Zealand fur seal are both known to be moving north, although this is due to the slow recolonisation of the New Zealand mainland, following their extirpation there by the first human settlers to New Zealand (Smith 1989; Collins et al. 2014).

Several studies have obtained long-term reproductive and biological rates of pinniped populations that can be related to climate indices. For example, correlative analyses have obtained strong negative relationships between sea surface temperatures along the west coast of the South Island and New Zealand fur seal pup births and pup mass along the same coast (Best et al. 2008; Roberts et al. 2020). Here, periods of relatively warm surface waters are caused by a weakening of south-westerly winds affecting upwelling strength and phytoplankton productivity. We are not aware of any long-term dietary information for this population, although it is likely that the availability of mesopelagic fish prey is reduced in warmer years (Carey 1992; Best et al. 2008; Roberts et al. 2020).

The breeding population of New Zealand sea lions at the Auckland Islands declined by c. 40% from the late 1990s up until around the year 2009 (Department of Conservation 2019). This population has exhibited multiple biological, demographic, and behavioural indicators of nutritional stress compared with a much smaller mainland population (Augé 2010; Roberts & Doonan 2016) including delayed maturation and sustained periods of low pup mass and survival (Roberts & Doonan 2016; Roberts et al. 2021). This pattern has been attributed to differential population densities comparing the Auckland Islands and mainland New Zealand populations, as well as temporal and spatial variation in prey availability (Augé 2010; Stewart-Sinclair 2013; Roberts & Doonan 2016). In addition, the diet and milk fat content of the Auckland Islands population has been found to vary through time, indicative of changes in prey availability and nutritional status (Riet-Sapriza et al. 2012; Stewart-Sinclair 2013). However, no convincing climate correlates of variable biological and demographic rates have been found to date (Roberts et al. 2020), and the Auckland Islands population has subsequently stabilised with no obvious climatic driver.

3.2.2. Changes in atmospheric climate

The probable changes in the atmospheric climate of New Zealand were briefly described in Section 2, and include: increasing air temperature, increased storm frequency, and strengthened westerlies in winter (Ministry for the Environment 2018). Little is known of how these changes would affect marine mammals occurring around New Zealand, although they may primarily affect pinnipeds, based on their terrestrial activity and breeding. For example, the exceptionally high mortality rate of New Zealand sea lion pups at Campbell Island/Motu Ihupuku in early 2020 was partially attributed to extreme cold and wet weather early in the breeding season (McNutt 2020; Foo and Boren, unpublished data). There is also some evidence that the sea swell can influence the behaviour of Hector’s dolphins in coastal areas, based on a decrease in sighting rates in Akaroa Harbour after big swell events (Dittmann et al. 2016).

Mass stranding events of some New Zealand cetacean species have been associated with stormy sea conditions. For example, strandings of pilot whale species (*Globicephala* spp.) around New Zealand are more likely during periods of increasing air pressure (i.e., after a period of low pressure, consistent with poor weather) in the days before stranding (Brabyn 1990). Six dusky dolphin (*Lagenorhynchus obscurus*) were washed up at the Chatham Islands after a stormy night with heavy onshore swell (Gaskin 1968), and a small number of recorded non-calf Hector’s and Māui dolphin mortalities have been linked to potential storm events (Department of Conservation 2020b). It has also been speculated that some of the beachcast neonate mortalities of South Island Hector’s dolphins recorded as resulting from “maternal separation” could potentially have been caused by storm events, although no definitive cause of death was obtained for most of these mortalities (Department of Conservation 2020b). The authors are not aware of any published evidence of any long-term change in stranding rates of any species, e.g., that might have arisen from a change in the prevalence of stormy sea conditions (Figure 5), although it was not clear if this had been assessed for any single species.

The prevalence and intensity of HAB events may increase with atmospheric (and sea surface) warming, coupled with increased rainfall expected in some regions of New Zealand (summarised by Ministry for the Environment and Stats NZ 2020). A pathological assessment of a mass New Zealand sea lion pup mortality event at the Auckland Islands during the major El Niño event in 1997/98 found no evidence of commonly occurring marine biotoxins in their tissues (Duignan 1999). It is likely that HAB events are more likely to occur around coastal regions of the New Zealand mainland (e.g., HAB events were recorded off the east coast of the South Island in 1997/98 causing mass fish kills) (Duignan 1999). Therefore, HABs should logically be more likely to affect dolphins and pinnipeds using coastal habitat adjacent to harbours and river estuaries.

3.2.3. Acidification

To our knowledge, the direct effects of ocean acidification have not been assessed for any marine mammal species, although they are likely to be extremely minimal for large-bodied vertebrates. Initial tank-based experiments indicate that relatively large-bodied finfish prey species will be relatively unaffected by ocean acidification (Law 2020). Adverse effects on bio-calcifying or small bodied vertebrate prey species are much more probable (Law 2020).

3.2.4. Sea-level rise

As with changes in atmospheric climate, increasing sea level is expected to primarily affect pinnipeds, since they are active and breed on land, often close to sea level (summarised by Schumann et al. 2013). However, the magnitude of sea-level rise up to the present day (c. 20 cm since 1900) (IPCC 2019) is highly unlikely to have affected any of the pinniped species occurring around New Zealand. Furthermore, although New Zealand sea lions and New Zealand fur seals exhibit marked natal philopatry to specific breeding grounds, they are evidently capable of shifting their breeding site depending on conditions, as well as in response to changes in population size through time (McNutt 2020), and so appear well-adapted to the increase in sea level up to the present day.

3.3 Possible future effects on New Zealand marine mammals

In this section we assess the possible impacts of future climate change on marine mammals around New Zealand, in terms of effects on population size and spatial distribution. This uses the taxonomic groupings shown in Table 1, which also includes a summary of the predicted effects from each assessed climate change related hazard, i.e.: increasing sea temperatures, changes in ocean circulation and effects on prey species (which are considered together), changes in atmospheric climate, increasing sea level, and ocean acidification. This assessment was based on a qualitative understanding of the direction of change in projected environmental variables (see Section 3.1), the observed responses of relevant species to climatic variability in the recent period (see Section 3.2), and other relevant published research.

Table 1. Potential effects of assessed climate change threats on the productivity and abundance of marine mammals around New Zealand ("+ve" = mostly positive effects; "-ve" = mostly negative effects; "+/-" = combination of positive and negative effects (e.g., dependent on location in a respective species' range); "–" = unlikely to significantly affect; "?" = information lacking to assess possible effects; "*" = effect already documented/inferred by the literature).The species under each assessment group are shown in Appendix 1.

ASSESSMENT GROUP	WARMING SEA TEMPERATURE, CHANGING OCEAN CIRCULATION, AND PREY	RISING SEA LEVEL	OCEAN ACIDIFICATION	CHANGES IN ATMOSPHERIC CLIMATE
Blue whales	-ve*	–	?	–
Bryde's whale	?	–	?	–
Southern right whale	-ve*	–	?	–
Pygmy right whale	?	–	?	–
Baleen whales (other)	-ve*	–	?	–
Sperm whale	+/-	–	?	–
Kogiids	+ve	–	?	–
Orca	+/-	–	–	–
Globicephalinae	+/-	–	?	–
Māui dolphin	-ve*	–	–	+/-
Hector's dolphin	+/-*	–	–	+/-
Bottlenose dolphin	+/-	–	?	+/-
Common dolphin	+/-	–	-ve	–
Dusky dolphin	+ve	–	-ve	–
Delphinoid (other)	+/-	–	?	–
Beaked whales	?	–	?	–
New Zealand fur seal	+/-*	-ve	-ve	+/-
New Zealand sea lion	?	-ve	–	+/-
Southern elephant seal	-ve*	-ve	-ve	+/-
Leopard seal	-ve	?	+/-	+/-*
Pinniped vagrants	-ve	-ve	?	+/-

Blue whale subspecies

Based on the observed negative relationship between sea surface temperature (SST) and chlorophyll concentration in subtropical waters (Figure 4), projected oceanic warming is likely to decrease the productivity of waters surrounding the North Island of New Zealand and the west coast of the South Island, including some of the upwelling regions used by Antarctic and pygmy blue whales. Based on recent observations (Barlow et al. 2020) it is likely that blue whales will respond by re-optimising their foraging patterns around New Zealand and the wider South Pacific region. Ongoing research based on spatial distribution modelling has predicted distributional changes of blue whales around New Zealand under some climate change scenarios up to the year 2100, and more extensive habitat loss under RCP 8.5 (Katharina Peters, Massey University / University of Canterbury, pers. comm.). Furthermore, the projected decline in krill biomass around the Southern Ocean region is predicted to have significant adverse effects on the recovery of blue whales and other baleen whale species, which may also impact on their abundance around New Zealand (Tulloch et al. 2019).

Bryde's whale

A decrease in productivity has been observed during warmer years in the region of New Zealand used by Bryde's whales, suggesting that their preferred zooplankton prey taxa may move or become less available under projected warming (Colbert 2019). The fine-scale foraging distribution of Bryde's whales around New Zealand is likely to continue to change in response to changes in the spatial availability of suitable prey species. The available information is sparse for assessing the population effects of future climate change on Bryde's whales around New Zealand, although potential climate-mediated changes in diet composition could be monitored using scat samples (e.g., Carroll et al. 2019).

Southern right whale

A southward redistribution of southern right whales has been predicted around New Zealand and the wider south-west Pacific Region under projected warming by the end of this century (Torres et al. 2013). If correct, then southern right whales may become less frequent visitors to the coastal waters of the South Island, although the habitat around their Auckland Islands breeding site may not be any less optimal (Torres et al. 2013), and the subantarctic region of New Zealand is likely to become more productive given projected warming (Figure 4). A decrease in the abundance of their copepod prey of the Southern Ocean was predicted by multispecies models under future climate change scenarios, which may negatively affect the population recovery of southern right whales in the Pacific Region (Tulloch et al. 2019). Note that a recent assessment suggested that the body condition of New Zealand southern right whales was good relative to other populations (Christiansen et al. 2020), although this was based on measurements in one month of a single year only around New Zealand. Changes in wind and wave patterns might affect the future quality of current calving habitat given this species' preference for sheltered conditions (Rayment et al. 2015).

Pygmy right whale

Little is known about the ecology of pygmy right whales (*Caperea marginata*) or of their potential responses to climate change. This species may be less migratory than other baleen whales and, so, may be less able to adapt to the probable changes in oceanographic patterns and food resources around New Zealand (Anton van Helden, New Zealand Department of Conservation, pers. comm.). The data are deficient for assessing the effects of climate change on this species, although potential climate-driven changes in zooplankton prey availability are a plausible stressor (Kemper 2002).

Baleen whales (other)

Other baleen whales occurring around New Zealand were also predicted to be badly affected by warming of the Southern Ocean region affecting their prey there, including fin whale (*Balaenoptera physalus*), humpback whale, and Antarctic minke whale (*B. bonaerensis*) (Tulloch et al. 2019). This may impair their ongoing recovery since the cessation of commercial whaling (Tulloch et al. 2019). Continued warming of the tropical breeding grounds of humpback whales could result in the Kermadec Islands becoming a future breeding ground for this species inside the New Zealand EEZ (Derville et al. 2019).

Sperm whale

Previous studies have found that the spatial distribution and breeding success of overseas sperm whale populations may be affected by temporary oceanic warming, and that this species may be vulnerable to projected climate change effects on their squid prey (Sousa et al. 2019). Ongoing research indicates that oceanic warming may affect sperm whale foraging around New Zealand (Guerra Bobo 2018), and drive longer-term changes in foraging patterns around New Zealand based on projected climate up to the year 2100 (Katharina Peters, Massey University / University of Canterbury, pers. comm.). Given the differential effects of warming on primary production across their range around New Zealand (Figure 4), the spatial foraging patterns of sperm whales around New Zealand may also alter in response to changes in the spatial abundance of their main prey.

Kogiids

Little is known of the ecology or distribution of kogiids – including pygmy (*Kogia breviceps*) and dwarf sperm whales (*K. sima*) – around New Zealand. Based on New Zealand stranding records, the pygmy sperm whale has the more temperate distribution (Bloodworth & Odell 2008) and breeds and calves in the Hikurangi Trough region off the eastern North Island (Anton van Helden, Department of Conservation, pers. comm.). Given projected oceanic warming, the dwarf sperm whale could become more abundant around New Zealand. Both species are known to be teuthophagous (Bloodworth & Marshall 2005; Beatson 2007), such that impacts on climate change effects on squid species may be influential.

Orca

The impacts of projected climate change on New Zealand populations of orca (*Orcinus orca*) are not well-understood, though are likely to vary across the four types known to occur around New Zealand and the Ross Sea area, which have different prey preferences (e.g., Type A orca primarily target minke whales, whereas Type D are thought to be teuthophagous (Anton van Helden, Department of Conservation, pers. comm.)). Based on their broad range of thermal tolerance and diverse prey mix around New Zealand (Department of Conservation 2021), this species appears sufficiently generalist to deal with projected changes to the New Zealand marine environment. However, the New Zealand mainland population is small (150–200 individuals) (Department of Conservation 2021), which may make them vulnerable to local shifts in prey availability. Furthermore, continued surface warming of subtropical waters may cause a reduction in productivity at the base of the food web around the North Island of New Zealand, which could impact on population growth potential and distribution.

Globicephalinae

This taxonomic group includes pilot whale species (*Globicephala* spp.), false killer whale (*Pseudorca crassidens*), Risso's dolphin (*Grampus griseus*), pygmy killer whale (*Feresa attenuata*), and melon-headed whale (*Peponocephala electra*). Not much is known of the ecology of most of these species around New Zealand (false killer whales are the best-studied species; e.g., Zaeschmar et al. 2014), although all are known to be predominantly oceanic (rather than coastal) and squid appear to be a primary prey group for most species. The potential population or distribution effects of projected climate change are not well-understood for any of these species. All except the long-finned pilot whale (*G. melas*) occur in the tropics so might become more prevalent around New Zealand given projected ocean warming. Conversely, long-finned pilot whales may gradually be replaced around New Zealand by their short-finned congener (*G. macrorhynchus*).

Māui dolphin

Māui dolphin are estimated to number fewer than 64 individuals (Constantine et al. 2021) so are innately susceptible to any threat that might compromise their survival or breeding. Their relatively small distributional range is constrained by the availability of suitable turbid water habitat and the availability of their probable main prey species appears to be low relative to the South Island areas occupied by Hector's dolphin (Roberts et al. 2019). The analysis of Derville et al. (2016) identified some areas of potentially suitable habitat around the North Island that are not occupied, although Māui dolphin have never been confirmed from genetic analysis to occur or strand along the north- and east coasts of the North Island (Constantine et al. 2021). Furthermore, Māui dolphin occupy the warm end of the species' distributional range (up to 22°C, according to Derville et al. 2016) and will be closer than South Island Hector's dolphin to the upper limits of their thermal tolerance range. From a physiological perspective, it is likely that the energy requirements of dolphins at northern range limits will increase with ambient sea temperature, as individuals dissipate heat to avoid heat stress (Kastelein et al. 1993), although the thermal tolerance of Māui dolphin, including calves, is unknown. For these reasons, Māui dolphin appear susceptible to the projected environmental changes over the next century, which may result in decreased productivity off the west coast of the North Island (Figure 4). Changes in rainfall, wind and wave patterns may impact on the spatial extent of turbidity plumes, affecting the spatial distribution of Māui dolphins (Roberts et al. 2019), which may have implications for existing spatial management (also relevant to South Island Hector's dolphin).

Hector's dolphin

The distributional range of South Island Hector's dolphins is broad and spans regions that are likely to become less productive under projected climate change (e.g., the west coast of the South Island) and those that may become more productive (e.g., the south-east of the South Island) (Figure 4). Red cod are the main prey of both the east- and west coast populations (Miller et al. 2013), and the recruitment of this species is thought to be responsive to changes in SST, with reduced recruitment strength in warm years (Beentjes & Renwick 2001). Hence, the availability of their main prey might be reduced given the projected warming of subtropical waters. In addition to prey, previous studies have highlighted the importance of surface water turbidity, depth and benthic substrate type in driving their distribution (Bräger et al. 2003; Brough 2018; Roberts et al. 2019). Of these, we speculate that turbidity and perhaps benthic substrate may also be influenced by projected changes in ocean climate and weather patterns. Warming around colder regions of the South Island may be beneficial for the thermoregulation of calves (Kastelein et al. 1993), and may also lead to the southward shift of suitable prey species from the north. The effects of increasing sea level and ocean acidification on the wider species are not well-understood though are suspected to be minimal.

Bottlenose dolphin

Bottlenose dolphins are versatile and evidently can re-optimise their foraging patterns given seasonal changes in prey availability (Hartel et al. 2015) . Bottlenose dolphins have been sighted all around the New Zealand mainland, although appear to be most abundant in warmer waters off the northern North Island (Stephenson et al. 2020). This region is likely to become less productive given oceanic warming during this century (Figure 4), although, based on their high abundance around the Kermadec Islands, bottlenose dolphins appear sufficiently generalist to exploit oligotrophic habitat. They also appear well-adapted to occupy newly optimal habitat as it becomes available. At the sub-population level, the effects of climate change on bottlenose dolphins are likely to be variable, and contingent on local processes. The Fiordland subpopulation is particularly vulnerable, assessed as Critically Endangered by the International Union for Conservation of Nature (IUCN) Red List (Currey et al. 2013), and thus could be particularly at risk from local environmental changes. This population is thought to be the southernmost resident population of bottlenose dolphins worldwide and at the cold-water range limits of the species (Currey et al. 2007), highlighting possible susceptibility to changes in ocean temperature. The Doubtful Sound/Patea population specifically is subject to habitat modification via large quantities of freshwater input from a hydroelectric power station (Gibbs 2001) which may be contributing to a decline in calf survival and thus population decline (Currey et al. 2008; Rowe et al. 2010). Projected warming of the oceans could benefit this subpopulation, however this may be offset if there is an increase in rainfall and thus freshwater input into the system.

Common dolphin

This species is abundant in waters around the North Island and off the west coast of the South Island (Stephenson et al. 2020), which are likely to become less productive by the end of this century (inferred from Figure 4). As such, oceanic warming may negatively affect common dolphins around New Zealand. Assuming a 3°C increase in temperature before the end of this century (under RCP 8.5), common dolphins may be replaced from the north by warmer-water long-beaked common dolphin (*Delphinus delphis tropicalis*), and they may gain a competitive advantage over dusky dolphins to the south, noting that these two species can be sympatric elsewhere (Svendsen et al. 2015).

Dusky dolphin

There is a general lack of long-term monitoring of dusky dolphins that could inform the prediction of climate change effects for this species around New Zealand. Dusky dolphins are likely to be most abundant off the east coast of the South Island (Stephenson et al. 2020), which may become more productive with oceanic warming (inferred from Figure 4). Hence, the New Zealand population may benefit from ocean warming by the end of this century, assuming ambient temperatures do not exceed the species' range of thermal tolerance and ocean acidification does not affect the availability of their preferred myctophid prey (Cipriano 1992).

Other delphinoid species

Several other delphinoid species occur around New Zealand, including species that are more abundant in the tropical and subantarctic regions, which may become more and less frequently sighted around New Zealand, respectively, given continued oceanic warming. As with less-frequently sighted pinniped species, there are likely to be caveats to this general pattern.

Beaked whales

The information for assessing projected climate change effects on beaked whale (Ziphiidae) species is minimal. As with pilot whales and other species belonging to the Globicephalinae, beaked whales are thought to predominantly feed on squid and fish offshore of coastal shelves (MacLeod et al. 2003), which may offer a degree of protection from changes nearer the surface. The effects of climate change will vary by species, contingent on temperature preference, ecology and migratory path (for species considered to migrate, such as Arnoux's beaked whale, *Berardius arnuxii*) (Anton van Helden, Department of Conservation, pers. comm.). For instance, we may see a greater frequency of more tropically distributed beaked whale species around New Zealand with oceanic warming, e.g., dense-beaked whale (*Mesoplodon densirostris*) or ginkgo-toothed beaked whale (*M. ginkgodens*) (see Appendix 1).

Low frequency sounds will travel further through seawater as the oceans acidify (Brewer & Hester 2009), which may affect beaked whale species, based on their relative sensitivity to noise disturbance (Cox et al. 2006).

New Zealand fur seal

New Zealand fur seals are wide-ranging with several demographically independent populations around New Zealand. They are abundant in the subantarctic region and around the South Island and are in the process of recovering their prehistorical breeding population around the North Island (Baird 2011). At the species level they appear to be resilient to the effects of climate change, based on their recent range expansion, their potential for rapid population growth relative to cetaceans, and their diverse mix of prey species, which varies regionally (Boren 2010). However, there are likely to be winners and losers at the sub-population level. The rapid decline of the Westland population since the mid-1990s (Roberts & Neale 2016) was strongly correlated with warm years of reduced upwelling strength in this region (Roberts et al. 2020), and occurred at the same time as a period of probable population growth for the east coast South Island population (Boren 2005). Similarly, subantarctic populations, e.g., at Snares Island and the Bounty Islands, may benefit from increased productivity in this region.

New Zealand fur seals may be more affected by sea-level rise than other New Zealand marine mammal species, given their preference for low-lying rocky habitat for breeding and haul-out sites, particularly in mainland areas where their movement is constrained by coastal sea-defences, roads, and other coastal structures. This species may be more susceptible than others to the effects of ocean acidification given their regional preference for small-bodied finfish prey species (Carey 1992), and to the predicted increase in westerly winds in winter months, which could impact on the survival of pups.

New Zealand sea lion

Much of the summary for New Zealand fur seals is also applicable to New Zealand sea lions, although there are fewer populations, comprising approximately an order of magnitude fewer individuals at the species level, which may increase their susceptibility to climate change effects. The large Auckland Islands population has already displayed periods of protracted population increase, then decline, and then stability, which have variously been attributed to changes in prey availability (Roberts et al. 2018), disease mortality of pups (Michael et al. 2019), and mortalities in commercial fishing nets (Meyer et al. 2017). Based on a predicted increase in productivity across the subantarctic region (Figure 4), New Zealand sea lions at the Auckland Islands might benefit from climate change, although the productivity of this population appears to have been relatively poor during periods of high chlorophyll-a concentration along the subtropical front (Roberts et al. 2020). While climate-driven changes in prey availability are likely to be an important driver of population change, as is likely to be true for Steller sea lions in the North Pacific (Trites et al. 2007), the effects of oceanic warming on subantarctic populations of New Zealand sea lion are difficult to predict.

Any increase in the prevalence or intensity of adverse weather conditions immediately after pupping would be a particular issue for the Campbell Island/Motu Ihupuku population (Foo and Boren, unpublished research). Given the lesser importance of small-bodied prey to their overall dietary mass relative to New Zealand fur seals (Meynier et al. 2009; Boren 2010; Lalas & Webster 2014), ocean acidification may have a relatively minor effect on New Zealand sea lions.

Southern elephant seal

It appears that climate change may already have contributed to the major population decline of southern elephant seals at Campbell Island/Motu Ihupuku (Taylor & Taylor 1989; Hilton et al. 2006). Based on this trend, it is likely that continued warming would ultimately lead to the cessation of breeding by southern elephant seals in the New Zealand subantarctic region, although this could be mitigated to some extent by increased productivity at the base of the food web in this region. The much larger population at Macquarie Island has recently declined in response to an increase in sea-ice duration around these islands (van den Hoff et al. 2014).

This trend was forecast to reverse as the hole in the ozone layer contracts and eventually becomes fully repaired in the Southern Hemisphere by the end of this century (van den Hoff et al. 2014, World Meteorological Organization 2018). The presence of a productive population just to the south of the New Zealand EEZ could facilitate the recolonisation of the New Zealand subantarctic region, if conditions there become optimal again.

Pinniped vagrants and leopard seal

All of the pinniped species attributed with vagrant status by the 2019 New Zealand Threat Classification review (Baker et al. 2019, and see Appendix 1) are most abundant in the Antarctic or subantarctic regions to the south of New Zealand. Based on their apparent cold-water preference, and the predicted poleward shift of marine mammals under projected warming, it appears unlikely that any of these species will become more common inside the New Zealand EEZ over the course of this century. The apparent increase in sightings of leopard seals in recent years is counter to the poleward shift hypothesis (Hupman et al. 2020), indicating that there will be caveats to this overall pattern, although it is not clear if this was driven by an increase in abundance or an increase in sighting effort through time.

4. Discussion

4.1 Limitations of this assessment

This assessment assumed the predicted climate changes that could occur under RCP 8.5. This is essentially a business-as-usual scenario that was selected by DOC to take a 'no regrets' approach to identifying potential risks to marine mammals. Other scenarios routinely used by IPCC (IPCC 2019) would have less pronounced effects on sea temperatures around New Zealand (Ministry for the Environment 2018):

- 0.7°C increase under RCP 2.6 (a "very stringent" emissions mitigation pathway that assumes CO_2 emissions decline to zero by 2100)
- 1.4°C increase under RCP 4.5 (described as an "intermediate" mitigation scenario by the IPCC)
- 1.8°C increase under RCP 6.0
- 3.0°C increase under RCP 8.5.

Sea temperatures are predicted to increase throughout the 21st century for all pathways except RCP 2.6, under which they are predicted to peak in the middle of this century and decline slightly thereafter (Ministry for the Environment 2018). Clearly, climate change impacts on New Zealand marine mammals will vary hugely depending on which of the emission pathways is followed and may be smaller than those occurring under RCP 8.5. For example, Albouy et al. (2020) estimated the vulnerability of global marine mammal assemblages to vary considerably comparing RCPs 2.6 and 8.5, including inside the New Zealand EEZ (Figure 2).

This assessment focused on marine mammals around New Zealand, such that the effects on sea-ice changes were out of scope. However, changes in sea-ice cover are likely to affect most of the NZTCS-assessed species occurring in the Ross Sea dependency to some extent (multiple pinniped species, some baleen whales, and killer whale eco-types) (Baker et al. 2019) and this could ultimately impact on the occurrence of some of these species around New Zealand, where they are considered vagrant species.

The first-pass assessment of climate change hazards was based on a qualitative extrapolation of recent patterns. For many New Zealand marine mammal species, the existing information is sparse for informing even a qualitative assessment of climate change risk. As such, this assessment will probably not be useful for identifying specific management actions for most, if not all, species. Instead, this assessment should be considered as a first step, identifying some of the key threats and priority species for more comprehensive assessment.

4.2 Priority climate change hazards for New Zealand marine mammals

Previous reviews have concluded that alterations in prey availability are likely to be the greatest climate change-related threat for global marine mammals (Learmonth et al. 2006; Schumann et al. 2013; Simmonds 2016). This may have adverse effects at the sub-species level, e.g., on New Zealand fur seals in the Westland region (Best et al. 2008; Roberts and Neale 2016; Roberts et al. 2020), Māui dolphin on the west coast of the North Island, or blue whales foraging at the South Taranaki Bight (Barlow et al. 2020). Several species of the New Zealand subtropical zone were identified that could become more prevalent around New Zealand with projected oceanic warming, including several oceanic dolphins and beaked whales (Table 1). Conversely, several subantarctic species could become scarcer, e.g., southern elephant seal and hourglass dolphin. However, the increased sighting rate of leopard seals around the New Zealand mainland in recent years (Hupman et al. 2020) indicates that there may be nuances to a simplistic pattern of poleward shift, noting that the apparent increase in leopard seal sightings could also have resulted from an increase in effort to record them.

Ocean acidification is likely to have some considerable impacts on the dynamics of food webs. However, unlike ocean warming effects on marine mammals via their prey (e.g., Barlow et al. 2020), we could find no specific examples of ocean acidification effects on marine mammals, and the magnitude of this threat is poorly understood relative to others.

The predicted increase in the prevalence and intensity of HABs may have localised effects on certain coastal species. Compared with factors that affect thermal habitat or prey availability, more frequent and intense HABs, rising sea level, and changes in atmospheric climate appear to be lesser threats to New Zealand marine mammals. However, it appears more feasible to minimise the probability of HABs or to mitigate coastal squeeze (from sea-level rise) on pinnipeds impacted by coastal developments.

4.3 Information gaps

Biological and ecological

Our ability to predict changes in the spatial distribution of marine mammal species may be hampered by a poor understanding of the physiological barriers that can hinder a species' ability to adapt, e.g., thermal tolerance limits beyond which food consumption must increase (Kastelein et al. 1993) or tolerance of ocean acidification. As such, we cannot accurately predict environmental thresholds for any species. However, we may have sufficient spatial information to indirectly infer what these thresholds might be, e.g., based on habitat modelling, noting that each species' distribution will also be shaped by species interactions that may confound the estimation of physiological constraints.

For many New Zealand marine mammal species, we lack quality information for estimating their current spatial distribution or for determining migratory paths. We may also lack basic information of their main prey, or the relevant size fractions or spatial distributions of key prey species. This can hinder our ability to develop relevant indices of prey availability or to assess the indirect effects of climate change via alterations to the marine ecosystem.

The absence of baseline data for a large proportion of New Zealand's marine mammal species is a significant barrier for monitoring population responses to climate variability and long-term change.

Quantitative risk assessment

This first-pass risk assessment of future climate change effects is a qualitative analysis of projected climate change impacts (under RCP 8.5), based on the extrapolation of recent observed trends. A fully quantitative assessment of recent/future climate change effects would be more challenging.

Threat Management Plans have been developed for New Zealand sea lions as well as Hector's and Māui dolphins, which were informed by multi-threat risk assessments (Roberts & Doonan 2016; Roberts et al. 2019). These risk assessments highlighted the potential threat of future climate change for these species, although, given the available information, were not able to satisfactorily assess or predict the population risk posed by climate change. This issue is probably true for most, if not all, New Zealand marine mammal species and is problematic for at least three reasons:

1. It is currently not possible to assess the urgency with which climate change hazards must be addressed to meet conservation management goals.
2. We are unable to assess the population risk posed by climate change relative to other anthropogenic threats, with the consequence that climate change hazards are likely to be overlooked.
3. While it is recognised that other anthropogenic threats to marine mammals will need to be managed in the context of climate change effects on their habitat, these cumulative effects cannot be assessed quantitatively.

Therefore, the plugging of information gaps required specifically for the *quantitative* assessment of climate change risk will help with the prioritisation of climate change hazards relative to other threats and help to focus the conservation response.

Approaches for the quantitative assessment of climate change effects include describing the relationship between environmental variables and reproductive demographic rates, which will be most responsive to changes in prey availability (Gaillard et al. 2000), or relationships with other measures/correlates of annual fecundity, such as time series of pinniped pup mass or the prevalence of cetacean offspring in pods (Webster 2008; Roberts & Neale 2016). Where established, these relationships can then be used as covariates in population risk models (e.g., Edwards and Roberts 2021). Note that correlative analyses relating key demographic rates to environmental variables benefit from 'marker years' of anomalous environmental conditions. This provides contrast for identifying relationships between climate indices and measures of marine mammal productivity.

Ecosystem models (e.g., ATLANTIS) (Audzijonyte et al. 2019) provide an input and assumption-hungry means of assessing climate change effects on marine mammal populations, while accounting for ecosystem effects. Models-of-intermediate-complexity-for-ecosystem-assessment (MICE) (e.g., Tulloch et al. 2019) can also do this, although will typically require far fewer untestable assumptions than ecosystem models and may be a better starting point for simulating the ecosystem effects of climate change.

Internationally, several approaches have now been developed for the quantitative risk assessment of climate change effects on marine mammals including spatial approaches (e.g., Albouy et al. 2020; Lettrich et al. 2019; Sousa et al. 2019), which could potentially be adapted for New Zealand marine mammals.

4.4 Recommendations

Monitoring

The monitoring of population size or demographic rates (from which population trajectory may be determined) is required to assess population responses to climate change. For example, Simmonds (2016) highlighted the need for good-quality long-term data sets for the quantitative assessment of climate change impacts on marine mammals. This is challenging because surveys for marine mammals tend to be expensive and time consuming. The most recent New Zealand Threat Classification review listed 30 marine mammal species as "Data Deficient" for the purposes of assessment (Baker et al. 2019). However, developments in remote sensing capabilities (e.g., acoustic buoys, drones, satellite imagery) may reduce the costs of monitoring in the future.

Where it is difficult to monitor population change directly, monitoring could instead focus on changes in breeding rate / age at first breeding (Gaillard et al. 2000) or biological rates that can proxy for this (e.g., body condition, or calf frequencies in groups).

Due to the considerable expense of obtaining annual snapshots of spatial distribution of marine mammal species, the monitoring of spatial distribution through time can, instead, be based on habitat models applied to temporally dynamic climate variables. However, this requires the application of rigorous approaches to habitat model development to ensure that the key drivers of distribution are represented. In practice, this will typically require a good prior understanding of a species' habitat requirements and the ability to produce good quality habitat observations in time and space (including of prey species). For the purposes of predicting into the future, the relevant habitat variables must also be available for this period (e.g., from Earth System Models).

Conservation management

Future conservation management planning should be established with climate adaptation strategies in mind (see Wilson et al. 2020). This should include the identification and removal of legislative barriers to necessary adaptations.

With respect to existing and future area-based management, adaptive management will almost certainly need to consider changes in species' distributions that are likely to occur given predicted changes in ocean climate and circulation patterns. A standard approach is to use habitat models including key variables that will be influenced by climatic variation (e.g., SST, proximity to oceanographic fronts and upwellings, etc.) to predict their spatial abundance/ presence given projected ocean climate. Consideration could be given to flexible area management, based on temporally dynamic oceanographic features and/or prey distributions, rather than fixed areas, as advocated for by Barlow et al. (2020).

With respect to fisheries, there will be resource overlap with some marine mammals that could be addressed via fisheries management. Climate driven changes in fish recruitment and biomass can be estimated from stock assessment models and using catch rate information, which can be informative of changes in prey availability through time. Some marine mammals interact more aggressively with fishing gear during periods of low prey availability (most obvious when driven by abrupt changes in climate) and understanding this could help with both the estimation and mitigation of fishery-related deaths.

With respect to coastal management, the mitigation of climate change effects on eutrophication and the prevalence and intensity of toxic algal blooms may be addressed by targeted improvements to water quality management and the control of discharges to the marine environment. Modifications to coastal sea defences to adapt to sea-level rise can exacerbate the potential impacts on coastal marine mammals, especially pinnipeds, via the degradation of littoral habitat and impaired access to preferred terrestrial breeding sites.

Apart from minimising fossil fuel emissions, managing the potential indirect effects of fishing, and coastal management activities, little else can be done to mitigate the effects of climate variables and ocean acidification on marine mammal prey. Depending on which RCP scenario turns out to be most accurate, these are issues that conservation efforts will largely be limited to understanding and managing around.

Collaborative approaches

Expertise with respect to New Zealand marine mammals tends to be restricted to a specific taxon or set of analytical skills. There is a strong need for collaboration across the New Zealand and international community of scientists, policy makers, stakeholders, tangata whenua, and the public. This would facilitate knowledge-sharing where commonalities exist across marine species and climate change threats. Scientific research should extend wider than the marine mammal community, e.g., knowledge on changing prey distribution will be important for other areas of marine science including the assessment of fish stocks. Collaboration would be facilitated by managers, scientists, and advisors working in cross-functional teams to find efficiencies across ecosystem components.

Opportunities for collaboration include data and resource sharing, academic conferences, workshops and hui for sharing and planning research, engagement with international fora such as the International Whaling Commission, and participation in national programmes including risk assessments. To this end, DOC is interested in maintaining relationships with relevant researchers within New Zealand and identifying other interested practitioners with a view to facilitating collaboration and communication for the development of research ideas and disseminating current research.

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Appendix 1

List of New Zealand marine mammal species considered by this assessment

'Assessment group' is the taxonomic unit used for the first-pass risk assessment.
'Status' is the latest New Zealand threat Classification status for each species/sub-species (Baker et al. 2019): NT = Not threatened; T-NC = Threatened – Nationally Critical; T-NE = Threatened – Nationally Endangered; T-NV = Threatened – Nationally Vulnerable; AR-R = At-risk – Recovering; AR-NU = At-risk – Naturally Uncommon; NRN-M = Non-resident Native – Migrant; NRN-V = Non-resident Native – Vagrant; DD = Data deficient.
'Range' indicates whether each species' global range has a warm (W = occurs in the tropics), cold (C = occurs in the Antarctic or subantarctic) or temperate distribution (T = occurs in both the tropics and subantarctic, or endemic to the coastal waters of the New Zealand mainland).

SPECIES/SUB-SPECIES	ASSESSMENT GROUP	STATUS	RANGE	MIGRATORY
Baleen whales (Mysticeti)				
Bryde's whale (*Balaenoptera edeni brydei*)	Bryde's whale	T-NC	W	Y
Pygmy blue whale (*Balaenoptera musculus brevicauda*)	Blue whales	DD	W	Y
Antarctic blue whale (*Balaenoptera musculus intermedia*)	Blue whales	DD	T	Y
Dwarf minke whale (*Balaenoptera acutorostrata* "dwarf")	Baleen whales (other)	DD	T	Y
Pygmy right whale (*Caperea marginate*)	Pygmy right whale	DD	T	?
Humpback whale (*Megaptera novaeangliae*)	Baleen whales (other)	NRN-M	T	Y
Southern right whale (*Eubalaena australis*)	Southern right whale	AR-R	C	Y
Antarctic minke whale (*Balaenoptera bonaerensis*)	Baleen whales (other)	DD	C	Y
Sei whale (*Balaenoptera borealis*)	Baleen whales (other)	DD	C	Y
Fin whale (*Balaenoptera physalus*)	Baleen whales (other)	DD	C	Y
Sperm whale and kogiids (Physeteroidea)				
Pygmy sperm whale (*Kogia breviceps*)[a]	Kogiids	DD	W	?
Dwarf sperm whale (*Kogia sima*)	Kogiids	DD	W	?
Sperm whale (*Physeter macrocephalus*)	Sperm whale	DD	T	Y
Orca				
Orca, killer whale (*Orcinus orca*)	Orca	T-NC	T	?
Orca, killer whale (*Orcinus orca*) 'Type B'	Orca	NRN-V	C	Y
Orca, killer whale (*Orcinus orca*) 'Type C'	Orca	NRN-V	C	Y
Orca, killer whale (*Orcinus orca*) 'Type D'	Orca	NRN-V	C	?
Globicephalinae				
Risso's dolphin (*Grampus griseus*)	Globicephalinae	DD	W	?
False killer whale (*Pseudorca crassidens*)	Globicephalinae	AR-NU	W	?
Pygmy killer whale (*Feresa attenuate*)	Globicephalinae	NRN-V	W	N
Melon-headed whale (*Peponocephala electra*)	Globicephalinae	NRN-V	W	?
Short-finned pilot whale (*Globicephala macrorhynchus*)	Globicephalinae	DD	W	?
Long-finned pilot whale (*Globicephala melas*)	Globicephalinae	NT	C	?
Small dolphins (Delphinidae)				
Bottlenose dolphin (*Tursiops truncates*)	Bottlenose dolphin	T-NE	W	Y
Pantropical spotted dolphin (*Stenella attenuate*)	Delphinoid other	NRN-V	W	Y
Fraser's dolphin (*Lagenodelphis hosei*)	Delphinoid other	DD	W	?
Striped dolphin (*Stenella coeruleoalba*)	Delphinoid other	DD	W	?
Rough-toothed dolphin (*Steno bredanensis*)	Delphinoid other	DD	W	?

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Appendix 1 continued

SPECIES / SUB-SPECIES	ASSESSMENT GROUP	STATUS	RANGE	MIGRATORY
Hector's dolphin (*Cephalorhynchus hectori hectori*)	Hector's dolphin	T-NV	T	N
Māui dolphin (*Cephalorhynchus hectori maui*)	Māui dolphin	T-NC	T	N
Common dolphin (*Delphinus* spp.)[b]	Common dolphin	NT	T	?
Dusky dolphin (*Lagenorhynchus obscurus*)	Dusky dolphin	NT	T	Y
Southern right whale dolphin (*Lissodelphis peronii*)	Delphinoid other	DD	C	Y
Spectacled porpoise (*Phocoena dioptrica*)	Delphinoid other	DD	C	?
Hourglass dolphin (*Lagenorhynchus cruciger*)	Delphinoid other	DD	C	Y
Beaked whales (Ziphiidae)				
Pygmy beaked whale (*Mesoplodon peruvianus*)	Beaked whales	DD	W	?
Goose-beaked whale (*Ziphius cavirostris*)	Beaked whales	DD	W	?
Dense-beaked whale (*Mesoplodon densirostris*)	Beaked whales	DD	W	?
Ginkgo-toothed beaked whale (*Mesoplodon ginkgodens*)	Beaked whales	DD	W	?
Hector's beaked whale (*Mesoplodon hectori*)	Beaked whales	DD	T	?
Strap-toothed whale (*Mesoplodon layardii*)	Beaked whales	DD	T	?
True's beaked whale (*Mesoplodon mirus*)	Beaked whales	DD	T	?
Spade-toothed whale (*Mesoplodon traversii*)	Beaked whales	DD	T	?
Shepherd's beaked whale (*Tasmacetus shepherdi*)	Beaked whales	DD	T	?
Gray's beaked whale (*Mesoplodon grayi*)	Beaked whales	NT	T	?
Andrews' beaked whale (*Mesoplodon bowdoini*)	Beaked whales	DD	T	?
Arnoux's beaked whale (*Berardius arnuxii*)	Beaked whales	DD	C	Y
Southern bottlenose whale (*Hyperoodon planifrons*)	Beaked whales	DD	C	?
Pinnipeds				
New Zealand sea lion (*Phocarctos hookeri*)	New Zealand sea lion	T-NV	T	N
New Zealand fur seal (*Arctocephalus forsteri*)	New Zealand fur seal	NT	T	N
Leopard seal (*Hydrurga leptonyx*)	Leopard seal	AR-NU	C	N
Southern elephant seal (*Mirounga leonine*)	Southern elephant seal	T-NC	C	N
Antarctic fur seal (*Arctocephalus gazella*)	Pinniped vagrants	NRN-V	C	N
Subantarctic fur seal (*Arctocephalus tropicalis*)	Pinniped vagrants	NRN-V	C	N
Weddell seal (*Leptonychotes weddellii*)	Pinniped vagrants	NRN-V	C	N
Crabeater seal (*Lobodon carcinophaga*)	Pinniped vagrants	NRN-V	C	N
Ross seal (*Ommatophoca rossi*)	Pinniped vagrants	NRN-V	C	N

[a] Pygmy sperm whale: While this species occurs in the tropics, they appear to breed at certain locations around New Zealand (Baker & van Helden 1990), so could also be considered as having a temperate distribution.

[b] Common dolphin: two species of common dolphins occur around New Zealand: the short-beaked common dolphin (*D. delphis*), and the long-beaked common dolphin (*D. capensis*). No distinction is made between these by this review, which are collectively referred to as common dolphins.