Climate Change Risk Assessment for Terrestrial Species and Ecosystems in the Auckland Region

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Te Kaunihera o Tāmaki Makaurau

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Climate Change Risk Assessment series 2019

Climate Change Risk Assessment 2019

As communities across the world set out to plan for climate change mitigation and adaptation, they first seek to understand how climate change will affect their city, region, or country.

The Climate Change Risk Assessment (CCRA) has been produced by Auckland Council's Research and Evaluation Unit (RIMU) in support of the Auckland Climate Action Plan (ACAP) at the request of the Chief Sustainability Office. Its aim is to provide information about the risk and vulnerabilities the Auckland region may face under a changing climate regime, which is already underway. In 2018, national climate change projections were scaled-down to produce a more specific picture of their likely effects within the Auckland region. Based on this, CCRA adopted the Intergovernmental Panel on Climate Change's (IPCC) representative concentration pathway (RCP) 8.5 ("business as usual") scenario as its guiding projection, given the lack of evidence of any meaningful and sustained decreases in emissions that would shift to other projection pathways.

The eight reports in the CCRA consider various components of key risks – that is, hazard, exposure, and vulnerability – across sectors and systems of interest: people (heat vulnerability, climate change and air quality), society (social vulnerability and flooding), and natural environment (terrestrial and marine ecosystems), as well sea level rise at regional and local scales. A summary report has also been produced.

Titles in the Climate Change Risk Assessment series:

An assessment of vulnerability to climate change in Auckland
Fernandez, M. A. and N. E. Golubiewski (2019)

Development of the Auckland Heat Vulnerability Index
Joynt, J. L. R. and N. E. Golubiewski (2019)

Air quality and societal impacts from predicted climate change in Auckland
Talbot, N. (2019)

Climate change risk assessment for terrestrial species and ecosystems in the Auckland region
Bishop, C. D. and T. J. Landers (2019)

Climate change risk assessment for Auckland's marine and freshwater ecosystems
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Auckland's exposure to sea level rise: Part 1 – Regional inventory
Golubiewski, N. E., K. Balderston, C. Hu and J. Boyle (2019)

Auckland's exposure to sea level rise: Part 2 – Local inventory (forthcoming)
Boyle, J., N. E. Golubiewski, K. Balderston and C. Hu (2019)

Summary: *Climate change risks in Auckland*
Auckland Council (2019). Prepared by Arup for Auckland Council

Executive summary

Anthropogenic (human-caused) climate change has the potential to radically alter ecosystems throughout the world, including the Auckland region. In particular, climate change poses significant challenges for ecosystem conservation and is predicted to become a major threat to biodiversity in the 21st century. Climate change risk assessments looking at species at risk have become very common overseas, however in New Zealand and particularly in Auckland, assessments of species and ecosystems have been limited. This lack of spatially explicit models of risk to ecosystems and species makes it difficult for science to inform conservation planning and land management.

This report represents a first attempt at a risk and vulnerabilities assessment for Auckland's terrestrial ecosystems and species. In it we assess some of the possible effects of climate change on Auckland's terrestrial ecosystems, indigenous species, and invasive pest species. As part of this assessment we attempt to identify which species and ecosystems are most at risk of negative impacts from climate change.

Uncertainty is the key message with respect to climate change effects on Auckland's terrestrial species and ecosystems. Overseas research shows that climate impacts are highly variable, depending on the taxonomic group, spatial scales and time periods considered. However, the majority of these studies do indicate alarming consequences for biodiversity. The interaction between native and exotic biodiversity in their response(s) to climate change is particularly important and these inter-species relationships are very complex and varied in time and space.

Almost all of Auckland's indigenous terrestrial ecosystems are already under threat from introduced animal pests and/ or plant pests, and lowland ecosystems are also at risk from ongoing clearance and fragmentation of habitat. Therefore, potentially the most serious and pressing impacts of climate change arise through its interaction with these pre-existing threats. Despite the critical research need, there is almost no specifically-targeted research on how climate change will affect the relative ecological fitness of pest plants versus native species in any of Auckland's indigenous ecosystems.

We used spatial data on the distribution of Auckland's 48 terrestrial ecosystem types, and published information on previously identified threats, to assess their vulnerability to six different climatic 'risk factors'. These risk factors were: more than 10 per cent of the regional extent of an ecosystem type being vulnerable to inundation in a 100-year flood; more than 10 per cent of regional extent lying within 50m of the coast; more than 30 per cent of regional extent lying within 500m of the coast; ecosystem types with a highly restricted distribution (<200ha total regional extent); ecosystems with their climatic limits in Auckland region; and ecosystems for which climate change had been identified as a specific threat.

Twenty (42%) of Auckland's 48 different indigenous ecosystem types were identified as having at least one risk factor that has the potential to make them more susceptible to the negative impact(s) of from climate change. And this rises to 28 (58%) if climate change effects increase the virulence and/ or spread of myrtle rust and kauri dieback. Some ecosystems – in particular coastal turf, oioi restiad-rushland and reedland, kauri-towai-rata montane podocarp forest, and pohutukawa-puriri broadleaved forest – are exposed to multiple risk factors. It seems reasonable to expect that ecosystems which are exposed to a higher number of risk factors are more likely to be negatively impacted by climate change. However, the relative vulnerability of ecosystems to the different threats is very difficult to assess without better data on exactly how they will respond to specific climatic drivers and stresses. Thirteen per cent of the total area of Auckland's indigenous ecosystems lie within the inundation zone of a 100-year storm surge event; including 78 per cent of the different ecosystem types. Thirteen (27%) of the ecosystem types have more than half of their regional extent within the 100-year storm surge inundation zone.

We also assessed the risk of individual species for a range of different taxa. Overseas studies have shown that a number of bat species are sensitive to climate change, and Auckland's bats will need enhanced active management to have the resilience to survive these challenges. Auckland's Herpetofauna are already stressed due to a range of existing threats and are also at risk of climate change impacts. New Zealand's invertebrates are one of the least studied groups of biodiversity. This general lack of knowledge and research activity in New Zealand invertebrates means the largest challenge is attempting to understand what their risks and vulnerabilities to climate change are. Climate-related changes in Auckland may add a variety of additional stresses to birds. An international assessment of birds found as many as nine per cent of all birds are vulnerable to climate change, and this number may be higher in Auckland given the low conservation status of many of our indigenous bird species. Auckland's seabirds are already in a delicate state with the majority of the 24 species 'at risk' or 'threatened' with extinction and the effects of climate change are challenging to assess for seabirds with limited species information available. Our best estimate of the major climate change effects most relevant to seabirds generally shows a low risk for most species in regards to sea level rise and increased pest pressure, but potentially moderate risk from increased severe weather events.

The Auckland region is home to at least 63 different threatened plant species and climate change has not been identified as a specific threat for any of these species. However, it is possible that climate change could interact and exacerbate identified threats such as physical disturbance and erosion, drought, fire and/ or weed invasion. The impact of climate change on the relative competitiveness of threatened verses weedy plant species is of crucial importance, as past experience with weed impacts in New Zealand suggests that native plants are often at a competitive disadvantage when compared to introduced species; particularly in disturbed, high-light environments that may become more common due to the impact of more frequent and severe weather events such as droughts and storms.

There is a complete absence of quantitative research on key climatic tipping points for Auckland's ecosystems. This type of data is of critical importance in order to understand the risks of different climate change effects and to inform adaptive management approaches to dealing with the negative impacts of climate change in the future. Therefore, commitment to the collection of long-term ecological datasets is an absolute imperative in order to improve our understanding of how Auckland's ecosystems will respond to the impact of climate change. However, it will probably be decades before this data is able to provide definitive answers to the many important questions about the impact(s) of climate change on Auckland's terrestrial ecosystems and species, and how to best manage them.

The potential serious impact of climate change on Auckland's indigenous terrestrial ecosystems, the lack of information about the best response to these impacts, and the time-lag associated with collecting ecosystem data means that action(s) to manage climate change threats will need to be taken before complete information is available. A common approach to this problem is to embed research, and its evaluation, as an interactive part of ecosystem management from its initiation in a process called adaptive management or 'learning by doing'. Taking a 'wait and see' approach in the absence of robust data is not an acceptable outcome.

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1.0 Introduction

1.1 Background

Auckland's land area, which is approximately 489,400ha in extent, includes a diverse range of ecosystems, species and landforms. The region's land and land-margins are home to at least 48 distinctive and different types of ecosystems (Singers et al. 2017). Collectively, these ecosystems provide habitat for a wide variety of native plants, animals and microorganisms, most of which are unique to New Zealand; there are over 20,000 indigenous plant and animal species in the region (Auckland Council 2015).

Anthropogenic (human-caused) climate change has the potential to radically alter ecosystems throughout the world (Primack 2014) including the Auckland region. In particular, climate change poses significant challenges for ecosystem conservation and is predicted to become a major threat to biodiversity in the 21st century, but accurate predictions and effective solutions have proven difficult to formulate (Dawson et al. 2011). At regional scales, climate change may lead to extensive shifts in species distributions and widespread extirpations or extinctions (Bradley 2010). Pearce et al. (2018) identified a number of predicted changes to Auckland's environment due to climate change, including a brief summary of potential effects on biodiversity as a result of the predicted changes to rainfall, increased storm and drought events, sea level rise, and increased temperatures.

Climate change risk assessments identifying species at risk have become very common overseas (Tonmoy et al. 2014), however there are few for New Zealand species and ecosystems, and even fewer for Auckland species and ecosystems. Therefore, there is a lack of sufficient knowledge about indigenous biodiversity that would allow adequate assessments of the three major components of vulnerability: sensitivity, exposure and adaptive capacity (Glick et al. 2011, Dawson et al. 2011). There are also challenges with bioclimatic modelling to assess changes in species distributions and other biological parameters with a variety of approaches used but little consensus regarding the performance of the models (Araújo and Rahbek 2006). This lack of spatially explicit models of risk to ecosystems and species makes it difficult for science to inform conservation planning and land management (Bradley 2010).

1.2 Impacts of climate change

General impact of climate change

Climate change requires terrestrial ecosystems and species to adapt to both changes in mean climate variables and to increased variability with greater risk of extreme weather events (Kolstrom et al. 2011), and sea level rise. However, the impact of climate change on terrestrial ecosystems is not limited to direct effects, such as storm damage, increased drought, or the impact of elevated temperatures on photosynthesis. Rather, climate change has the potential to initiate multiple, interacting processes that affect ecosystems (Williamson et al. 2009), some positive and others negative (Sturrock et al. 2011).

The variable response of different indigenous species, and competing plant and animal pests, to climate change means it has the potential to fundamentally alter the composition, structure and biogeography of ecosystems (Allen et al. 2010). To date, many studies have concentrated on the effects of climate change on individuals and species (e.g. Root et al. 2003, Walther 2004). However, assessing actual effects of climatic changes on specific ecosystems is complicated by possible changes in inter-species competition and other biotic interactions (Walther 2010). Species show differential responses to climate change effects – both within and across trophic levels (Edwards and Richardson 2004, Both et al. 2009) – and these differential responses have significant consequences in determining the way in which climate change will impact the species composition and functioning of ecosystems (ibid.).

A further complication relates to the phenomenon of ‘extinction debt’ (Tilman et al. 1994) the process whereby species and ecosystems are still reacting to the impact of historical habitat loss and disruptions and have yet to reach equilibrium with their current conditions (Tanentzap et al. 2012). This is particularly the case for New Zealand’s lowland ecosystems, which have been particularly impacted by habitat loss and fragmentation, plant and animal pests, and species loss (Walker et al. 2006).

Anticipating how climate change will affect mutualistic and antagonistic interactions among species (such as predator and prey interactions) and ecosystems represents an important research and monitoring challenge (Schmitz and Barton 2014). A recurrent finding in climate change research is that there is substantial variability among studies in both the magnitude and direction of the effects of any given climate change driver on any given type of biotic interaction (Tylianakis et al. 2008, Bellard et al. 2012, Asseng et al. 2013, Pacifici et al. 2015). Extrapolating these complex impacts across entire networks of species interactions yields unanticipated effects on ecosystems (ibid.) and a high level of uncertainty is inherent within any climate change impact assessment (Lindner et al. 2014).

Given the uncertainty surrounding climate change predictions, the information presented in this report should be considered only as a first step in our climate change risk assessments for Auckland's unique and special terrestrial biodiversity. We identify areas of possible risk for specific species and ecosystems, but the uncertainty means that considerable research will be required to better inform the council's biodiversity management in response to climate change threats.

Climate change in the Auckland region

Forests – which are the dominant terrestrial ecosystem in the Auckland region - are likely to show complex transient responses to rapid changes in climate (Prentice et al. 1993). This is because changes in mean climate can have significant effects on terrestrial ecosystem through a wide range of pathways, including: primary productivity (Melillo et al. 1993); altered phenology (Kramer et al. 2000, Parmesan 2006, Bertin 2008); population, life-history and species composition changes (McCarty 2001); changes in growing season (Stenseth et al. 2002); increased risk of damage from pests and diseases (Kurz et al. 2008, van Mantgem et al. 2009, Allen et al. 2010, Tubby and Weather 2010) and altered geographical distribution (Parmesan 2006).

Ecosystem level impacts of climate change are the net result of impacts on individual species, and the projected changes to Auckland's environment from climate change may have a range of effects on native and introduced species. These may include changes to their distributions, both altitudinally and latitudinally (Hickling et al., 2006, Parmesan and Yohe, 2003, Lenoir et al., 2008), changes to phenology such as timing of breeding (Crick et al. 1997, Fitter and Fitter 2002), reduced genetic diversity (Bellard et al. 2012), changes in productivity (O'Neill et al. 2008, Reyer et al. 2014), increased physical disturbance and loss from weather extremes such as droughts and storms (Parmesan et al. 2000, Thibault and Brown 2008) and increased risks from invasive species (Thuiller et al., 2008). These changes can have overall effects on population dynamics and abundances (Jenouvrier 2013). Native species, particularly those which are 'at risk' or 'threatened' (Townsend et al. 2008), are those of most concern as increased pressures on already stressed populations may arise from climate related changes.

Climate change can affect ecosystems and species - both directly and indirectly - through disturbances. Disturbance is an integral 'part of life' for ecosystems and therefore most indigenous plants and animals are adapted to some level of natural disturbance. However, climate change can affect ecosystems by altering the frequency, intensity, duration and timing of fire, drought, disease and pathogen outbreaks, and disturbances from storms and cyclones (Dale et al. 2001). Climate change will increase the frequency and severity of climatic extremes (Pearce et al. 2017) which has resulting effects – both direct and indirect - on ecosystem extent, structure and function.

Every terrestrial ecosystem is subject to a range of disturbances, ranging from those that barely alter the structure, species composition or health of the ecosystem to those that dramatically change it (Bormann and Likens 1979). An extensive literature supports the hypothesis that natural disturbance is fundamental to the development of structure and function of forest ecosystems (Pickett and White 1985, Attiwill 1994) and the Auckland region has undergone dramatic changes in the extent and composition of different ecosystem types over the past 50,000 years in response to changes in climate, sea level and associated disturbance regimes (Newnham 1990, Newnham and Grant-Mackie 1993, Newnham et al. 2007). However, the speed and extent of these pre-human changes are considerably slower than changes due to anthropogenic impacts, particularly since European colonisation of Auckland. For example, Sandiford et al. (2003) outline vegetation change in southern Auckland from beech dominated forest, scrub and grassland c.18,000 years ago to a forested landscape dominated by conifers and other angiosperm trees as the climate warmed during the Holocene. This transition took place over c.10,000 years, was dominated by forest trees and was exclusively confined to indigenous plants. In the last 150 years Auckland has lost more than 70% of its indigenous forest cover (Figure 1), most of which has been replaced grassland that is largely comprised of exotic plants.

The Auckland region lies within the temperate broadleaf and mixed forests biome (Olson et al. 2001). This means that if the continual disturbance from agricultural activity, vegetation clearance or other artificial sources is removed, most locations would revert to some type of forest ecosystem via scrub and shrubland. Until the arrival of humans around 800 years ago, indigenous forest covered most of the terrestrial parts the Auckland region for at least the last 18,000 years (Lancashire et al. 2002). Auckland's ecosystems have been modified over the ages by natural processes such as fluctuating sea levels, changing climate and volcanic activity. The main challenges relating to impact of climate change on Auckland's ecosystems in the current context are the speed of change – which is much more rapid compared to past climate change events – and the landscape within which the change is occurring. Most of Auckland's indigenous ecosystems and particularly its threatened ecosystems comprise tiny 'island' remnants of habitat surrounded by a 'sea' of exotic pasture, pine plantations and urban development.

The extent of Auckland's native ecosystems has been dramatically reduced over the past 300 years In pre-human times approximately 96% of the Auckland region's land area was covered in native scrub and forest, reducing to 27% by 2012 (Figure 1), a

72% reduction in extent (Auckland Council ecosystem extent data). For freshwater wetlands, which would have comprised much of the remaining 4% of pre-settlement land cover, the loss has been even more dramatic; up to 99%+ in the fertile, lowland parts of the region. Until the mid-late twentieth century native ecosystems were progressively replaced with exotic dominant ecosystems, such as pasture and pine plantations, in rural parts of the region. Unprotected remnants of native habitat within and around the Auckland metropolitan area were also cleared, re-contoured and covered with urban development.

The loss and fragmentation of Auckland's ecosystems has occurred at the same time as an unprecedented and dramatic 'invasion' of exotic plants and animals from all parts of the globe. This 'invasion' is mostly the result of the intentional and unintentional introductions by humans of insects (Margaritopoulos et al. 2009, Garnas et al. 2016), vertebrate animals (Atkinson 2006) and plants (Mack and Lonsdale 2001) as a result of the increasing volume of global trade (*ibid.*, Margaritopoulos et al. 2009) and tourism (Pickering and Mount 2010). Increasing both trade and tourism are widely regarded as being critical to New Zealand's economic success and are projected to continue to increase in the future, at least in the short to medium term.

Many of these exotic plants (e.g. *Tradescantia*, moth plant, ginger, climbing asparagus) and animals (e.g. rat species, mice, possum, stoat, pig) have become severe pests of indigenous ecosystems. Fragmentation and disturbance of native ecosystems has assisted the invasion of animal and plant pests (Figure 2) by substantially increasing edge-to-area ratio of indigenous vegetation remnants, providing open sites for weed establishment, and introducing new disturbance regimes which favour exotic over native biodiversity (e.g. fire disturbance).

Therefore, many native ecosystems are likely to be more vulnerable to the negative impacts of climate change because:

1. Many are already under high stress due to their reduced and highly fragmented distributions, and the constant depredations of plant and animal pests (Figure 1 a and b). This high level of background stress makes them more vulnerable to the synergistic stresses associated with climate change (Laurance and Williamson 2001, Camarero et al. 2011, Fox et al. 2014).
2. The severely reduced area of many of Auckland's ecosystem types (Figure 2) means they are more vulnerable to being wiped out or severely affected 'by chance' in a severe weather event.

3. The main mechanism by which the constituent species of ecosystems can adapt to climate change – latitudinal or altitudinal migration over time – is much more difficult in a fragmented landscape dominated by exotic ecosystems.

Many of the current threats to the long-term viability of forest ecosystems in the Auckland region relate to human impacts (Singers et al. 2017) – e.g. habitat destruction and fragmentation, invasion by pest plants, pest animal browse and predation, browse and trampling by domestic stock - rather than climate change. While climate change is likely to exacerbate some of these human impacts (e.g. Sheppard 2013), they can be considered, for the present at least, a bigger threat to many of Auckland's indigenous species and ecosystems.

In this report we assess some of the possible effects of climate change on Auckland's terrestrial ecosystems, indigenous species, and invasive pest species. As part of this assessment we attempt to identify which species and ecosystems are most at risk of negative impacts from climate change. With little species data available for Auckland species, it is not possible to provide an in-depth analysis of individual taxa however we provide comments on the major taxonomic groups as well as a case study risk assessment of Auckland's seabirds using expert opinion (Todd Landers, seabird ecologist).

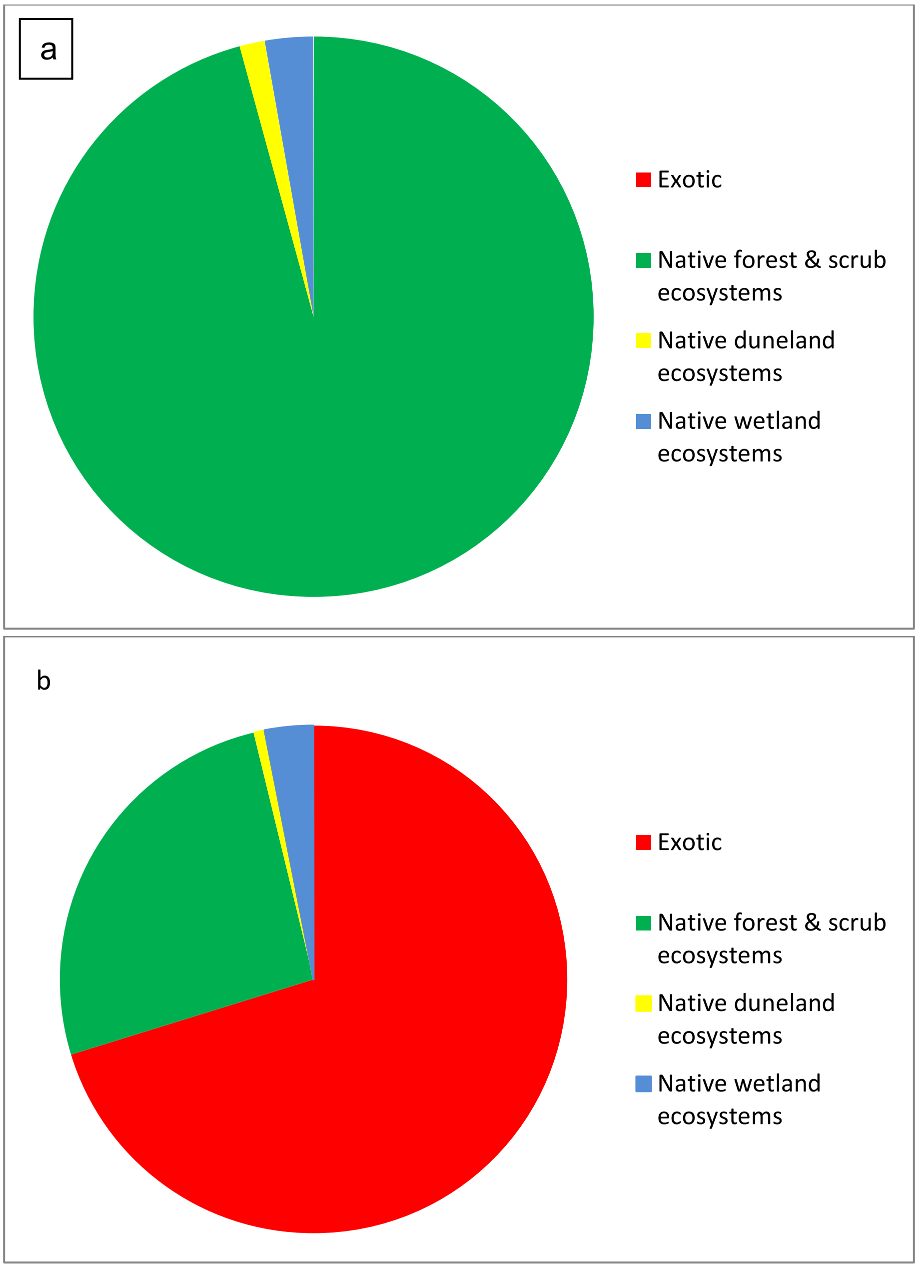

Figure 1: a) Estimated historic/ potential proportion of Auckland's terrestrial ecosystem types (total land area = 480,000ha) and b) Current proportions of Auckland's terrestrial ecosystem types (total land area = 480,000ha).

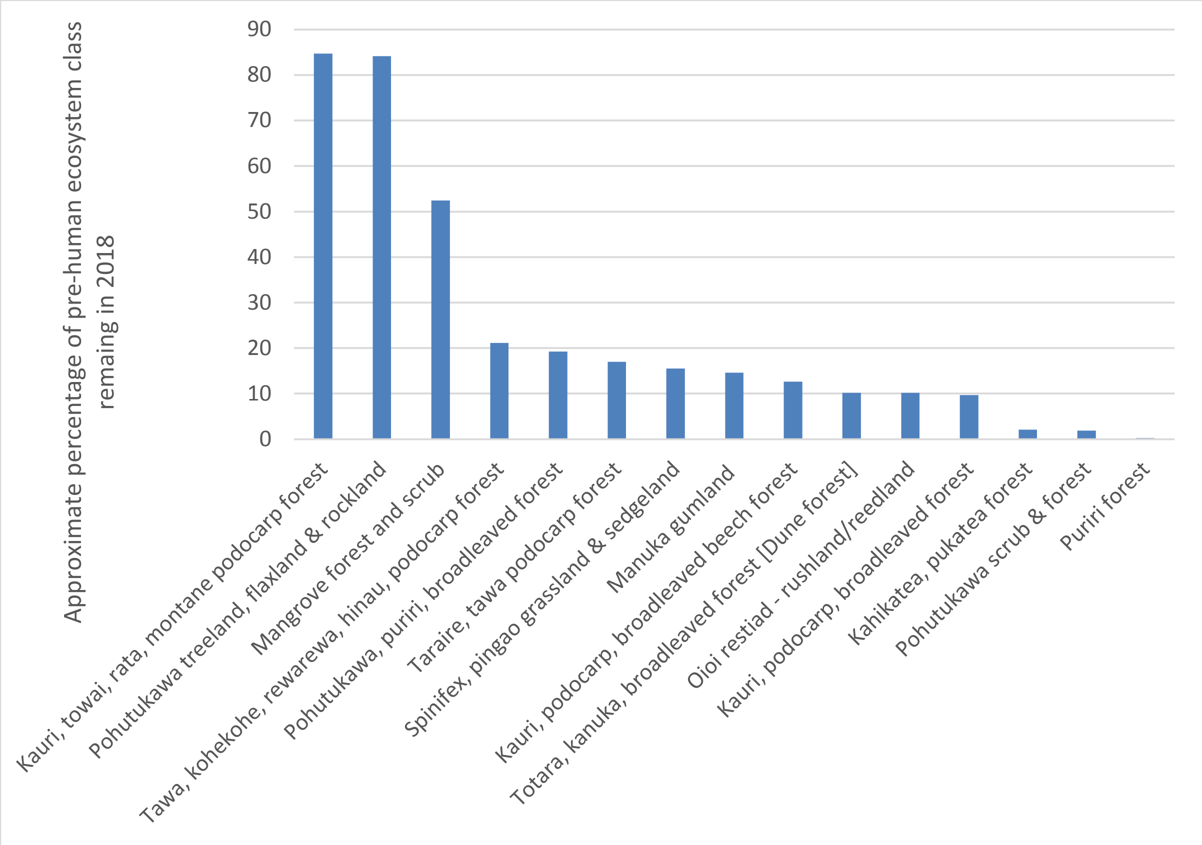

Figure 2: Proportion of pre-human extent remaining for some key Auckland region ecosystem types. Data adapted from Auckland Council current and potential ecosystems layers (Auckland Council. Current Ecosystem Extent [feature class]. (2014). Auckland: Auckland Council Biodiversity team. Available: Auckland Council GIS database [Sept 2018].)).

2.0 Methods

2.1 Ecosystems

The ecosystem analysis presented in this report focuses on the general characteristics and distribution of indigenous terrestrial ecosystems in the Auckland region. Auckland Council's map of Current Ecosystem Extent (CEE) was the main source for information on the extent, location and spatial distribution of Auckland's terrestrial ecosystems. The CEE is a map outlining the extent of the c.48 indigenous ecosystem types within the Auckland region described by Singers et al. (2017). While this map is the best available resource for this type of analysis, it is still a work in progress and has some significant gaps in the coverage of some locations and ecosystem types. In particular, its coverage of threatened and unusual ecosystems that occur in tiny, isolated pockets – e.g lakeshore turf, coastal turf and flaxland – is incomplete[1]. Therefore, the results presented below are only as precise as the ecosystems map and this output should be seen as a first iteration. The ecosystems map continues to be improved as further fieldwork is carried out to improve mapping and identification of Auckland's indigenous ecosystems.

The ecosystem risk assessments below are largely based on five different 'risk factors' (Table 1) which were examined in order to identify the ecosystem types which are likely to be more vulnerable to the impact of climate change. These 'risk factors' were chosen for practical reasons. That is, they are risks that are directly related to the impacts of climate change and for which there was sufficient and appropriate information to enable us to carry out a quantitative analysis (risks 1-4 in Table 1). Or they relate to climatic risks that have been previously identified in the scientific literature (risk 5 in Table 1). Recent publication of 'drought-risk' maps for the Auckland region (Pearce et al. 2018) could have been used to quantitatively compare Auckland's terrestrial ecosystem distribution with sub-regional areas that are at risk of drought stress. However, due to time-constraints we have not provided such an analysis in this report, although we do consider drought stress as part of the qualitative analysis.

A range of additional impacts of climate change on terrestrial ecosystems that are not covered in the Table 1 'risk factors' have been widely identified previous studies. These impacts include increased drought stress, increased fire frequency, increased impacts from plant and animal pests, more frequent or severe out-breaks of existing

[1] These 'tiny and isolated' ecosystem types have distinct species compositions and (presumably) genotypes, and therefore it is important they are considered as part of this risk assessment. However, we note that they comprise a very small fraction (<0.2%) of the mapped indigenous ecosystems in the Auckland region and therefore have little impact on our general conclusions.

pathogens, and/ or the establishment of new pathogens (see for example Parmesan et al. 2000, Simberloff 2000, Dale 2001, Flannigan et al. 2006, Kurz et al. 2008, Thibault and Brown 2008, Thuiller et al. 2008, van Mantgem et al. 2009, Allen et al. 2010, Tubby and Weather 2010). As there is little or no species or ecosystem specific data on how the New Zealand flora and fauna will respond to these risks we have not included a quantitative assessment of their affects. However, we do consider these risk factors as part of the qualitative assessments of climate change risks for individual ecosystems and species in this report.

Table 1: Summary of 'risk factors' used for assessing the vulnerability of Auckland's indigenous terrestrial ecosystems to climate change.

Risk factor analysis	Justification
1 - Native ecosystems at risk of inundation during a 100-year flood event	These are the ecosystems most likely to be directly affected by physical disturbance – e.g. from flooding, storm surge, excess salt deposition, debris flow and/ or sedimentation – during severe storms.
2 - Native ecosystems within 50m and 500m of the coastline	The coastal area is particularly prone to increased disturbance from an increased frequency and/ or intensity of extreme climatic events. This is due to the more exposed nature of the coastal environment to physical damage from storms and other climatic events, its inherent susceptibility to some more localised types of disturbance (e.g. coastal erosion or salt spray damage), and the highly fragmented and modified nature of indigenous ecosystems in the lowland and coastal zones (Walker et al. 2006).
3 - Native ecosystems with highly restricted and fragmented distributions	The regional distribution of rare and uncommon ecosystems is more likely to be affected by a random extreme climatic disturbance event that severely impacts one of the small number of sites where an ecosystem is present.
4 - Native ecosystems at their climatic limits	By their very nature ecosystems at climatic limits are much more likely to be affected if the current climatic envelope changes. That is, they are comprised of species which might be more vulnerable to being 'pushed-out' by different species more adapted to new climatic and disturbance regimes.
5 - Native ecosystems which have been specifically identified as being at risk from climate change effects	Singers et al. (2017) description of Auckland's terrestrial and wetland ecosystems includes a summary of their key threats, including climate change. These threats have been identified as part of active biodiversity management within New Zealand or in published literature. If a given ecosystem was known to be vulnerable to climate change this was included in the assessment.

To investigate which ecosystems are vulnerable to inundation during flood events native ecosystems mapped in Auckland Council's Current Ecosystem Extent were overlain with mapping of the potential inundation zone during a 1 in 100-year flood event under a 2m sea level rise scenario (model ARI100_SLR2m) (Pearce et al. 2018). A 2m sea-level rise is not expected to be reached until 2100, or later, under 'business as usual' carbon emissions scenarios. However, this time period is well within the average life spans of most New Zealand forest trees and is also within the life spans of many other plant species which are common in Auckland's forest and scrub ecosystems. Given the relatively long time periods over which ecosystems respond to external drivers (Tilman et al. 1994) we thought it was important to take a 'horizon view' of potential climate change effects.

To understand the proportion of different indigenous ecosystem types that might be vulnerable to increased coastal hazards, native ecosystems mapped in the CEE were overlain with a map of the 'coastal zone'. Climate change will result in an increased frequency and intensity of storm events, leading to exacerbated coastal erosion, and amplified risk of damaging high winds, salt spray damage, storm surge and flood impacts during extreme weather events (Lorrey et al. 2017). Ecosystems in the coastal zone are particularly vulnerable to these effects. We defined the coastal zone by mapping simple linear buffers lying inland from the Mean High-Water Spring Tide (MHWST) line (unpublished Auckland Council spatial dataset, accessed October 2018).

Two different buffers were used in the analysis; 50m inland and 500m inland of MHWST. These two distances were chosen to encompass those ecosystems that are at greater immediate risk of direct physical disturbance from coastal effects such as erosion (50m band) and those ecosystems that will also be vulnerable to high winds and salt deposition during severe storms (500m band). The 500m band is a relatively blunt instrument for defining the coastal zone – which is likely to be narrower in some locations and much wider in others, depending on landform, prevailing winds and the exposure of a specific section of coastline to storm effects. However, there is no generally accepted and delineated 'coastal zone' for the Auckland region and therefore we used this compromise approach.

To investigate the vulnerability of indigenous terrestrial ecosystems to significant habitat loss from climate change the CEE map was used to:

1. Identify and investigate the spatial distribution of indigenous ecosystem types with highly restricted spatial extents. With 'highly restricted' subjectively defined as ecosystems with <200ha extent within the Auckland region.

2. Identify indigenous ecosystem types with a significant proportion of their extent within the area vulnerable to inundation during a 100-year flood event. With ‘significant’ subjectively defined as >10% of regional extent for threatened indigenous ecosystems and >30% of regional extent for non-threatened indigenous ecosystems.
3. Identify ecosystems that have a significant proportion of their extent within the coastal zone. With ‘significant’ subjectively defined as 10%+ of total extent being within 50m of MHWST OR 30%+ of total extent being within 500m of MHWST.

This is because these are the ecosystems whose regional extent and/ or health is more vulnerable to being severely affected by disturbance (e.g. flooding, drought, salt deposition, wind throw, erosion, landslide) and other impacts (e.g. decrease in productivity, increased weed competition) associated with climate change. Even very localised physical disturbance can have a severe impact on rare ecosystems if it ‘just happens’ to occur on or nearby remnant(s) of an unusual ecosystem type.

The CEE map was also used to examine the spatial distribution of ‘cold-climate’ ecosystems within the Auckland region. These include two ‘montane’ ecosystems found at high altitudes (rimu-towai forest and kauri-towai-rata forest) and one lowland ecosystem whose distribution is thought to be at least partially determined by regular frosts (kahikatea forest). Polar and mountaintop species are particularly vulnerable to changes in mean climate variables. They show severe range contractions and have been the first groups in which entire species have gone extinct due to recent climate change (Parmesan 2006). The two high altitude forest types are vulnerable to displacement by native species from lower altitude as they migrate upwards in response to warmer conditions, outcompeting the extant native plants in these locations. Under all future climate change scenarios frosts are expected to decrease throughout the Auckland region (Pearce 2018) and this could alter the distribution and composition of the kahikatea forest ecosystem. However, the changes in the frequency and intensity of local-scale frosts, for example on valley floors where kahikatea forest is found, is less clear (*ibid.*).

2.2 Species

The ecosystem analyses outlined above are based on ecosystem distribution and do not consider the affect(s) of climate change on individual plant and animal species; including both indigenous and introduced (pest species. Nevertheless, the ecosystem risk assessments presented below mean that the vulnerability of indigenous species which live, feed and breed in the c.48 ecosystems considered is incorporated to some extent. This is particularly the case for threatened forest and scrub dwelling birds, reptiles and more widely distributed (but uncommon) invertebrates. However, there are a wide range of threatened species that are not covered by this analysis including seabirds, shorebirds, wetland birds, and other coastal birds, threatened plants of open habitats (both coastal and inland), and plant and invertebrate species with very restricted distributions.

Ideally, we would be able to apply the same types of spatial analysis to individual species as carried out with ecosystems, particularly threatened and uncommon species. However, reliable data on the location, size, health and distribution of most threatened species is not readily available, and for those few species where it is available much of it is not mapped comprehensively. Therefore, the information presented in the Species section is in the form of a general review of the effects of climate change on the major taxonomic groups relevant to Auckland, including invasive pest species.

With little species-specific data available for Auckland's flora and fauna, it is not possible to provide an in-depth analysis of specific taxa. We do, however provide a case study Risk Assessment of Auckland's seabirds using expert opinion, as well as a "Threatened plants" analysis which includes consideration of climate change risks in relation to all threatened plant species known to be present in Auckland (de Lange et al. 2018).This includes plants categorised as 'nationally - endangered'[2] species and 'nationally - at risk'[2], but not 'regionally threatened'[2].

The regional distribution of all nationally endangered plant species – as listed in de Lange et al. (2018) - was determined using plant distribution information in Auckland Council databases and other publicly available records and distribution information. A subjective risk assessment was carried out for each nationally threatened plant species based primarily on:

1. The number of records for each species, and the number of individual plants at each location. Plant species with highly restricted distributions are more vulnerable to the impact of stochastic disturbances that disrupt their habitat or biology.

[2] 'Nationally endangered' plants include those that are actively threatened with extinction and so require active management (Townsend et al. 2008). 'Nationally at risk' plants include those at risk of extinction but not in any immediate danger, and so require monitoring (ibid.). Regionally threatened plant species includes those that are nationally 'threatened' and 'at risk', but also includes plant species that have very localised distributions within the Auckland region, but are not considered threatened species outside of the Auckland region (i.e. when their population distribution across the whole of New Zealand is included). Regionally threatened plant species were not assessed in this report, unless they were also listed as 'nationally threatened' or 'nationally at risk'.

2. The physical location of threatened plant species. Plant species in locations which are likely to be more susceptible to an increased frequency and intensity of climatic disturbance (e.g. coastal cliffs) or other threats which might act in combination with climate change effects (e.g. ongoing habitat loss and development of coastal and lowland sites) were regarded as being at greater risk of negative impacts from climate change.
3. Existing threats to each of the nationally plant threatened species. Most of this information was sourced from de Lange et al. (2010) and NZPCN (2019). Species which have already exhibited vulnerability to climate change, or climate related effects (e.g. drought) could be expected to be at greater risk of negative impacts from climate change.
4. The biology and autecology of individual species. Threatened species that are adapted to disturbance – or which require regular disturbance to allow their re-establishment or remove competing vegetation - may be less vulnerable[3] to some of the physical disturbances associated with climate change. In particular, those species which require regular fire disturbance may conceivably benefit from an increased frequency and severity of droughts. Most of this information was also sourced from de Lange et al. (2010) and NZPCN (2019).

Auckland Council (2013 draft) also provides a list of plant species whose distributional limits lie within or close to boundaries of the Auckland region; including threatened, uncommon and non-threatened plant species. Nationally threatened species that also reach their distributional limits in the Auckland region were covered as part of the threatened plant assessments outlined above. A list of threatened plants which are also at their distributional limits in the Auckland region is provided in Appendix B. Species at their distributional limits are regarded as being more susceptible to the impacts of climate change, as species distributions are often determined by climate (Leathwick et al. 2012). Space and time constraints meant in this report we have not provided individual assessments for plants at their distributional limits in Auckland that are classified as 'non-threatened', 'naturally-uncommon', or 'relict', or regionally threatened plants that are not nationally threatened.

[3] This assumes that any 'benefits' derived from more regular disturbance are sufficient to offset potential 'negative' effects; such as an increase in the relative fitness of co-occurring weed species or the physical removal of habitat for species with very restricted distributions.

3.0 Results

3.1 Ecosystems

The four sections below presents summary information about Auckland ecosystem types that might be at risk from climate change impacts. These risk factors are: ecosystems at risk of inundation during severe flooding; ecosystems which have a large proportion of their total area within the coastal zone; ecosystems with highly restricted distributions; and ecosystems with obvious 'climatically determined' limits. General information on the distribution, threats and potential impacts of climate change for all the Auckland regional ecosystem types identified in Singers et al. (2017) is also summarised in Appendix A.

3.1.1 Ecosystems at risk of inundation

Using the 2m sea level rise scenario (model ARI100_SLR2m) a total of c. 13,270ha of indigenous terrestrial ecosystems are at risk of inundation during a severe storm event[4] (Table 2). Unsurprisingly, coastal ecosystems represent the largest area of ecosystems affected in terms of total area. In particular, mangroves comprise 73% of the total area of indigenous ecosystems affected, and mangrove and duneland vegetation (which includes the Oioi, knobby clubrush sedgeland and Spinifex, pingao grassland/sedgeland ecosystem types) collectively comprise 86% (Table 2).

However, for many terrestrial ecosystems the total area of potential inundation is less important than the proportion. For example, 7.6ha of coastal turf is vulnerable to inundation during storm events; this relatively small area represents 64% of all the mapped coastal turf known in the region (although it comprises only 0.06% of the total area of indigenous ecosystems at risk of inundation). If even half of this area was destroyed or severely damaged by storms, this would result in a significant reduction in the regional distribution of this ecosystem type.

We subjectively classified the most at risk ecosystem types under this criterion as those endangered ecosystems where 10%+ of the regional distribution is vulnerable to inundation during a 100-year flood, or other ecosystem types where 30%+ of the regional distribution is vulnerable to inundation. The potential threats from climate change to each of the at risk ecosystems is discussed in more detail below.

[4] But not necessarily the same storm event. This is because a severe event is likely to affect only a proportion of all the ecosystems in the inundation zone; depending on its strength and direction.

Table 2: Regional ecosystem types from Singers et al. (2017) vulnerable to inundation during a 100 year storm surge event (model ARI100_SLR2m).

Ecosystem description (and code) CL = cliff, DN = dune, MF = mild forest, SA = coastal saline, VS = regenerating, WL = wetland, WF = warm forest	**IUCN threat status**[5]	**Area vulnerable to inundation in 100 year flood (ha)**	**% of total area of this type affected**
Mangrove forest and scrub (SA1)	Least concern	9737.2	96
Lakeshore turf (WL15)	Crit. Endangered	15.6	75
Oioi, knobby clubrush sedgeland (DN5)	Crit. Endangered	348.5	74
Coastal turf (SA5)	Crit. Endangered	7.6	64
Flaxland (WL18)	Crit. Endangered	30.9	57
Oioi restiad-rushland/reedland (WL10)	Endangered	76.6	52
Spinifex, pingao grassland/sedgeland (DN2)	Endangered	1392.4	48
Machaerina sedgeland (WL11)	Crit. Endangered	82.9	27
Raupo reedland (WL19)	Endangered	291.2	25
Kahikatea, pukatea forest (WF8)	Crit. Endangered	72.2	17
Pohutukawa treeland/rockland (CL1)	Vulnerable	204.7	8
Manuka, tanglefern scrub/fernland (WL12)	Crit. Endangered	35.2	8
Pohutukawa scrub and forest (VS1)	Endangered	136.1	6
Totara, kanuka, broadleaved forest [dune forest and scrub] (WF5)	Crit. Endangered	145.8	5
Pohutukawa, puriri, karaka broadleaved forest [coastal forest] (WF4)	Endangered	171.1	4
Manuka gumland (WL1)	Crit. Endangered	2.1	2
Shore bindweed, knobby club rush gravelfield/stonefield (SA4)	Endangered	0.9	2
Manuka-kanuka scrub (VS3)	Least concern	115.5	1
Broadleaved scrub/forest (VS5)	Least concern	65.0	1
Kahikatea forest (MF4)	Crit. Endangered	7.5	1
Kanuka scrub and forest (VS2)	Least concern	247.8	1
Kauri forest (WF10)	Endangered	4.0	0.3
Kauri, podocarp, broadleaved forest (WF11)	Endangered	63.5	0.2
Puriri forest (WF7)	Crit. Endangered	0.4	0.2
Taraire, tawa, podocarp forest (WF9)	Endangered	8.8	0.1
Iceplant, glasswort herbfield/loamfield (SA7)	Crit. Endangered	0.04	0.1
Tawa, kohekohe, rewarewa, hinau, podocarp forest (WF13)	Vulnerable	7.0	0.1
Kauri, podocarp, broadleaved beech forest (WF12)	Endangered	2.8	0.1
TOTAL		**13,272**	**13**[6]

[5] The IUCN threat status classifications used throughout this report are determined by pressures such as past habitat loss and fragmentation, the impacts of plant and animals pests, and predicted future vulnerability to human disturbance. Therefore, they do not represent a climate change risk assessment.

[6] As a proportion of all indigenous terrestrial ecosystems mapped in the CEE

Mangrove forest and scrub (SA1) occupies frost free tidal estuaries, inlets, rivers and streams and is associated with locations that have a salinity of > five per cent (Johnson & Gerbeaux 2004). The SA1 complex comprises seven different ecosystem variants all of which have highly varied structural characteristics, distributions and species compositions (Singers et al. 2017). Almost 10,200ha of mangrove forest and scrub is mapped in the region and around 90% of this is dominated by mangrove (*Avicennia marina* subsp. *australasica*) scrub and forest (variant SA1.2). Other mapped variants include sea rush rushland (SA1.3; c.5% of total), sea grass grassland (SA1.1; c.4% of total), and shell barrier beaches (SA1.5; c.1% of total). Only trace amounts of the other three variants are mapped. While mangroves are an extensive ecosystem in the Auckland region, the overwhelming majority of this ecosystem type and its variants (96%) lies within the area vulnerable to inundation during a 100-year flood. The physical locations in which mangroves grow means they are somewhat adapted to physical disturbance from storms, and it has been suggested that mangroves could provide coastal zones with a natural resilience to coastal hazards that engineered structures lack (Horstman et al. 2018).

However, global changes in mangrove distribution due to climate change processes such as sea level rise, changing ocean currents, increased storminess, increased temperature and changes in precipitation are considered to be highly likely (McKee et al. 2012, Ellison 2015) and Auckland's mangroves are exposed to a similar range of threats. In New Zealand, distributional changes due to increasing temperature are uncertain, but are likely to be less important than changes in sea-level and increased rates of sedimentation and storm frequency (Lundquist et al. 2011).

The impact of sea level rise in particular on mangrove distribution is likely to vary in response to local topography, coastline development and sediment budgets (Morrisey et al. 2007, Swales et al. 2009). Mangroves are particularly sensitive to increasing sea level because they cannot survive when permanently submerged and in many parts of the Auckland region they have little room to migrate up the shore due to coastal development or steep coastlines (Swales et al., 2009; Lundquist et al., 2011), a condition often referred to as "coastal squeeze". Swales et al. (2009) assessed the potential for mangrove expansion in Auckland's east coast harbours and estuaries at 2050 and 2090. Scenario Three in their study is the scenario that best aligns with sea-level rise projected under RCP 8.5 in Pearce et al. (2018). Under this scenario, the area of potential mangrove habitat was predicted to decline by 11km^2 by 2090, an approximately 24% reduction in potential habitat.

Migration of all variants of the SA1 ecosystem type will be restricted where coastal defences are present and climate change could result in the SA1.2 variant displacing much rarer 'saltmarsh' (SA1.3, SA1.4 and SA1.6) and 'substrate driven' (SA1.5 and SA1.7) variants of this ecosystem type.

Overall, it is unclear exactly how Auckland's mangrove ecosystems will respond to climate change. However, the ubiquity of mangroves in the coastal zone and their key role in supporting and regulating physical and ecosystem processes means the distribution and health of mangrove ecosystems should be more closely monitored in future.

Lakeshore turf vegetation (WL15) occupies a narrow range of habitat on shallow-gradient, fluctuating lake shorelines (Singers et al. 2017). The habitat usually comprises a narrow band between permanent aquatic vegetation (in deeper water) and taller sedgeland, rushland and scrub communities on the landward margins of lakes. The Auckland region has few large natural lakes[7]. The region has a larger number of smaller natural freshwater lakes, many of which are associated with sand dune deposits in the coastal parts of the region. Some better-known examples include the string of dune lakes along the South Kaipara Peninsula (e.g. lakes Rototoa, Kuwakatai, Kereta and Wainamu), Awhitu Peninsula (e.g. Pokorua, Pehiakura and Whatihua), and Ngaroto to the north of Pakiri on the east coast (e.g. Tomarata, and Spectacle). Mapping of the distribution and extent of this ecosystem in the Auckland region is incomplete and there is likely to be more than is currently known. In addition, this ecosystem is ephemeral and therefore needs to be re-surveyed on a regular basis.

Weed invasion, eutrophication, pest animals and uncontrolled stock access are the biggest threats to lakeshore turf (Champion et al. 2001, Johnson and Rogers 2003, Ogle 2003, Singers et al. 2017). These current threats will probably remain of more concern than climate change; at least in the short to medium term. The ecosystem type is sparsely, but relatively widely distributed in the region, which reduces the risk of severe damage from climate-related stochastic disturbance. In the long-term, increasing salinity due to sea level rise and storm surges could have an impact on coastal lakeshore turfs (e.g. those at Whatipu). The impact of more frequent and severe droughts is another significant threat to both coastal and inland lakeshore turfs, particularly if these droughts promote conditions which favour the growth of introduced plant pests (weeds). Lakeshore turf ecosystems should therefore be closely monitored to gain a better understanding of any negative impact(s) of climate change, and other threats.

[7] Only six natural lakes >20ha in size. The two largest lakes in the region, Rototoa and Pupuke, collectively comprise almost half of the total area of natural lakes.

Oioi (*Apodasmia similis*), knobby clubrush (*Isolepis nodosa*) sedgeland (WL10) occupies dune plains or coastal plains (Esler 1969 & 1970) which are areas of flat land between dune ridges (Singers et al. 2017). Extensive, good quality examples of this ecosystem type occur at Whatipu and Papakanui Spit. Very similar vegetation also occurs in Auckland on wind-swept coastal hillslopes with raw sandy soils and this variant of the ecosystem type is particularly notable along the western coastal cliffs of the Awhitu Peninsula (Singers et al. 2017). The low-lying, coastal and highly exposed nature of the locations where oioi-knobby clubrush sedgeland grows means this ecosystem type could be particularly vulnerable to disturbance from an increased frequency and/ or intensity of storm events. This ecosystem is adapted to stresses such as salt exposure, inundation and physical disturbance from the mass movement of its sand dune substrate. However, very severe erosion has the potential to completely remove the physical habitat on which this ecosystem depends.

While there is a relatively large area of this ecosystem type, compared to many of Auckland's other ecosystems (Table 2), more than 85% of the region's oioi-knobby clubrush sedgeland is concentrated in two low-lying coastal sand plains that are vulnerable to storm damage and sea level rise (Whatipu and Papakanui Spit). Examples of this ecosystem type at Baylys Beach, west of Dargaville in the Kaipara District, have been heavily affected by the erosion of cliff faces due to storm damage in the past few years (A. Jamieson pers. comm.) and erosion from sea-level rise and increased storm intensity therefore poses a significant threat to Auckland region examples of oioi-knobby clubrush sedgeland.

Coastal turf or herbfield (SA5) occurs where persistent salt-laden winds prevent any vegetation taller than about 50mm from becoming established (Singers et al. 2017). Coastal turf is found on coastal promontories of hard rock and, infrequently, consolidated sand and gravel (Rogers and Wiser 2010). Less than 12ha of coastal turf has been mapped in the Auckland region, and this is probably an overestimate of the total area of this ecosystem type as most of the mapped locations include the surrounding vegetation as part of the 'coastal turf' (Stanley 2018). Regional distribution includes small[8] patches of habitat along the south Muriwai to Waitakere coastline, on the north-eastern coast of Aotea (Great Barrier Island) and on other Hauraki Gulf islands (Singers et al. 2017). Further survey work is required to determine the true extent of this ecosystem type in the region. Coastal turf is highly vulnerable to stochastic effects – particularly coastal erosion effects - due to the highly exposed nature of its habitat and the very small size and highly fragmented

[8] The extent of these areas is very limited. For example, Stanley (2018) studied nine different patches of coastal turf along the Waitakere coastline which had an average size of 29 m^2 (0.0029 ha) and a range of 3-164m^2 (0.0003- 0.0164ha).

nature of the remaining patches of this ecosystem. Therefore, it needs to be closely monitored if it is to be managed effectively in response to climate change (and other) threats.

Flaxlands (WL18) are a special class of 'swamp-wetland' ecosystem that occurs on young landforms (Bagnall and Ogle 1981) that regularly flood or receive nutrient rich surface water flows from surrounding land. As their name suggests, the ecosystem is characterised by abundant flax (harakeke; *Phormium tenax*), often in association with a small range of other native wetland plants. Their regional distribution is very patchy; a total of only 54ha of flaxland is identified in the current ecosystem extent, with an average stand size of just 0.7 ha.

Many flaxland remnants are associated with coastal lakes and duneland wetlands, which means they are particularly exposed to disturbance from increased frequency and/ or severity of storms, and sea-level rise. However, the relative vulnerability of individual remnants is likely to be highly site specific, and detailed examination of the (at least) 50 examples of this ecosystem that lie within 500m of the coast is beyond the scope of this study. Away from the coastal zone, flaxland may be vulnerable to the impact of 'drying-out' during long periods of drought. However, contemporary and historical threats such as drainage for agriculture[9], stock damage and weed invasion are probably more significant issues for flaxland remnants in the Auckland region.

Oioi restiad-rushland/reedland (WL10) occupies moderate fertility wetlands within the freshwater zone of estuaries in the Auckland region (Singers et al. 2017). Further survey work is required to accurately delineate this ecosystem type, but it is likely to be present at the mouths of many streams discharging into estuaries, or within coastal wetlands and lagoons (*ibid*.). For example, almost all the streams along the Waitakere coastline, Tapora peninsula and eastern Aotea/ Great Barrier Island have examples of this ecosystem type close to the coastline. Oioi is the dominant plant species but other wetland plants such as baumea, purua, kuta, lake clubrush, raupo and flax are common secondary components (Deng et al. 2004).

Almost 110ha of this is mapped in the region, but this is likely to be an under-estimate of the total extent of oioi-restiad rushland as significant sections of coastline have not been mapped with the precision necessary to delineate this ecosystem. The areas of habitat that have been mapped are highly fragmented in nature; with an average patch size of just 0.9 ha, however in many cases the small patches of oioi-restiad rushland are associated with other indigenous wetland ecosystem types as part of a larger wetland system. The largest mapped examples are on the Tapora

[9] Including both direct drainage and conversion of flaxlands to pasture, and the impact of a lowered water table when drainage in surrounding pastureland is improved, but the flaxland itself is left 'intact'.

Peninsula, Claris area on Aotea/ Great Barrier Island and on Waiheke Island. Its coastal location and fragmented distribution probably make this ecosystem more vulnerable to climate change impacts. In particular, the risk of displacement due to increasing salinity from sea level rise and/or storm surges is relatively high. Most of the mapped larger patches of oioi-restiad rushland are bordered by pasture on their inland margins, and upstream reaches, and this reduces the scope for this ecosystem to 'migrate' in response to changing salinity. The potential for significant climate change impacts means this ecosystem should be closely and systematically monitored for possible negative impacts.

Spinifex (*Spinifex sericeus*), pingao (*Ficinia spiralis*) grassland and sedgeland (DN2) ecosystem grows on active dunelands where there is an abundant supply of wind-blown sand (Singers et al. 2017). Active dunelands provide a harsh, nutrient-poor, droughty and exposed habitat for plant growth. Only a few highly-specialised plant species are able to tolerate these conditions, and therefore dunelands are naturally species poor (Esler 1970). The ecosystem also provides habitat for a suite of specialised coastal birds and reptiles (Singers et al. 2017). Dunelands are a feature of the coastal environment throughout the Auckland region, on both the mainland, Waiheke Island and Aotea/ Great Barrier Island. Around 1100ha of spinifex-pingao grassland are mapped in the region, which is a common vegetation component of the c. 60 separate duneland 'sites'. The largest concentrations of this ecosystem are found at Papakanui Spit/ Muriwai Beach, Tapora Peninsula in the Kaipara Harbour, Whatipu, Pakiri Beach and Claris on Aotea/ Great Barrier Island.

The loose unconsolidated nature of the sand that comprises active dunelands, and their exposed coastal location, means this ecosystem could be quite vulnerable to disturbances from increased storm severity and frequency. However, the region-wide distribution of dunelands means that it is likely that severe damage would be relatively localised. Therefore, the overall impact of climate change on the health and distribution of this ecosystem, while likely to be negative, is still uncertain.

Machaerina sedgeland (WL11) is found in medium-fertility wetlands in shallow depressions and along the sheltered margins of lakes and lagoons, including dune lakes (Singers et al. 2017). This critically endangered ecosystem is distributed widely through the Auckland region, being found in small areas on the margins of most lakes and shallow coastal basins (ibid.). This general ecosystem class includes a wide range of regional variants and in the Auckland region individual wetlands tend to be dominated by a few species, based on the fertility, soil type and landform at individual wetland locations (Singers et al. 2017). The greatest concentration of Machaerina sedgeland occurs in the string of dune lakes along the South Kaipara Peninsula and the Waitakere coastline.

More than 370 different ‘patches’ of this ecosystem type are mapped in the region and they have a combined area of more than 400ha. However, almost 30% of the entire mapped regional extent of Machaerina sedgeland is located in a single, low-lying coastal wetland adjacent to the Kaipara Harbour (Marie Neverman Reserve) and almost half of the regional extent is within just three sites (Marie Neverman, Te Henga-Bethells wetland and the Whatipu wetland complex). All three of these locations are <3m above sea level and within 800m of the coast, and therefore could be expected to be particularly vulnerable to negative impacts from storm surges, saltwater intrusion and coastal inundation.

This is a freshwater wetland ecosystem and while some Machaerina sedgeland contains species which are tolerant of brackish water, a dramatic increase in salinity is likely to alter conditions and enable displacement by other species. This wetland type is highly vulnerable to invasion by a range of weeds (Eser 1998) and eutrophication (Singers et al. 2017). Therefore, climate-related inundation or flooding that exacerbates these other stresses (e.g. through sedimentation, run-off and distribution of weed propagules) are likely to result in particularly severe impacts for Machaerina sedgeland.

Raupo (*Typha orientalis*) reedland (WL19) is one of the most distinctive and commonly seen wetland ecosystems within Auckland’s rural landscape. It is often found as small patches in the bases of gullies, surrounded by exotic pasture. However, many of these wetland remnants, while indigenous, have regenerated following the loss of the original native forest ecosystems on these sites (Singers et al. 2017). In more ‘natural’ settings raupo reedland is the dominant indigenous wetland ecosystem in high nutrient or eutrophic sites and/ or wetlands on recent mineral soils.

Raupo reedland occurs on the margins of lakes, lagoons, ponds and river oxbows, and in flooded valleys. The remaining wetlands are more common in coastal regions and coastal duneland areas (ibid.), such as the South Kaipara Peninsula and Hauraki Gulf islands, in the Auckland region. This ecosystem is adapted to deal with a widely fluctuating freshwater table and it may therefore be better able to tolerate future drought stress than some other wetland ecosystem types.

Around one quarter of the raupo reedland ecosystem type is within the 100-year flood zone (Table 2), however the proportion of larger, naturally-formed raupo reedlands with high biodiversity values within the 100-year flood zone is likely to be significantly higher. For example, 21 of the 25 largest and best quality examples of raupo reedland in the Auckland Region are particularly vulnerable to climate related disturbances (unpublished Auckland Council data)[10]. This is more than 90% of the total area of raupo reedland within the 25 best and largest examples of this type. The vulnerability of these sites is due to their coastal location and/ or location within first or second order streams < 3km from the coast; this means they are more susceptible to severe flooding, sedimentation and negative impacts from saltwater intrusion during severe storms

For the reasons outlined above, the raupo reedland ecosystem is probably particularly vulnerable to the impact of climate change; at least in terms of the larger, 'natural' examples of this ecosystem type with high naturalness and indigenous biodiversity values. The ability of raupo to disperse widely in throughout the landscape and take advantage of the patchy availability of suitable habitat means that simple examples of this ecosystem type are likely to remain throughout the region.

Kahikatea-pukatea forest (WF8) remnants, commonly known as 'swamp forest', are scattered throughout the Auckland region in locations with poor draining alluvial, organic and gley soils, a seasonally high water-table, and minimal frosts (Singers et al. 2017) Because fertile flat land is highly suitable for agriculture, this ecosystem has been greatly reduced from its former extent and is now restricted to mostly small remnants. Around 80% of the remaining patches of this ecosystem type consists of functionally isolated remnants < 3ha in size.

The most significant impact of climate change on this ecosystem type is probably related to changes in hydrological regime, most notably an increase in drought. Lowering the water-table in kahikatea, pukatea swamp forest – for example, during drainage of land surrounding the small remnants – has allowed the invasion of weeds and/ or the replacement of typical swamp forest plants by native species more suited to drier habitats (ibid.). The potential for climate-related drought impact on swamp forest is exacerbated by the small size of many of the remaining fragments; small fragments being less buffered against, and more exposed to, drought stress.

[10] Good quality, relatively large examples of raupo reedland with high biodiversity values are concentrated in the following locations, listed in decreasing size order: Duneland lakes and streams on the South Kaipara Peninsula; Waiheke Island; Great Barrier Island; Bethell's/ Te-Henga wetland; Dune lakes and streams on northern Awhitu Peninsula; Tawharanui Peninisula; Ponui Island; Waiatarua wetland; and Whatipu wetland.

3.1.2 Coastal ecosystems

Ecosystems closest to the coast are likely to be most vulnerable to the impact of sea-level rise, increased storm surges and other coastal disturbance associated with an increased intensity and frequency of coastal storms and cyclones (Scavia et al. 2002). Climate change will not introduce any new types of coastal hazards, but it will exacerbate and increase the frequency of coastal erosion, and raise groundwater levels in coastal areas and inland low-lying coastal plains (Bell et al. 2017).

Ecosystems in coastal regions are also particularly vulnerable to the direct (e.g. windthrow[11]) and indirect (e.g. fire) effects of severe storms (Connor et al. 1989, Myers and van Lear 1998). The Auckland region is predominantly coastal in nature; more than 20% of the regions land area is within 500m of the coast, and almost half the land area is within 1500m of the coast (Auckland Council geospatial data). Many of these locations are at elevations which mean they are not at risk of inundation from sea-level rise and/ or storm surges and therefore are not captured by the inundation risk assessment presented in the previous section of this report.

The long-term ecological effects of damage from increased frequency and intensity of climatic related disturbance in the coastal zone are less certain, and are likely to depend on a range of interacting factors including:

- general ecosystem type (e.g. wetland vs. forest)
- lower order ecosystem classification (e.g. eutrophic vs. mesotrophic wetland);
- type of climate-related disturbance (e.g. drought vs. sediment deposition from floods vs. wind throw)
- landscape characteristics (e.g. landscape dominated by indigenous ecosystems vs. rural landscape with pockets of indigenous ecosystems vs. urban landscape with pockets of indigenous ecosystems).

For example, Connor et al. (1989) found that flooding and sedimentation associated with severe storms (hurricanes) did not have any long-term detrimental effects on wetlands within natural systems, but often had severe and long-lasting effects in wetlands that had been modified by human impacts.

In order to determine which regional ecosystems types are likely to be more vulnerable to the effects of increased coastal disturbance as a result of climate change effects, we examined the distribution of terrestrial indigenous ecosystems in the coastal zone – defined as 50m and 500m inland from the Mean High Water Spring Tide (MHWS line Table 3 and Table). Two subjective thresholds were used as

[11] The breaking or uprooting of trees by wind

the triggers for determining those indigenous ecosystems that are at an increased risk from the impact of climate change; more than 10% of total regional extent within 50m of MHWST and more than 30% of total regional extent within 500m of MHWS.

Table 3: Indigenous terrestrial ecosystems within 50m of MHWST around the Auckland coastline.

Indigenous ecosystem type (and code) CL = cliff, DN = dune, MF = mild forest, SA = coastal saline, VS = regenerating, WL = wetland, WF = warm forest	**Total area on mainland (ha)**	**Hauraki Gulf islands (ha)**	**Regional total (ha)**	**IUCN threat status**	**% of total habitat**
Mangrove forest and scrub (SA1)	n/a[1]	n/a[1]	c.10,200[1]	Least concern[2]	c.90[1]
Pohutukawa scrub forest (VS1)	0	131.65	131.65	Endangered	100
Shore bind weed knobby club rush gravelfield stonefield (SA4)	0.39	39.15	39.55	Endangered	70
Pohutukawa treeland flaxland rockland (CL1)	326.1	1256.06	1582.16	Vulnerable	61
Iceplant glasswort herbfield loamfield (SA7)	0	31.23	31.23	Crit. Endangered	52
Coastal turf (SA5)	1.29	0.92	2.22	Crit. Endangered	27
Spinifex, pingao grassland (DN2)	170.01	100.85	270.86	Endangered	25
Pohutukawa puriri broadleaved forest (WF4)	582.1	205.46	787.56	Endangered	17
Oioi restiad rushland and reedland (WL10)	12.99	5.52	18.52	Endangered	17
Flaxland (WL18)	4.73	0.32	5.05	Crit. Endangered	9
Oioi knobby club rush sedgeland (DN5)	17.5	6.86	24.36	Crit. Endangered	5
Lakeshore turf (WL15)	0.21	0.03	0.24	Crit. Endangered	5
Manuka tangle fern scrub fernland (WL12)	7.68	10.1	17.79	Crit. Endangered	5
Kanuka scrub forest (VS2)	415.95	593.97	1009.92	Least concern	4
Kahikatea pukatea forest (WF8)	11	5.24	16.23	Crit. Endangered	4
Raupo reedland (WL19)	28.51	4.88	33.38	Endangered	3
Totara kanuka broadleaved forest dune forest (WF5)	34.21	35.9	70.11	Crit. Endangered	2
Manuka kanuka scrub (VS3)	124.39	54.58	178.97	Least concern	2
Machaerina sedgeland (WL11)	7.9	0.25	8.15	Crit. Endangered	2
Broadleaved scrub forest (VS5)	53.29	25.08	78.37	Least concern	1
Puriri forest (WF7)	1.62	0	1.62	Crit.	1

Indigenous ecosystem type (and code) CL = cliff, DN = dune, MF = mild forest, SA = coastal saline, VS = regenerating, WL = wetland, WF = warm forest	**Total area on mainland (ha)**	**Hauraki Gulf islands (ha)**	**Regional total (ha)**	**IUCN threat status**	**% of total habitat**
				Endangered	
Kauri podocarp broadleaved forest (WF11)	89.44	7.27	96.7	Endangered	1
Kauri podocarp broadleaved beech forest (WF12)	19.39	0	19.39	Endangered	0.4
Kauri forest (WF10)	4.45	0	4.45	Endangered	0.4
Gumland heath (WL1)	0.15	0	0.15	Crit. Endangered	0.1
Taraire, tawa, podocarp forest (WF9)	9.15	0.44	9.59	Endangered	0.1
Tawa kohekohe rewarewa hinau podocarp forest (WF13)	6.01	0	6.01	Vulnerable	0.1
Sea rush oioi (SA1.3)	1.37	0.3	1.67	n/a	n/a
Shell barrier beaches (SA1.5)	0.58	0	0.58	n/a	n/a
Basaltic lava rockland coastal needle grass tussockland (SA1.7)	0.52	0.36	0.88	n/a	n/a
TOTAL AREA	1928.46	2515.76	4444.23		

1 = significant areas of mangrove habitat lie below MHWST so this type of analysis is not appropriate for this ecosystem. However, all mangrove habitat is concentrated along Auckland's coastal margin.

2 = several variants of the general mangrove ecosystem type are regarded as uncommon or historically rare (*sensu.* Williams et al. 2007) and may be threatened.

Table 4: Indigenous terrestrial ecosystems within 500m of MHWST around the Auckland coastline.

Indigenous ecosystem type (and code)	**Mainland**	**Hauraki Gulf islands**	**Regional Total**	**IUCN threat status**	**% of total habitat**
Mangrove forest and scrub (SA1)	n/a[1]	n/a[1]	c.10,200[1]	Least concern[2]	100[1]
Pohutukawa scrub forest (VS1)	919.34		919.33	Endangered	100
Spinifex, pingao grassland (DN2)	275.33	1312.22	1587.55	Endangered	100
Iceplant, glasswort, herbfield loamfield (SA7)	59.45		59.45	Crit. Endangered	100
Coastal turf (SA5)	1.36	6.52	7.87	Crit. Endangered	96
Pohutukawa treeland flaxland rockland (CL1)	1624.77	718.42	2343.18	Vulnerable	90
Pohutukawa puriri broadleaved forest (WF4)	2038.60	1756.36	3794.95	Endangered	84
Shore bind weed knobby club rush gravelfield stonefield (SA4)	41.81	0.39	42.20	Endangered	75

Indigenous ecosystem type (and code)	Mainland	Hauraki Gulf islands	Regional Total	IUCN threat status	% of total habitat
Oioi knobby club rush sedgeland (DN5)	73.46	163.98	237.45	Crit. Endangered	52
Kanuka scrub forest (VS2)	7142.79	2112.06	9254.85	Least concern	39
Oioi restiad rushland reedland (WL10)	18.26	23.35	41.61	Endangered	39
Gumland heath (WL1)		33.92	33.92	Crit. Endangered	33
Lakeshore turf (WL15)	0.03	1.58	1.61	Crit. Endangered	31
Flaxland (WL18)	0.32	14.17	14.49	Crit. Endangered	27
Manuka kanuka scrub (VS3)	674.44	1268.74	1943.18	Least concern	23
Manuka tangle fern scrub fernland (WL12)	63.26	22.47	85.73	Crit. Endangered	22
Raupo reedland (WL19)	93.33	142.46	235.78	Endangered	21
Kahikatea pukatea forest (WF8)	6.60	64.11	70.71	Crit. Endangered	17
Machaerina sedgeland (WL11)	7.77	58.64	66.40	Crit. Endangered	16
Totara kanuka broadleaved forest dune forest (WF5)	120.72	260.33	381.05	Crit. Endangered	12
Kauri podocarp broadleaved forest (WF11)	840.19	1109.58	1949.77	Endangered	10
Broadleaved scrub forest (VS5)	197.10	202.46	399.56	Least concern	7
Kauri podocarp broadleaved beech forest (WF12)	11.77	269.72	281.49	Endangered	6
Manuka, wire rush restiad rushland (WL2)		0.64	0.64	Crit. Endangered	5
Taraire, tawa, podocarp forest (WF9)	223.63	91.12	314.75	Endangered	4
Puriri forest (WF7)	1.77	5.97	7.74	Crit. Endangered	3
Hebe, wharariki flaxland and rockland (CL2)	0.57		0.57	Least concern	1
Kauri forest (WF10)		14.88	14.88	Endangered	1
Tawa kohekohe rewarewa hinau podocarp forest (WF13)	0.96	49.30	50.26	Vulnerable	1
Kahikatea forest (MF4)		4.03	4.03	Crit. Endangered	1
TOTAL AREA	14437.61	9707.41	24145.02		

1 = significant areas of mangrove habitat lie <u>below</u> MHWST so this type of analysis is not appropriate for this ecosystem. However, all mangrove habitat is concentrated along Auckland's coastal margin.

2 = several variants of the general mangrove ecosystem type are regarded as uncommon or historically rare (*sensu.* Williams et al. 2007) and may be threatened.

Comparing these data with the inundation vulnerability results presented in the previous section shows there is some overlap between the two risk factors. Five of the eight (63%) ecosystem types identified as at risk from inundation during storms were also at risk for at least one of the two coastal categories. However, this coastal analysis also identified seven different ecosystem types that had a lower risk of inundation, and each of these is briefly addressed below. There was a significant correlation between 'at risk' ecosystems in the 50m and 500m coastal bands. All the 'at risk' ecosystems within the 50m coastal band (eight total), were also 'at risk' under the 500m coastal band criteria. Four ecosystem types were identified as 'at risk' within the 500m band only (Table 4 and 7). Threats from climate change to all the 'at risk' ecosystems not covered in the section above are considered in more detail below.

Shore bindweed-knobby clubrush gravelfield (SA4) is associated with gravel and boulder beaches and the estuarine areas of large rivers (Singers et al. 2017). Its distribution is only very local in the North Island. This historically rare ecosystem (Williams et al. 2007) is very limited in extent within the region; just 56ha are mapped in the region and more than 90% of this is associated with the margins of Hauturu (Little Barrier) Island. Other very small areas are known at Matingarahi, Tapapakanga and Waiheke Island.

Key ecosystem processes are the landform, raw soil and high salinity (Singers et al. 2017) and these probably have some resilience to climate change impacts – provided these physical habitats are not entirely destroyed by storm damage or submerged by rapid sea-level rise. This ecosystem was never common but has been significantly reduced by a wide range of threats including vehicle damage, habitat loss from development, damage and trampling by grazing animals, and displacement of native plants by weeds (ibid.). Drought tolerant weeds are an identified threat to shore bindweed-knobby clubrush gravelfield (Wiser et al. 2010) and these will probably increase with climate change.

Iceplant-glasswort herbfield (SA7) is an obligate coastal ecosystem that is strongly influenced by salinity in association with physical disturbance and guano from seabirds; it is also known as 'petrel scrub' (Wright 1980, Singers et al. 2017). The ecosystem was formerly widespread on coastal sites throughout NZ, although the limited size of individual patches mean that it is regarded as a historically rare ecosystem (Williams et al. 2007). Petrel scrub has become extinct from the mainland and most offshore islands, however restoration of seabird colonies on predator free coastal habitat may assist its future expansion.

This ecosystem has a very limited distribution within the Auckland region; around 60ha are mapped in the region, almost all of which is on the Mokohinau Islands. However, there are very small remnants in other locations with active seabirds (e.g. coastal rock stacks at Te Henga Beach). Petrel scrub requires active seabird burrows to arrest succession to tall forest, and therefore its biggest threat is predatory mammals that have exterminated or supressed seabird populations (Jones et al. 2008). The elevation of currently mapped locations means that they are not threatened with inundation, but would be highly exposed to more frequent and intensive storms. However, physical destruction of existing habitat could cause their resident birds to move elsewhere and potentially 're-create' this ecosystem in another location. Therefore, the impact of climate change on seabird populations is probably the primary factor determining the long-term persistence of petrel scrub. This ecosystem is also highly vulnerable to invasion by herbaceous weeds (Singers et al. 2017) which are already a problem in within some locations in the Auckland region, e.g. Mahuki Island (A. Jamieson pers. comm.).

Pohutukawa-puriri-broadleaf forest, or coastal broadleaved forest (WF4), is found in frost free areas from the Three Kings Islands to Mahia on the east coast and New Plymouth on the west coast of the North Island (Singers et al. 2017). Effects from some changes in the general climate – such as an increase in mean annual temperature and reduction in frost frequency – might have a lesser impact on coastal broadleaved forest This is because it is a warm-climate ecosystem whose limits are determined by the absence of frost, and warm-climate species are predicted to expand their ranges southward and to higher altitudes in response to climate change (Hennessy et al. 2007, McGlone et al. 2010). However, other climatic changes such as increases in drought stress and the frequency and severity of storms may have deleterious effects.

Increases in drought severity have the potential to modify species composition by favouring drought-tolerant plant species, and this is a particular threat if these are exotic plants displacing natives. Given the current state of our knowledge it is unclear exactly what the climatic 'tipping points' might be in terms of drought frequency and/ or severity. More than 4500ha of this ecosystem type is mapped in the region. However, it was much more widespread in pre-human times and the current distribution is highly fragmented (average patch size of c.4 ha) and probably only represents around 20% of its historical extent (ibid.). Animal pests and a wide range of weeds are significant threats. Climate change effects that operate synergistically with these impacts are probably the biggest threat to coastal broadleaved forest.

Coastal broadleaved forest is almost purely coastal in distribution (84% is within 500m of MHWST). Therefore, increased physical disturbance from erosion during more severe storms has been cited as a possible negative impact of climate change, particularly if these disturbances also facilitate the invasion of weeds (Singers et al. 2017). Fortunately, there are a number of relatively large, good quality examples of this ecosystem within public reserves that are also free of animal pests and receive regular weed control; these include Hauturu (Little Barrier) Island, the northern coastline of Aotea (Great Barrier) Island, Tawharanui Open Sanctuary, Wenderholm Regional Park, and the Waitakere coastline within Waitakere Regional Park. The widely dispersed nature of these sites means this ecosystem type is less vulnerable to severe impact from a single intensive storm event.

A recent additional risk to coastal broadleaved forest is the recent arrival of myrtle rust (*Austropuccinia psidii*) to northern New Zealand (and Raoul Island) in 2017. Pohutukawa, which is often the dominant component (in terms of biomass) within this ecosystem and has an important role as an 'ecosystem engineer', is known to effected by myrtle rust (Galbraith and Large 2017, de Lange et al. 2018). There is currently no known effective treatment for myrtle rust and current evidence suggests that, as a precautionary measure, all the New Zealand Myrtaceae species previously considered to be 'Not Threatened' needed to be re-classified (de Lange et al. 2018, see Appendix D). The role of climate change in increasing the geographical spread and/ or virulence of myrtle rust, especially with respect to species specific effects, is still uncertain. However, if climate change did increase the risk of myrtle rust impacts on pohutukawa this would represent a significant risk to this ecosystem type in the Auckland region

Manuka gumland (WL1) occurs across the same range as kauri forest (i.e. north of 37^{o} south latitude) and has been greatly reduced in extent over the past few hundred years to the point where it is now present only as small pockets (Clarkson et al. 2011). There is only one known example of 'true' gumland in the Auckland region at Waikumete Cemetery (B. Clarkson pers. comm. 2014). Although there are other examples in Albany, Orewa and Whangaparaoa which have probably been induced by the very high fire frequencies associated with human settlement of New Zealand. Gumlands occupy some of the lowest fertility soils in New Zealand and are well adapted to water and drought stress.

The most important threats to gumland ecosystems are the impact of weeds and clearance for development. Climatic impacts which increase the relative ecological fitness of weedy plants over native species therefore have the potential to severely impact gumlands. Increased fire frequency, which is a potential impact of climate change and is often associated with drought, has been shown to promote the invasion of weeds into gumland type wetlands in New Zealand (Johnson 2005, Perry et al. 2014). Their very restricted distribution means Auckland's gumlands are also more vulnerable to severe, localised, climate-related disturbances.

Pohutukawa scrub and forest (VS1) is found in frost free locations along the coastline of the northern North Island and in localised places around the Rotorua lakes (Singers et al. 2017). Often abundant on very raw soils or parent rock exposed to salt-laden winds (Bergin and Hosking 2006). The best Auckland region example is on Rangitoto Island. Direct effects from some of the changes in general climate – such as an increase in mean annual temperature, reduction in frost frequency and more frequent storms - are probably less likely to negatively affect this ecosystem type. This is because it is a 'warm-climate' ecosystem that is well adapted to coastal disturbance. However, other climatic changes, such as more frequent and severe drought stress and the increased fire frequencies associated with increased drought stress (Stephens et al. 2013), could have negative impacts on pohutukawa forest. Rangitoto island, which contains more than 90% of the mapped regional extent of this ecosystem type, is particularly vulnerable to fires due to its lack of fresh water and high public usage.

Other potential indirect threats of climate change include changes in the interactions between pohutukawa forest and animal pests, plant pests and/ or pathogens. The best and largest examples of this ecosystem in Auckland are now free of animal pests, but the ecosystem is invaded by a wide range of weeds which can displace natives and alter successional pathways (Singers et al. 2017). Myrtle rust, which was recently detected in New Zealand, also has the potential to severely affect pohutukawa (Galbraith and Large 2017) and the interactions of climate change with the effects of this pathogen are currently unclear (see WF4, coastal broadleaved forest information above).

Pohutukawa treeland, flaxland and rockland (CL2) (i.e. pohutukawa cliff forest) is the predominant native cover on steep, erosion and drought-prone coastal cliffs exposed to salt and strong winds from the far North to north Taranaki (west coast) and Poverty Bay (east coast). Pohutukawa cliff forest is widespread in the Auckland region; around 2600ha is mapped in the region, in around 1000 different locations. However, many of these remnants are highly modified by weeds. The best examples occur on the Waitakere coast and on Hauraki Gulf islands (Singers et al. 2017). Pohutukawa cliff forest is probably more vulnerable to increased frequency and intensity of disturbance events (especially storms and drought) due to its exposed coastal location, and the erosion prone, droughty nature of the substrate on which it grows.

This ecosystem type is also highly vulnerable to the impact of browsing mammals (especially possums (Payton 2000)) and introduced weeds (Wiser and Allen 2006). The impact of new pathogens, in particular myrtle rust, also have the potential to cause widespread devastation. Myrtle rust has the potential to severely affect pohutukawa (Galbraith and Large 2017) and the interactions of climate change with the effects of this pathogen are currently unclear (see WF4, coastal broadleaved forest information above and Appendix D). Climate change impacts that increase the severity of one or more of these threats could have a severe impact on the long-term health of pohutukawa cliff forest. However, the interactions between climate change and these other threats are uncertain and have received little or no attention in terms of quantitative research.

Kanuka scrub and forest (VS2) is found throughout New Zealand, from North Cape to Otago, in locations where former native forest cover has been removed by disturbance (both natural and human-induced). This ecosystem type thrives in warm to cool semi-arid climates. It probably has one of the lowest vulnerabilities with respect to climate change of any Auckland ecosystem due to the ecological traits of its main constituent, kanuka (*Kunzea robusta*). Increases in drought stress and more regular climate-related disturbance may benefit this ecosystem type at the expense of other mature indigenous forest types. This is because many species of kanuka are particularly well adapted to drought stress (Burrows 1973, Smale 1994, Meurk 2008) and commonly replace tall forest in New Zealand following frequent fires (Wardle 1991). Kanuka scrub and forest is also widespread throughout Auckland (comprising 31% of the area of all scrub and forest) and New Zealand, which means it is at very low risk of severe impact from stochastic disturbance.

This ecosystem has tolerated multiple climatic upheavals over the last several million years and, until recently, it seemed likely that it would cope with future changes as well. However, *Kunzea robusta* and several other kanuka species (cf. de Lange (2014)) that are present in the Auckland region have recently been re-classified as threatened species due to the arrival of myrtle rust (*Austropuccinia psidii*) to northern New Zealand (and Raoul Island) in 2017. Myrtle rust has the potential to severely affect all myrtle species and the interactions of climate change with the effects of this pathogen are currently unclear (see WF4, coastal broadleaved forest information above and Appendix D). However, if climate change did increase the risk of myrtle rust impacts on *Kunzea robusta* this would represent a significant risk to this ubiquitous and important ecosystem type in the Auckland region.

3.1.3 Ecosystems with highly restricted distributions

While many ecosystems can be vulnerable to the impact of climate change, ecosystems with highly localised and/ or restricted distributions are much more vulnerable to regional extinction or severe reduction of their range from a random physical disturbance event. The frequency and severity of extreme weather events is likely to increase as a result of climate change. Weather related disturbance events such as landslides, flooding, erosion, sedimentation, wind throw, and deposition of salt-spray can have a very severe impact on the health of ecosystems in localised areas. In the worst cases they may be completely inundated, removed, or buried as a result of climatic disturbances. Rare ecosystems are more vulnerable to disturbances from severe weather events that – just by chance – affect one of the few locations they are present.

Table 5: Indigenous ecosystems in Auckland vulnerable to regional extinction, or a significant reduction in extent from stochastic disturbance events (e.g. flood, storm damage, landslide, drought etc.) due to their severely restricted extent (<200 ha).

Indigenous ecosystem type (and code)	Total area	IUCN threat ranking
Lakeshore turf (WL15)	5 ha	Crit. Endangered
Coastal turf (SA5)	8 ha	Crit. Endangered
Manuka-wire rush restiad rushland (WL2)	13 ha	Crit. Endangered
Hebe-wharariki flaxland (CL6)	42 ha	Least concern
Shore bindweed, knobby club rush gravelfield and stonefield (SA4)	56 ha	Endangered
Iceplant-glasswort herbfield and loamfield (SA7)	60 ha	Crit. Endangered
Rimu-towai forest (MF24)	80 ha	Crit. Endangered
Manuka gumland (WL1)	102 ha	Crit. Endangered
Oioi rushland and reedland (WL10)	107 ha	Endangered
Kauri-towai-rata montane podocarp forest (MF25)	157 ha	Endangered

Ten regional ecosystem types have a total extent of less than 200ha (Table 5). With the exception of hebe-harakeke flaxland, all of these ecosystems are classified as endangered under IUCN red list criteria (IUCN 2017); six of them are critically endangered. All endangered ecosystem types are characterised by very patchy and/or restricted distributions. Six of the threatened ecosystem types in Table 5 are almost totally coastal or mostly coastal in their distribution; including lakeshore turf, coastal turf, manuka-wire rush restiad rushland, shore bindweed-knobby clubrush gravelfield, iceplant-glasswort herbfield, and oioi rushland. This makes them particularly vulnerable to being disturbed in severe weather events

The remaining two ecosystems are rimu-towai forest and kauri-towai-rata montane podocarp forest. These relatively high altitude (for Auckland) ecosystems are restricted to rugged volcanic summits and steep hill slopes above 450m on the Hunua Ranges and Aotea (Great Barrier) Island, and above 600m on Hauturu (Little Barrier) Island. The climate in these locations is characterised by high rainfall, frequent cloud cover and high exposure to severe winds. This is a very localised distribution which is also particularly vulnerable (due to its altitude, exposure and topography) to disturbance during severe storms. Both these forest types are classified as 'Mild Forest' (MF) ecosystems within the Singers and Rogers (2014) classification system; locations where mean summer temperatures range from 15°C to 17.5°C (ibid.). This contrasts with the overwhelming majority[12] of Auckland's indigenous forest ecosystems which are classified as 'Warm Forest'(WF) within this system.

Six of the ten ecosystem types with highly restricted distributions were also identified as being at risk due to their coastal locations in the two sections above, and their general risks and vulnerabilities discussed in these sections. Climate change risks in relation to the remaining four ecosystems are briefly summarised below.

Manuka, wire rush, restiad rushland (WL2) occurs as part of inland wetlands in northern NZ on older (1500-7000 years) organic parent material (Clarkson et al. 2004). Found on the margins of some dune lakes in Auckland (Singers et al. 2017) it has a highly restricted distribution. Less than 13ha of this ecosystem has been mapped in the Auckland region which makes it vulnerable to severe, localised, climate-related disturbances that happen to negatively affect the few small fragments that remain. Drainage and development for agriculture means there are few other places for the ecosystem to migrate to. As a wetland ecosystem, this type is also more vulnerable to being affected by drought, however it is much more tolerant of extended dry periods than many other wetlands (Singers et al. 2017). Therefore, many of the main threats to this ecosystem are non-climate related and these are likely to remain important into the future; including clearance for development, altered hydrology (due to drainage), trampling by stock and weed invasion. Important potential direct and indirect climate change related risks include a reduction in water input due to more frequent and prolonged droughts, altered hydrological regimes, and the synergistic effects of drought and invasive weeds.

[12] Based on Auckland Council data from the Current Ecosystem Extent and Potential Ecosystem Extent maps, 98% of current indigenous forest ecosystems in the region are 'Warm Forest' and 99.97% of potential forest ecosystems would be classified 'Warm Forest'.

Hebe-wharariki flaxland (CL2) occurs on cliffs, rock outcrops, highly erodible steep slopes and colluvial slopes at the bases of these features (Singers et al. 2017). Despite its 'least concern' threat ranking, this ecosystem type has a very restricted distribution within the Auckland region; just 42ha is mapped in the region, with an average 'patch size' of around one hectare. In Auckland, the best examples of this ecosystem lie within the regions four largest and best tracts of intact indigenous forest; Waitakere Ranges, Hunua Ranges, Aotea (Great Barrier) and Hauturu (Little Barrier) islands. Its steep and erosion prone habitat probably make hebe-wharariki flaxland more vulnerable to the impact of physical damage from increasingly frequent and severe storms and erosion. However, many of the species are adapted to these disturbances and the relatively widespread distribution of this ecosystem within the Auckland region reduces the risk of stochastic disturbance affecting a significant proportion of remnants in a single event.

Hebe-wharariki flaxland is relatively well protected from the synergistic impacts of animal pests and climate change – due to ongoing control or elimination of animal pests – and development. However, the open sites where this ecosystem occurs are quite vulnerable to invasion by disturbance adapted and light demanding weedy plants such as pampas, boneseed, Cape ivy, evergreen buckthorn and gorse. Climate change affects which increase the fitness of these weedy species in relation to indigenous plants could have serious impacts on this ecosystem.

Rimu-towai 'rainforest' (MF24) is mostly found on low fertility steepland and plateaux above 450m in the upper North Island that have high rainfall, frequent cloud cover and exposure to high winds (Singers et al. 2017). In the Auckland region rimu-towai rainforest is restricted to three locations in the Hunua Ranges above 450m (total c. 80 ha); almost all this ecosystem is concentrated in a single block along the summit of the main Hunua ridgeline Its highly restricted distribution is largely determined by climate (in this case precipitation). Therefore rimu-towai rainforest is likely to be quite vulnerable to changes in general climate that alter rainfall patterns, and to the physical destruction of its habitat from mass erosion events that often accompany more severe storms; especially given the steep, high altitude, erosion prone locations in which it is found The 'tipping point(s)' with respect to the absolute changes in rainfall, or increases in drought stress, that would begin to have a negative effect on this ecosystem are poorly understood. The steep and inaccessible nature of the locations where rimu-towai rainforest grows means threats from human-development are minimal, and weeds are uncommon. Climate change and the impact of pest mammals (notably goats (Payton 2000) and possums) are probably its biggest current threats.

Kauri-towai-rata montane podocarp forest (MF25) is a higher altitude ecosystem type with a very limited New Zealand extent. It is restricted to predominantly rugged volcanic summits of the northern Kaimai and Coromandel Ranges, and Aotea (Great Barrier) Island and Hauturu (Little Barrier) Island within the Auckland region, and is colloquially known as 'cloud forest' (Singers et al. 2017). The distribution of this ecosystem is largely determined by climate; the summits of these volcanic ranges experience high rainfall, long periods of cloud cover, and frequent to high gale-force winds (Ecroyd 1982). Therefore, it is likely to be vulnerable to changes in general climate that alter rainfall patterns. However, the 'tipping point(s)' and/ or effects of climate change on this ecosystem are poorly understood. As with MF24, the steep, high altitude, erosion prone locations where kauri-towai-rata montane forest is found make it more vulnerable to physical destruction during the more frequent and severe storms that will occur as a result of climate change.

3.1.4 Ecosystems at their climatic limits

Auckland experiences a subtropical climate. Summers tend to be warm and humid, while winters are relatively mild, and many parts of the region only receive a few frosts each year. Rainfall is typically plentiful all year round, with sporadic very heavy falls. Lying north of the main mountain chains and the volcanic plateau, the region is less vulnerable to outbreaks of Antarctic air than most of New Zealand. However, it is one of the first areas to encounter storms of tropical origin (Chappell 2013).

In pre-human times, the Auckland region was almost completely covered in forest and scrub associations classified as 'warm forest' in the Department of Conservation's national ecosystem classification system (Singers and Rogers 2014) Ninety-nine per cent of indigenous scrub and forest within the Auckland region is classified as 'warm forest', or a scrub association which is likely to transition to 'warm forest' over time. The exceptions to this dominance of 'warm forest' ecosystems are three 'mild forest' ecosystems which comprise the remaining 1%[13] (by area) of indigenous forest. They are kahikatea forest, rimu-towai forest, and kauri-towai-rata montane forest.

Climate change is likely to result in a general warming of the Auckland climate, a reduction in the number of frost events, and an increase drought stress for some locations (Pearson et al. 2018). These types of changes are probably more likely to affect the distribution of the cooler, milder forest ecosystem types (Table 6) than warm forest and scrub, as they present a more dramatic departure from the status quo. Kauri-towai-rata montane forest has been identified as being potentially

[13] Or 0.87% of all indigenous ecosystems, including non-forest types such as dunelands, low-stature wetlands and open water.

vulnerable to increased drought frequency reducing the soil moisture levels, as this ecosystem currently experiences few periods of soil moisture deficit (Singers et al. 2017). Drought-induced forest mortality is becoming more frequent globally, and similar humid ‘cloud’ forests have been severely affected elsewhere in the world (Allen et al. 2010).

Table 6: Indigenous terrestrial ecosystem types present within the Auckland region that maybe at their ‘climatic limits’ in terms of temperature and/ or precipitation.

Indigenous ecosystem type (and code)	Total area (ha)	Threat ranking	Description
Rimu, towai forest (MF24)	103.6	Crit. endangered	In Auckland this type is restricted to ridges, hill-slopes and plateaux above 450m in the Hunua Ranges that experience high rainfall, frequent cloud cover and wind exposure.
Kauri, towai, rata montane podocarp forest (MF25)	204.0	Endangered	Higher-altitude forest ecosystem of very limited extent that is colloquially known as ‘cloud-forest’. Restricted to the rugged summits (600m+) of northern volcanic ranges such as Hirakimata (Mt Hobson) and Hauturu
Kahikatea forest (MF4)	671.0	Crit. endangered	In Auckland the distribution of this type is noted as being at least partly determined by regular frosts. Present on lowland flat, fertile, swampy terraces throughout the region but concentrated in Coatesville, Kaukapakapa and Clevedon.

Rimu-towai forest (MF24) is the only other Auckland region ecosystem type with a high-altitude restricted distribution. However, climate is not the only factor that influences the composition and structure of this ecosystem type - landform and soil drainage are also important (Singers et al. 2017) - and climate change has not been identified as a specific risk for this ecosystem. All the Auckland region examples of both rimu-towai forest and kauri-towai-rata forest are part of large tracts of native forest and scrub and are surrounded by intact examples of other native ecosystems. If these high-altitude ecosystem types are displaced and/or their species composition is significantly altered as a result of climate change, it is other native plants that are the most likely replacements. The ‘replacement ecosystems’ are likely to be kauri-podocarp broadleaved forest, tawa-kohekohe-rewarewa-hinau-podocarp forest, or lower stature broadleaved scrub on very steep landforms.

Rimu-towai forest (MF4) is the third type of mild forest ecosystem found within the Auckland region. This ecosystem is found throughout the region; 232 different patches are mapped in the region and they are mostly quite small, having a mean size of 2.9ha (median 1.7ha). Only three of these remnants are >25ha in extent and a further nine remnants are >10ha. The three main extant threats to kahikatea forest throughout its range are a lowering of the water table (due to drainage on surrounding farmland), increased fertility (mostly from use of fertilizer on surrounding agricultural land) and weed invasion (Smale et al. 2005). Climate change impacts which exacerbate these effects could be expected to have a more severe impact on this ecosystem.

Unlike the two other high-altitude forest types summarised in this section – both of which have very restricted distribution within New Zealand – kahikatea forest is relatively widespread outside the Auckland region, where it occurs throughout the North Island and through much of the South Island. This means that if this ecosystem was 'lost' from the Auckland region it would almost certainly remain viable in locations further south.

3.1.5 Ecosystems summary

This section summarises information on the various climate change risk factors we identified for indigenous ecosystems in the sections above (Table 7). Twenty (42%) of the 48[14] different indigenous ecosystem types described in Singers et al. (2017) were identified as having at least one risk factor that has the potential to make them more susceptible to the negative impact(s) of climate change. Negative impacts could include changes such as a loss of native plant species typical within the ecosystem, or a reduction in extent. In some cases, native biodiversity might be replaced by exotic species, but this is not necessarily the case for all changes. For example, ecosystems that are part of large, intact tracts of native forest might be displaced by another native ecosystem that is better adapted to the altered environmental conditions and/ or new disturbance regime. However, indigenous species within the much smaller, fragmented ecosystem remnants that are typically of lowland and coastal environments of mainland Auckland are much more likely to be displaced by exotic species (Timmins and Williams 1991; McGlone 2001; Walker et al. 2006; Sullivan et al. 2009).

It seems reasonable to expect that ecosystems which are exposed to a higher number of risk factors are more likely to be negatively impacted by climate change. However, the relative vulnerability of ecosystems to the different threats outlined in Table 7 is very difficult to assess without better data on exactly how they will respond to specific climatic drivers and stresses. There is almost no published research on how climate change effects will affect the relative ecological fitness of pest plants verses native species in any of Auckland's indigenous ecosystems. Almost 20 years

[14] Including ecosystem variants.

ago McGlone (2001) identified the need for an expansion of long-term monitoring sites for indigenous ecosystems, in order to investigate how different climate change effects might affect the interaction between native and exotic biodiversity. These inter-species relationships are very complex and varied in time and space (Tylianakis et al. 2008, Walther 2010, Pacifici et al. 2015) and the actual impact of climate change on ecosystems is likely to be driven as much by inter-species interactions as by the physical changes themselves (Schmitz and Barton 2014). However, to date little progress has been made towards this goal in the Auckland region, and we still lack the necessary data to make accurate predictions about exactly how specific aspects of climate change will affect our indigenous ecosystems.

Table 7: Summary of climate change risk factors for Auckland's indigenous ecosystem types.

Ecosystem type [ecosystem code] (number of risk factors)	More than 10% of ecosystem extent is vulnerable to inundation in a 100-year flood	Coastal location I (>10% within 50m of coast)	Coastal location II (>30% within 500m of coast)	Restricted distribution (<200ha ecosystem extent in the region)	Ecosystem at climatic limits in Auckland region	Climate change specifically identified as a threat for this ecosystem
Coastal turf [SA5] (4)	RISK	RISK	RISK	RISK		
Oioi restiad-rushland and reedland [WL10] (4)	RISK	RISK	RISK	RISK		
Mangrove scrub and forest and other variants [SA1] (4)	RISK	RISK	RISK			RISK
Lakeshore turf [WL15] (3)	RISK		RISK	RISK		
Spinifex-pingao grassland and sedgeland [DN2] (3)	RISK	RISK	RISK			
Shore bind weed-knobby club rush gravelfield and stonefield [SA4] (3)		RISK	RISK	RISK		

Ecosystem type [ecosystem code] (number of risk factors)	**More than 10% of ecosystem extent is vulnerable to inundation in a 100-year flood**	**Coastal location I (>10% within 50m of coast)**	**Coastal location II (>30% within 500m of coast)**	**Restricted distribution (<200ha ecosystem extent in the region)**	**Ecosystem at climatic limits in Auckland region**	**Climate change specifically identified as a threat for this ecosystem**
Iceplant-glasswort herbfield and loamfield [SA7] (3)		RISK	RISK	RISK		
Kauri-towai-rata montane podocarp forest [MF25] (3)				RISK	RISK	RISK
Pohutukawa-puriri broadleaf forest [WF4] (3)		RISK	RISK			RISK
Pohutukawa scrub and forest [VS1] (2)		RISK	RISK			
Pohutukawa treeland, flaxland and rockland [CL1] (2)		RISK	RISK			
Rimu-towai forest [MF24] (2)				RISK	RISK	
Manuka gumland [WL1] (2)			RISK	RISK		
Oioi-knobby club rush sedgeland [DN5] (2)	RISK		RISK			
Kanuka scrub and forest [VS2] (1)			RISK			
Flaxland [WL18] (1)	RISK					
Machaerina sedgeland [WL11] (1)	RISK					

Ecosystem type [ecosystem code] (number of risk factors)	More than 10% of ecosystem extent is vulnerable to inundation in a 100-year flood	Coastal location I (>10% within 50m of coast)	Coastal location II (>30% within 500m of coast)	Restricted distribution (<200ha ecosystem extent in the region)	Ecosystem at climatic limits in Auckland region	Climate change specifically identified as a threat for this ecosystem
Raupo reedland [WL19] (1)	RISK					
Manuka-wire rush restiad rushland [WL2] (1)				RISK		
Hebe-wharariki flaxland [CL6] (1)				RISK		
Kahikatea forest [MF4] (1)					RISK	

Table 7 does not include information on risk factors relating to the impact of introduced pathogens on Auckland's ecosystems; of which the most notable recent examples include kauri dieback (*Phytophthora agathidicida*) and myrtle rust (*Austropuccinia psidii*). Climate change has been shown to influence pathogen development and survival rates, disease transmission, and host susceptibility (Benning et al. 2002, Anderson et al. 2004, Crowl et al. 2008) and most host-parasite systems are predicted to experience more frequent or severe disease impacts with climatic warming (Harvell et al. 2002)

Given the relatively recent detection of kauri dieback and myrtle rust it is still uncertain exactly how they will affect different ecosystem types, and the long-term impacts of these effects on indigenous biodiversity. Therefore, it is also unclear how future climate change will interact with the effects of these pathogens, or how much their recent invasion and spread is due to climate change over the past several decades. If climate change does increase the virulence and/ or spread of myrtle rust or kauri dieback then an additional eight of Auckland's regional ecosystems could be at significant additional risk from the impact(s) of climate change (Table 8); bringing the total number of 'at risk' ecosystems to 28 (58%).

Table 8: Summary of climate change risk factors, including ecosystems ‘at risk’ due to myrtle rust or kauri dieback negatively affecting a species which is primary ecosystem component

Ecosystem type [ecosystem code] (number of risk factors)	**Number of risk factors from** Table 7	**At risk from myrtle rust**	**At risk from kauri dieback**
Coastal turf [SA5] (4)	4		
Oioi restiad-rushland and reedland [WL10] (4)	4		
Mangrove scrub and forest and other variants [SA1] (4)	4		
Kauri-towai-rata montane podocarp forest [MF25] (4)	3		RISK
Pohutukawa-puriri broadleaved forest [WF4] (4)	3	RISK	
Lakeshore turf [WL15] (3)	3		
Spinifex-pingao grassland and sedgeland [DN2] (3)	3		
Shore bind weed-knobby club rush gravelfield and stonefield [SA4] (3)	3		
Iceplant-glasswort herbfield and loamfield [SA7] (3)	3		
Manuka gumland [WL1] (3)	2	RISK	
Pohutukawa scrub and forest [VS1] (3)	2	RISK	
Pohutukawa treeland, flaxland and rockland [CL1] (3)	2	RISK	
Rimu-towai forest [MF24] (2)	2		
Manuka-wire rush restiad rushland [WL2] (2)	1	RISK	
Oioi-knobby club rush sedgeland [DN5] (2)	2		
Kanuka scrub and forest [VS2] (2)	1	RISK	
Flaxland [WL18] (1)	1		
Machaerina sedgeland [WL11] (1)	1		
Raupo reedland [WL19] (1)	1		
Hebe-wharariki flaxland [CL6] (1)	1		
Kahikatea forest [MF4] (1)	1		
Kauri forest (includes 2 variants) [WF10] (1)	0		RISK
Kauri-podocarp-broadleaved forest [WF11] (1)	0		RISK
Kauri-podocarp-broadleaved-beech forest [WF12] (1)	0		RISK
Manuka-kanuka scrub (includes 2 variants) [VS3] (1)	0	RISK	
Manuka-tangle fern scrub and fen [WL12] (1)	0	RISK	
Totara-kanuka-broadleaved forest [WF5] (1 variant only) (1)	0	RISK	

One important consideration is whether indigenous plants and animals displaced by the impact of kauri dieback and myrtle rust will be replaced by other native species, or by exotic plants and weeds. Past experience suggests that ecosystems which are fragmented and stressed are much more likely to suffer negative consequences from these types of external stress (Laurance and Williamson 2001, Camarero et al. 2011, Fox et al. 2014); positive (or less negative) outcomes are much more likely within well-buffered, well-managed and resilient ecosystems (McGlone 2001, McGlone et al. 2010, Martin & Watson 2016). Almost all of Auckland's indigenous terrestrial ecosystems are already under threat from introduced animal pests and/ or plant pests, and lowland ecosystems are also at risk from ongoing clearance and fragmentation of habitat. Potentially the most serious and pressing impacts of climate change arise through its interaction with these pre-existing threats (McGlone 2001). However, as climate change mainly impacts through exacerbating pre-existing ecological and biodiversity problems, ongoing management of these biodiversity threats can, to an extent, help us deal with its impacts (ibid.).

3.2 Species

The results presented above are based on ecosystem distribution and don't consider the vulnerability of individual species to climate change effects. Taking the ecosystem approach means that the vulnerability of species which 'live, feed and breed' in the different ecosystems in the region is incorporated to some extent. This is particularly the case for threatened forest and scrub dwelling birds, reptiles and more widely distributed (but uncommon) invertebrates. However, there are a wide range of species that are not covered by this analysis; including seabirds, wetland birds, coastal and wader birds, threatened plants of open habitats (both coastal and inland), and plant and invertebrate species with very restricted distributions.

Ideally, we would be able to apply the same types of spatial analysis to threatened species as that which has been carried out for ecosystems. However, the reality is that reliable data on the location, size, health and distribution of most threatened species is not available, and for those few species where it is available much of it is not held in spatial (map) form. Therefore, the information presented in this section is necessarily more speculative in terms of the assessments made.

3.2.1 Bats

Overseas studies have shown a number of bat species which are sensitive to climate change (Rebelo et al. 2010, Sherwin et al. 2013, Razgour et al. 2013). Auckland contains two of New Zealand's seven native bat taxa, the long-tailed bat (North Island; *Chalinolobus tuberculatus*) and the northern short-tailed bat (*Mystacina tuberculata aupourica*). Both Auckland bats are threatened with extinction (O'Donnell et al. 2018). Their major threats are from predation and competition from invasive mammals, habitat degradation and disturbance (O'Donnell et al. 2010). Auckland bat populations may also be negatively affected indirectly by the relatively recent plant diseases kauri dieback and myrtle rust which may result in significant changes to the ecosystems bats use. Vespulid wasps are predicted, as are other pests, to get worse in Auckland from climate change, and thus may also have increased negative impacts on bats (O'Donnell et al. 2018, Auckland Council 2018). Bats are clearly vulnerable to Auckland's changing climate and will need enhanced management to have the resilience to survive these challenges on their populations.

3.2.2 Reptiles and amphibians

Auckland has several native reptile and amphibian species including:

- The tuatara, the only surviving member of the reptile order Rhynchocephalia (Lutz 2006).
- Seven gecko species.
- Eleven skink species.
- Hochstetter's frog (4 taxa).

Most of these species are 'at risk' or 'threatened' with extinction (Hitchmough et al. 2016, Newman et al. 2013). Reptiles are generally good at avoiding thermal stress and high body temperatures as well as resisting water loss (Huey et al. 2010), yet there is growing evidence that climate change warming will drive many species to extinction (Sinervo et al. 2010). Tuatara, which have temperature-dependent sex determination, have been predicted in climate models to produce 100% male hatchlings in less than a 100 years from rising temperatures, which will lead to local population extinctions (Mitchel et al. 2010). Amphibians are at serious risk as well, with an international assessment finding up to 15% of all species vulnerable to climate change (Foden et al. 2013). Frogs are particularly sensitive to temperature variation and humidity due to their permeable skin (López-Alcaide and Macip-Ríos 2011). Auckland's already very stressed Herpetofauna with their low conservation status and the potential issues above mean they are likely at risk of a variety climate change impacts; however, there are few empirical studies of Auckland, let alone New Zealand, species with regards to how these taxa will be affected by climate change. Thus, given this general uncertainty, conserving Auckland's Herpetofauna should be a management priority, such as reducing predation by invasive mammalians, restoring native habitat, preventing further habitat destruction, and tackling other biosecurity risks (namely poaching) (Anderson et al. 2012).

3.2.3 Invertebrates

New Zealand's invertebrates are one of the least studied groups of biodiversity, with only approximately a third of the known ~13,000 terrestrial taxa assessed for their conservation status and of those, a third are categorised as 'Data Deficient' (Stringer and Hitchmough 2012). This lack of knowledge and research activity in New Zealand invertebrates makes this group one of the largest challenges in the attempt to understand what their risks and vulnerabilities are to climate change (Holwell and Andrew 2014). Overseas studies have shown that invertebrates are sensitive to variations in seasonal temperatures (Bale et al. 2002, Deutsch et al. 2008), with examples of range shifts such as seen in a number of butterflies (Parmesan et al. 1999). While butterflies have been able to adjust latitudinally to the warmer temperatures, there may be many invertebrates which will have difficulty in highly fragmented landscapes (Deutsch et al. 2008). This is of particular note for Auckland's invertebrates with the region's highly fragmented landscape. Even more challenging to assess are the trophic-level changes that may take place, such as timing changes in invertebrate life history stages and their host plants and the predators that regulate these systems (Harrington et al. 1999), or how changes to pollination cycles might affect these systems (Visser and Both 2005). Changes in resources availability, on top of the above temperature sensitivities, will have profound effects on insects' physiology, behaviour and ecology (Holwell and Andrew 2014). Auckland's invertebrates will also likely be affected by changes in invasive species (see section 3.2.7 below), such as from increased predation and competition by pest animals such as from rats and wasps (Lester et al. 2014).

3.2.4 Birds

Most New Zealand bird species are high on the food chain as predators, and thus are useful indicators of the ecosystems they're part of (Furness and Greenwood 1993, Temple and Wiens 1989). About one third of New Zealand's birds are 'at risk' or 'threatened' with extinction, and in Auckland this figure is even higher with over 40% of the ~170 Auckland bird species 'at risk' or 'threatened' (Robertson et al. 2017). Climate-related changes in Auckland may add a variety of additional stresses to birds, such as changes to their physiology and energy needs from higher temperatures (Pendlebury et al. 2004), to their foraging or breeding behaviours and thus potentially reduced breeding success (Nils Chr et al. 2002), to effects on their distribution and food sources right down the food chain from increased extreme weather events and droughts (Crick 2004, Auer and King 2014). Phenological changes have also been seen in a number of overseas avifaunal examples, such as changes to egg laying (Crick et al. 1997, Crick and Sparks 1999). Birds do appear to be adapting to some climate changes, however without local examples it is hard to estimate how Auckland birds will be affected. An international assessment of birds found as many as 9% of all birds are vulnerable to climate change (Foden et al. 2013), but this number may be higher in Auckland with the predicted climatic changes. There is a particular concern for what effect the potential increases in invasive species (see section 3.2.7 below), such as of rats, mustelids and wasps, will have on Auckland's birds.

3.2.5 Case study: seabirds risk assessment

New Zealand is internationally recognised as the seabird capital of the world with approximately one quarter of all seabirds breeding in the country, and Auckland itself is one of New Zealand's seabird hotspots with 24 species breeding in the area (

Table 9) (Gaskin and Rayner 2013). Seabirds are linkages between marine and terrestrial ecosystems as top predators which forage at sea and breed on land where they deposit marine nutrients. They are known as the most threatened group of birds (Lascelles et al. 2016), with threats both at sea and on land, including their high vulnerability to invasive mammalian pests (Borrelle et al. 2016). Their threatened conservation status, challenging long reproductive cycles requiring bi-parental care, and large spatial habitat requirements may result in increased vulnerability to climate change impacts. Consequently, seabirds have been proposed as potential indicators of climate change (Towns et al. 2012).

Auckland's seabirds are already in a delicate state with the majority of the 24 species 'at risk' or 'threatened' with extinction (

Table 9). As with the taxa discussed above, the effects of climate change are challenging to assess for seabirds with limited species information available. Our best estimate of the major climate change effects most relevant to seabirds generally shows a low risk for most species in regards to sea level rise and increased pest pressure, but potentially moderate risk from increased severe weather events (

Table 9).

Sea level rise will pressure most those seabirds which nest close to the shore. In Auckland, this includes little penguin, and especially New Zealand fairy tern. Little penguin are at moderate risk as they have some flexibility to nest further up elevation from the sea, whereas fairy tern may not. Fairy tern are New Zealand's rarest endemic bird with only about 40 individuals remaining, including fewer than 10 breeding pairs (Preddey and Pulham 2017). This 'Nationally Critical' seabird (Robertson et al. 2017) breeds only at three regular breeding areas at Papakanui, Mangawhai and Waipu sandspits, and more recently at Pakiri River mouth (Pulham and Wilson 2013). This once widely distributed seabird is now confined to only a few coastal-front areas which are occasionally inundated from high tides, showing the high risk this species has to climate change impacts.

Introduced pest animals are a major threat for seabirds through predation of eggs, chicks and adults (Croxall et al. 2012, Fukami et al. 2006, Taylor 2000). Some pest plants are also dangerous to seabirds, such as box thorn (*Lycium ferocissimum*), which can kill petrels from impacts with their stiff thorns as the birds fly into the shrubs (Cox et al. 1967). Auckland's seabirds are affected by a range of pests, some of which are thought to become more of a threat with the effects of climate change (Table 10). Although most of Auckland's seabirds are not likely to be affected much by the potential increases in pests resulting from climate change (

Table 9) (Pearce et al. 2018), this assessment is based on the current distribution of seabirds, of which most are confined to pest-free offshore islands (Gaskin and Rayner 2013). To improve the conservation status of these birds it will be necessary to create pest-free habitat on the mainland of Auckland, which will be a challenge with the added pressure from climate change.

Severe weather events are expected to become more frequent in Auckland (Pearce et al. 2018) and are likely to affect most of Auckland's seabirds at some level (

Table 9). These effects are likely to be confined to their breeding colonies where flooding and slips could damage their nests. This has been seen in the New Zealand endemic seabird, the westland petrel (*Procellaria westlandica*), where high levels of damage to their breeding colonies from slips took place from the severe storm ex-tropical cyclone *Ita* (Waugh et al. 2015).

Complex changes to seabirds behavioural ecology as a result of climate change are another potentially important threat, such as a result of changes in prey availability from warming oceans and ocean acidification (Fernandez et al. 2017, Pearce et al. 2018, Foley & Carbines 2019, Provencher et al. 2019). These changes are likely to influence the food chain from the bottom up by changing the distribution and abundance of plankton, crustaceans, affecting the squid and fish which feed on these taxa, which are the food seabirds rely on (Taylor 2000). Consequently, seabird foraging trips from their breeding colonies to their feeding areas at sea may change as a result of their inability to find enough prey, which risks offspring not getting fed quickly enough. This appears to be the case with flesh-footed shearwaters in the Hauraki Gulf where tracking data has shown trip lengths have been increasing (G. Taylor pers. comm.). Mass food failures related to large scale oceanic changes and the consequential negative effects on breeding success have also been documented in other seabirds in the Pacific (Warham 1996). These large scale changes are extremely hard to assess with seabirds as they require complex modelling using a range of biotic and abiotic variables, of which many we are only just starting to understand. The complexity increases further when considering other potentially increased threats as a result of a changing climate such as increases in pathogens/parasites and other factors internal to the birds such as physiological changes from heat stress, which has been shown to decease breeding success in African cormorants (Sherley et al 2012).

Table 9: Auckland's seabirds with their New Zealand conservation status (Robertson et al. 2017) and effects of climate change impacts based on expert opinion (Todd Landers, Seabird Ecologist).

Seabird	Current conservation status	Impact of sea level rise	Impact of pests	Severe weather
Australasian gannet *Morus serrator*	Least concern	Low	Low	Moderate
Black petrel *Procellaria parkinsoni*	Threatened	Low	Low	Moderate
Black shag *P. carbo*	At risk	Low	Low	Moderate
Black-billed gull *L. bulleri*	Threatened	Low	Low	Moderate
Black-winged petrel * *P. nigripennis*	Least concern*	Low	Low	Moderate
Caspian Tern *Hydroprogne caspia*	Threatened	Low	Low	Moderate
Common diving petrel *Pelecanoides urinatrix*	At risk	Low	Moderate	Moderate
Cook's petrel *Pterodroma cookii*	At risk	Low	Low	Moderate
Fairy Tern *Sternula nereis*	Threatened	High	High	Moderate
Flesh-footed shearwater *Puffinus carneipes*	Threatened	Low	Low	Moderate
Fluttering shearwater *P. gavia*	At risk	Low	Low	Moderate
Grey-faced petrel *P. macroptera*	Least concern	Low	Moderate	Moderate
Little black shag *P. sulcirostris*	At risk	Low	Low	Moderate
Little penguin *Eudyptula minor*	At risk	Moderate	Moderate	Moderate
Little shag *P. melanoleucos*	Least concern	Low	Low	Moderate
Little Shearwater *P. assimilis*	At risk	Low	Low	Moderate
New Zealand storm petrel *Fregetta maoriana*	Threatened	Low	Low	Moderate
Pied shag *Phalacrocorax varius*	At risk	Low	Low	Moderate
Red-billed gull *L. scopulinus*	At risk	Low	Low	Moderate
Sooty shearwater *P. griseus*	At risk	Low	Low	Moderate
Southern black-backed gull *Larus dominicanus*	Least concern	Low	Low	Moderate
Spotted shag* *Stictocarbo punctatus*	Least concern*	Low	Moderate	Moderate
White-faced storm petrel *Pelagodroma marina*	At risk	Low	Low	Moderate
White-fronted tern *Sterna striata*	At risk	Low	Low	Moderate

* = Although not nationally 'at risk' or 'threatened', regionally 'at risk' or 'threatened'

Table 10: Threats to Auckland seabirds with the pest status based on the Proposed Regional Pest Management Plan (Auckland Council 2017) and the projected change from climate change related impacts.

Pest	Pest status	Climate change related effects
Box thorn *Lycium ferocissimum*	Pest plant	Unknown
Dog *Canis lupus familiaris*	Not pest animal	Unlikely any changes
Feral cat *Felis catus*	Pest animal	Increased litters (Auckland Council, 2018); more suitable areas for stray cats (Aguilar et al., 2015)
Feral deer *Cervus, Axis, Dama, Odocoileus, Elaphurus* spp. including any hybrid	Pest animal	Unknown
Feral goat *Capra hircus*	Pest animal	Unknown
Feral pig *Sus scrofa*	Pest animal	Unknown
Marram grass *Ammophila arenaria*	Pest plant	Unknown
Mouse *Mus musculus*	Pest animal	May rise with increased food sources (e.g. increased mast events).
Mustelids (ferret, stoat, weasel) *Mustela furo, M. ermine, M. nivalis*	Pest animal	May rise with increased availability of rat and other prey species.
Pine plantations *Pinus radiata*	Not pest plant	Unknown
Possum *Trichosurus vulpecula*	Pest animal	Unknown
Rabbit *Oryctolagus cuniculus*	Pest animal	Prolonged breeding seasons resulting in larger infestations (Malcolm Harrison, pers. comm.)
Rat (ship, Norway, kiore) *Rattus rattus, R. norvegicus, R. exulans*	Pest animal	Prolonged breeding seasons resulting in larger infestations (Malcolm Harrison, pers. comm.)

3.2.6 Threatened plants

The Auckland region is home to at least 63 different threatened plant species, the threat-rankings of which are listed in de Lange et al. (2018). A brief summary of the New Zealand and Auckland regional distribution, habitat requirements, main threats and a subjective assessment of the potential impacts of climate change is provided for each of these threatened species in Appendix C. The information from this appendix is summarised here.

The plants in Appendix C fall into two main groupings, which are treated separately below.

The first group includes 42 ‘traditional’ threatened plant species. These are species with somewhat to extremely localised populations due to their highly specific habitat or regeneration requirements, vulnerability to the impact of plant or animal pests, destruction of the habitat in which they occur, or some combination of two or more of these factors. Most of these species have been classified as threatened or near-threatened species through several iterations of the New Zealand threatened vascular plant lists (i.e. de Lange et al. 2004, de Lange et al. 2009, de Lange et al. 2012, de Lange et al. 2018).

The second group includes 21 species, most of which are much more widespread in the Auckland region and some of which are abundant (e.g. kanuka and pohutukawa). This second group have only been included in the most recent threatened vascular plant list (de Lange et al. 2018) due to their potential vulnerability to the impact of myrtle rust (20 species) or kauri dieback (one species). The reasons for their inclusion as threatened species are, as outlined in de Lange et al. (2018), provided in Appendix D of this report.

Twenty-three (55%) of the 42 ‘traditional’ threatened plants were subjectively assessed as being at low or moderate-low risk with respect to any negative effects of climate change, seven (17%) at moderate risk, and 12 (28%) at moderate-high or greater risk. The 12 species in the highest risk bracket had the following risk characteristics:

- An obligate coastal distribution that is restricted to low-lying, coastal habitats which are very vulnerable to coastal inundation and storm effects, in conjunction with immediate and on-going threats from non-climate-related sources such as habitat loss, regeneration failure or severe browsing. This included eight species.
- An extremely restricted distribution to one (known) location. This included a single species.
- An obligate coastal distribution that is also extremely restricted. This included three species. Kaka beak (*Clianthus puniceus*) and purple hebe (*Veronica speciosa*) are examples of species with these characteristics that are at extreme risk of negative impacts from climate change. Both species are known

from only one location[15] in the Auckland region that is highly exposed to the effects of coastal erosion, storm damage and/ or inundation.

'Climate change' has not been identified as a specific threat for any of the 63 threatened plant species presented in Appendix C. However, it is possible that climate change could interact and exacerbate identified threats such as physical disturbance and erosion, drought, fire and/ or weed invasion. The most commonly identified threat for the 42 'traditional' threatened plants was displacement or over-topping by introduced plants (weeds), which is negatively affecting at least 19 (45%) of these species. It is very difficult to make accurate predictions about how climate change will affect the relative fitness of weeds verses native species without much more detailed research on the autecology of individual plants, and their interactions in natural systems (Schmitz and Barton 2014). These species interaction effects are often complex (Walther 2010) and can be highly species or even site specific (Tylianakis et al. 2008, Pacifici et al. 2015). However, past experience with weed impacts in New Zealand suggests that native plants are often at a competitive disadvantage when compared to introduced species (Williams 1997, Ewel et al. 2000, Lee et al. 2000).

Other commonly identified threats were habitat loss due to activities such as drainage for agriculture or clearance for coastal development as a threat for 16 (38%) species; browsing and/ or trampling by domestic and feral mammals as a threat for 14 (33%) species; competition with taller stature native plants as a threat for 10 (24%) species; and a decline in native fauna as a threat for 6 (14%) species. It is possible that the disturbance related impacts of climate change could have a positive effect on some threatened species. More than half (52%) of the 42 'traditional' threatened plants listed in Appendix C have been identified as requiring more regular disturbance (including more regular fires for some species) to allow their continued regeneration.

The risk assessments presented in Appendix C only applied to 'natural' populations of these threatened plants. Most of the species assessed can be cultivated and grown in controlled conditions and they are therefore unlikely to be completely extirpated from the Auckland region. Rather they would become 'extinct in the wild'.

[15] These two species are found at different single locations: purple hebe from Muriwai and kaka beak from talus at the base of eroding mudstone cliffs next to the Kaipara Harbour (de Lange et al. 2010, NZPCN 2019).

3.2.7 Invasive species – pest animals and plants (weeds)

Invasive species are important factors contributing to the global biodiversity crisis (Vitousek et al. 1997) and are considered one of the main threats to New Zealand's native biodiversity (Clout 2001). Many experts believe climate change will enhance many invasive species' success (Mooney and Hobbs 2000, Thuiller et al. 2008, Thuiller et al. 2005). New Zealand was identified in an international climate change modelling study as one of five hotspots which has suitable conditions for increased invasive species (Bellard et al. 2014). These numbers may increase as warmer temperatures increase the risk of sub-tropical species invading and becoming pests in Auckland (Auckland Council 2017). Increased severe weather events and the resulting disturbance may help spread pests in the region and damage intact ecosystems making them easier to invade (Auckland Council 2017).

The current Proposed Regional Pest Management Plan (Auckland Council 2017) has classified over 40 pest animal species and over 200 pest plants (weeds) in Auckland (note: this includes pests in all ecosystems), living up to the title as the "weediest city in the world" (New Zealand Herald 2006). Thirty-three of these pest plants and 13 of the pest animals have been identified as potentially becoming more of an issue with climate change (Auckland Council 2018) (Table 11). For example, distributional modelling of the pest plant Chinese fan palm (*Trachycarpus fortunei*) (Auckland Council 2017) under RCP 8.5 showed increases in range expansion in Auckland and the majority of the North Island due to increased temperatures (Aguilar et al. 2017). These palms are dispersed by birds, gravity and human cultivation, and are a risk to urban reserves and potentially riparian wetland margins (Aguilar et al. 2017, Ishii and Iwasaki 2008). Only one pest, oxygen weed (*Lagarosiphon major*), is thought will be disadvantaged by climate change effects.

Increased risks from pest animals and weeds in Auckland as a result of the warming climate will almost certainly have detrimental effects on a variety of native plants and animals. Many of the species which are in the 'at risk' and 'threatened' categories are already under pressure. An increase in pests may result in these threat categories worsening. Pest animals, such as mice, rats, mustelids (stoats, weasels, ferrets), and possums, are known to be an important factor reducing native wildlife (Clout 2001, Clout and Russell 2008). Thus, one of Auckland's largest challenges will be, to manage pests to levels which allow native species to increase their populations and increase their resilience to other potential risks from climate change (discussed below).

Table 11: Climate change impacts on Auckland pests (based on analysis from Auckland Council 2018).

Pest	Pest type	Climate change impact
Alder *Alnus glutinosa*	Pest plant	Habitat effects and soil changes (increased Nitrogen fixation)
Balloon vine; Love in a puff *Cardiospermum grandiflorum* and *C. halicacabum*	Pest plant	Exacerbated risk to soil and species diversity from warmer temperatures and increased canopy disturbance
Banana passionfruit *Passiflora tripartita var. mollissima, P. mixta and P. tarminiana*	Pest plant	Habitat effects (prefers disturbed, open forest)
Bangalow palm *Archontophoenix cunninghamiana*	Pest plant	Habitat effects (drought tolerant; warm temperate/subtropical species); Native displacement (e.g. nikau palm)
Blue passion flower *Passiflora caerulea*	Pest plant	Habitat effects (disturbed areas)
Brazilian pepper tree *Schinus terebinthifolius*	Pest plant	Exacerbated risk to species diversity from warmer temperatures as prefers (sub-) tropical conditions
Buddleja, butterfly bush *Buddleja davidii*	Pest plant	Habitat suitable in both current and in future conditions with climate change
Cape honey flower *Melianthus major*	Pest plant	Exacerbated risk to native flora from warmer temperatures and increased disturbance
Cenchrus spp. Syn. *Pennisetum* spp (excluding kikuyu and pearl barley)	Pest plant	Exacerbated risk to coastal habitats and riparian margins from warmer temperatures
Climbing spindleberry *Celastrus orbiculatus*	Pest plant	Exacerbated risk of smothering plants and canopy collapse from increased disturbance
Drooping prickly pear *Opuntia* spp.	Pest plant	Habitat effects as increase from elevated temperatures and CO_2
Egeria *Egeria densa*	Pest plant	Potential exacerbated risk to species diversity
Ferny asparagus *Asparagus plumosus*	Pest plant	Exacerbated risk to soil and species diversity from warmer temperatures
Gorse *Ulex* spp.	Pest plant	Exacerbated risk to species diversity from warmer temperatures
Guava *Psidium cattleianum*	Pest plant	Exacerbated risk to species diversity
Many-flower marsh-pennywort *Hydrocotyle umbellata*	Pest plant	Exacerbated risk to species diversity from warmer temperatures
Khasia berry *Cotoneaster simonsii*	Pest plant	Potentially advantaged through increased disturbance
Oxygen weed *Lagarosiphon major*	Pest plant	May become less invasive in Auckland due to preference for cooler temperatures
Lantana *Lantana camara*	Pest plant	Exacerbated risk of invading pasture (toxic to stock)

Pest	Pest type	Climate change impact
Loquat *Eriobotrya japonica*	Pest plant	Increased risk to species diversity as advantaged by warmer temperatures
Mickey mouse plant *Ochna serrulata*	Pest plant	Increased risk to species diversity
Monkey apple *Syzygium smithii*	Pest plant	Increased species diversity risk as may be advantaged by elevated CO_2
Morton Bay fig *Ficus macrophylla*	Pest plant	Exacerbated risk to species diversity from warmer temperatures
Nut grass *Cyperus rotundus*	Pest plant	Exacerbated risk to dairy, sheep, and beef production and horticulture from warmer temperatures and elevated CO_2
Paperbark poplar *Melaleuca quinquenervia*	Pest plant	Risk to species diversity (including threatened spp.) with prediction Auckland with become optimal habitat
Parrot's feather *Myriophyllum aquaticum*	Pest plant	Potential increased risk to species diversity
Queensland poplar *Homalanthus populifolius*	Pest plant	Likely increased risk to species diversity
Queensland umbrella tree *Schefflera actinophylla*	Pest plant	Increased competitive ability and risk to species diversity
Senegal tea *Gymnocoronis spilanthoides*	Pest plant	May be increased risk to species diversity from advantage of warmer temperatures
Strangling fig *Ficus microcarpa*	Pest plant	Potential increased risk to species diversity from warmer temperatures
Tutsan *Hypericum androsaemum*	Pest plant	Likely increased risk from beneficial conditions for habitat
Velvet groundsel *Roldana petasitis*	Pest plant	May be increased risk to species diversity
Yellow guava *Psidium guajava*	Pest plant	Likely increased risk to species diversity
Yellow passionfruit *Passiflora ligularis*	Pest plant	Likely increased risk to species diversity
Bearded dragon *Pogona barbata*	Pest animal	Increased risk of establishing in Auckland and thus to species diversity
Blotched blue tongued skink *Tiliqua nigrolutea*	Pest animal	Increased risk to species diversity and threatened species with increased risk of establishing outside of captivity
Feral cat *Felis catus*	Pest animal	Increased risk to species diversity and threatened species from increased reproductive ability (more litters) from warmer temperatures
Mosquito fish *Gambusia affinis*	Pest animal	May be exacerbated risk to species diversity and threatened species
Hedgehog *Erinaceus europaeus*	Pest animal	Increased risk to species diversity from potential expansion of reproductive season
Myna *Acridotheres tristis*	Pest animal	May be increased risk to species diversity and threatened species from potential increase of regional distribution
Perch *Perca fluviatilis*	Pest animal	Likely exacerbated effects on water quality

Pest	**Pest type**	**Climate change impact**
Plague skink *Lampropholis delicata*	Pest animal	May be increased risk to species diversity and threatened species from likely advantage of climate change
Possum *Trichosurus vulpecula*	Pest animal	Could exacerbate overall climate change effects through their effect of decreasing net storage of carbon from herbivory
Red-eared slider (+ other spp.) *Trachemys scripta elegans, T. scripta scripta, T. scripta troostii*	Pest animal	May result in species being able to reproduce in the wild and thus an increase of the negative effects (e.g. on species diversity, threatened species, soil disturbance, water quality)
Shingleback dragon *Tiliqua rugosa*	Pest animal	May result in species being able to reproduce in the wild and thus an increase risk to species diversity and threatened species
Snake-neck turtle *Chelodina longicollis*	Pest animal	Increased risk to species diversity and threatened species
Paper wasps *Vespula vulgaris, V. germanica, P. chinensis, P. humilis*	Pest animal	May be advantaged and thus an increased risk to dairy stock, forestry workers, horticulture, soils, species diversity, threatened species, and to human health and recreational activities

4.0 Summary and conclusions

Concern and uncertainty are the key messages with respect to climate change effects on Auckland’s terrestrial species and ecosystems. The majority of these studies do indicate alarming consequences for biodiversity (Bellard et al. 2012). However, we have not identified any quantitative studies on how Auckland’s indigenous species and ecosystems are likely to respond to the threats associated with climate change; such as increased drought stress, reduction in frosts, higher rates of erosion and sediment deposition, changes in the spatial and temporal distribution of rainfall etc. Overseas research shows that climate impacts are very variable, depending on the taxonomic group, spatial scales and time periods considered.

The interaction between native and exotic biodiversity in their response(s) to climate change is particularly important and these inter-species relationships are very complex and varied in time and space (Tylianakis et al. 2008, Walther 2010, Pacifici et al. 2015). The actual impact of climate change on ecosystems is likely to be driven as much by inter-species interactions as the physical changes themselves (Schmitz and Barton 2014).

Twenty (42%) of the 48 different indigenous ecosystem types described in Singers et al. (2017) were identified as having at least one risk factor that has the potential to make them more susceptible to negative impact(s) from climate change. And this rises to 28 (58%) if climate change effects increase the virulence and/ or spread of myrtle rust and kauri dieback. Some ecosystems – in particular coastal turf, oioi restiad-rushland and reedland, kauri-towai-rata montane podocarp forest, and pohutukawa-puriri broadleaved forest – are exposed to multiple risk factors. However, determining how these and other ecosystems will respond to climate change is very difficult to assess without better species-specific, site-specific and threat-specific research; including research which examines the interaction effects between these three factors.

Almost all of Auckland’s indigenous terrestrial ecosystems are already under threat from introduced animal pests and/ or plant pests, and lowland ecosystems are also at risk from ongoing clearance and fragmentation of habitat. Singers et al. (2017) identified climate change impacts as a significant contemporary threat for just two of Auckland’s ecosystems; inundation and coastal erosion of pohutukawa-puriri-broadleaved forest and drought within kauri-towai-rata montane podocarp forest. The most ubiquitous and important threats included: the impact of plant pests/ weeds (identified as a threat in 28 ecosystem types); browsing and physical damage from mammalian pests and/ or domestic stock (16 ecosystem types); the impact of mammalian predators (11 ecosystem types); eutrophication through nutrient and sediment enrichment (eight ecosystem types); the ongoing, as opposed to historical, effects of habitat clearance and fragmentation (seven ecosystem types); drainage to improve agricultural land (six ecosystem types); an increase in fire frequency (three ecosystem types); and the impact of pathogens such as kauri dieback (three ecosystem types) and myrtle rust (six ecosystem types). Therefore, potentially the most serious and pressing impacts of climate change arise through its interaction with these pre-existing threats (McGlone 2001). Despite this critical research need, there is almost no specifically-targeted research on how climate change effects will affect the relative ecological fitness of pest plants verses native species in any of Auckland's indigenous ecosystems.

The interaction between indigenous species and ecosystems, and plant pests/ weeds, in their responses to climate change impacts is of critical importance. The negative impact of weeds have currently (i.e. not including future additional effects from climate change) been identified as an important threat for 58% of Auckland's indigenous ecosystems and 45% of the threatened plant species that are found within the region.

Changes in drought stress, and its associated disturbances such as fire, or synergistic interactions with pathogens, are likely to be of importance for a wide range of Auckland's indigenous ecosystems and species. Drought has the potential to affect a wide range of New Zealand ecosystems (Wardle 1991) and has been shown to cause dieback and/ or canopy death in forest ecosystems throughout New Zealand (Atkinson & Greenwood 1972, Jane and Green 1983, Skipworth 1983, Grant 1984). For example, recent droughts over the 2015/16 winter and 2016/17 summer severely affected some indigenous terrestrial ecosystem types, while having little visible impact on others. In particular, taraire-tawa podocarp forest was noted as under severe drought stress within regional parks along the eastern coast of mainland Auckland (Matt Maitland and Tim Lovegrove pers. comm.). The bare crowns of dead adult taraire, some probably hundreds of years old, were a common sight in taraire-tawa forest remnants throughout the region and there was a die-off of taraire saplings and seedlings in the forest understorey.

Therefore, changes in the pattern of drought stress do have the potential to alter the composition of Auckland's ecosystems. However, we currently lack the detailed knowledge about how different species ecosystems react to changes in drought stress that would allow us to make accurate predictions about likely future changes. How drought stress interacts with fire is also of critical importance as fire has dramatically affected New Zealand's landscapes and ecosystems in the post human-settlement era and, with the exception of a handful of wetland ecosystems, New Zealand plant species have few adaptions to regular fires (Perry et al. 2014).

We note that even though some of the ecosystems with very restricted distributions (e.g. coastal turf, lakeshore turf and manuka-wire rush restiad rushland) might disappear as a result of climate change effects, or more likely the synergistic interaction between climate change and existing stresses, this does not mean that the plant species[16] in them will be extirpated from the Auckland region. There are no species which are confined to these ecosystem types, all can be found as minor components of different vegetation associations in other parts of the landscape. However, not managing these ecosystems to ensure their continued presence in the landscape means we are neglecting the 'genetic' and 'biotic processes'[17] components of indigenous biodiversity. Protecting all these different biodiversity components is a primary objective of both the New Zealand Biodiversity Strategy (DOC 2000) and the Auckland Council Indigenous Biodiversity Strategy (Auckland Council 2012).

The Auckland region is home to at least 63 different threatened plant species, and these plants fall into two main groupings; 42 'traditional' threatened plant species and 21 species included in the most recent threatened vascular plant list (de Lange et al. 2018) due to their potential vulnerability to plant pathogens. For the 'traditional' threatened plants the impact(s) of climate change are likely to depend on complex interactions between the threatened species and existing threats; 'climate change' has not been identified as a specific threat for any of these species. Inter-species interactions with weeds and other native plants are likely to be of particular importance as displacement or over-topping by other species was identified as a key threat for 45% of these species. However, it is very difficult to make accurate predictions about how climate change will affect the relative fitness of competing plants and threatened species without much more detailed research.

The interactions between climate change effects and the virulence and spread of kauri dieback and myrtle rust to susceptible species, and the 'knock-on' effects within the ecosystem(s) in which susceptible species are found, are even less certain. These pathogens have only been detected relatively recently and there is still uncertainty about their effect on indigenous ecosystems, especially how other indigenous species within these ecosystems might respond to the reduction in fitness

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[16] And also, presumably, the indigenous invertebrates and micro-organisms within these same communities; although we have no evidence for this.

[17] Biodiversity comprises four main components which are usually expressed as genetic diversity, the identity and number of different types of species, biotic communities [i.e. ecosystems], and biotic processes [e.g. decomposition, soil formation, pollination] (DeLong 1996).

or functional extinction of susceptible species. This is particularly the case for myrtle rust. It is still unclear which indigenous species are likely to be most affected and what consequences this will have for the species composition and ecosystem processes in the ecosystems in which they are found. Myrtle species such as pohutukawa, kanuka, northern rata, manuka and maire-tawake are the primary structural components within many indigenous ecosystems. Their removal would result in a fundamental change in the structure and function of these ecosystems and potentially initiate a cascade of other deleterious effects. Other myrtle species such as ramarama, rohutu and the various climbing rata species are important secondary ecosystem components, but the ecosystems in which they are found might be better able to adjust by other native species 'stepping into the gap' left by their removal or severe reduction in biomass.

Climate change has the potential to affect a wide range of ecosystems and ecosystem processes and responding to all these changes will probably require the deployment of significant resources. The level of resources required to deal with all environmental/ biodiversity changes might be politically untenable; particularly if these same resources are also required to deal with the social and economic consequences of climate change. If this is the case, it is important to distinguish between climate change impacts on indigenous ecosystems and species that are not desirable, and those changes that are unambiguously negative. For example, climate change effects could lead to the regional extinction of indigenous species and ecosystems[18]. While this would probably rightly be regarded as a negative impact, if these ecosystems and species were secure outside the Auckland region, or secure overseas then it is probably better to expend scarce resources on dealing with threats that will have an impact on halting national (or global) biodiversity loss.

The loss of native plant species typical within an ecosystem, or a severe reduction in ecosystem extent, is regarded as a negative effect. This is unambiguously the case if native biodiversity is replaced by exotic species, there is a reduction in the resilience of the native ecosystem, or a reduction in the provision of ecosystem services. However, this is not necessarily the case for all species or ecosystems. For example, indigenous ecosystems that are part of large, intact tracts of native forest might be displaced by another native ecosystem that is better adapted to the altered environmental conditions and/ or new disturbance regime.

[18] For example, species such as annual fern and *Cyclosorus interruptus*, and ecosystems such as coastal turf and lakeshore turf, have characteristics that make them highly vulnerable to the impact(s) of climate change and other threats. This means they may become actually or functionally extinct with the Auckland region. However, they seem likely to remain secure outside the region.

4.1 Knowledge and research gaps

This report represents a first attempt at a risk assessment for Auckland's terrestrial ecosystems and species. There is a range of additional analyses that could be carried out and incorporated into any updated risk assessments. These include the following tasks:

1. Better define the 'coastal hazard zone' in terms of biodiversity effects. The approach taken in this report was to use a simple 'distance buffer' around the coastline, but this could be significantly improved by incorporating data on sensitivity to coastal erosion, landform and exposure to high winds to create a more realistic 'coastal hazard zone' and then re-run the ecosystem and species analysis.
2. Combine the drought stress, severe rainfall and high wind projections provided by Pearce et al. (2017) with spatial information on the current extent of ecosystems within the Auckland region to investigate which ecosystem types are more at risk of experiencing more extreme droughts and other climatic stresses.
3. A full spatial analysis of risk to threatened plants using an approach similar to that carried out for ecosystems. That is, identifying which populations and how much of the total regional population is within the 100 year storm surge inundation zone, within 50m of the coast, and within the coastal hazard zone. However, this requires much better data on the spatial distribution of our threatened species, much of which still needs to be collected.
4. Expand the plant species risk assessment to include data on range restricted, uncommon and regionally threatened plant species, which have not been included in the analysis presented in Appendices B and C.
5. Use the level IV Land environments of New Zealand (LENZ) environment framework of Leathwick et al. (2002) to spatially analyse the current distribution of Auckland's regional ecosystem types in relation to their current climatic, landform and soils. Climate change predictions could then be used to create a 'future LENZ framework' and investigate how Auckland's regional ecosystem types could shift in response to future climate change.

There is a complete absence of quantitative research on key climatic tipping points for any of Auckland's ecosystems. This type of data is necessary in order to fully understand the risks of different climate change effects and to inform adaptive management approaches to dealing with the negative impacts of climate change in the future. However, this type of research requires long-term quantitative datasets; 30 years is probably the minimum time period which would be adequate for many types of analyses. These datasets simply do not exist for almost all of Auckland's indigenous species and ecosystems and therefore climate change predictions are unlikely to improve past the provision of generalised forecasts for periods well into the future. However, expansion of long-term monitoring sites for biodiversity and climate and modelling of biotic interactions, especially with regard to indigenous-exotic interactions, are badly needed (McGlone 2001).

Commitment to the collection of long-term ecological datasets is an absolute imperative in order to improve our understanding of how Auckland's ecosystems will respond to the impact of climate change. This includes information on species distribution, ecosystem composition, climate data and ecosystem processes. These long-term datasets are the only feasible means by which complex interactions that we need to study can be investigated. RIMU commenced more general quantitative monitoring of Auckland's forest and wetland ecosystems around 10 years ago, and this programme has been steadily expanded in the last five years to encompass a wider range of ecosystem types, landscapes and environmental issues. Within the last year increased funding through Auckland Council's Natural Environment Targeted Rate (NETR) has also allowed council to consider quantitative monitoring across a representative example of all the regional ecosystem types outlined in Singers et al. (2017) and the collection of much better data on a wider range of threatened species. However, it will be decades before this data is able to provide definitive answers to the many important questions about the impact(s) of climate change on Auckland's terrestrial ecosystems and species, and how to best manage them.

The potential serious impact of climate change on Auckland's indigenous terrestrial ecosystems, the lack of information about the best response to these impacts, and the time-lag associated with collecting ecosystem data means that action(s) to manage climate change threats will need to be taken before complete information is available. Taking a 'wait and see' approach in the absence of robust data is unacceptable. A common approach to this problem is to embed research, and its evaluation, as an interactive part of ecosystem management from its initiation in a process called adaptive management (Holling 1978) or 'learning by doing'. The critical feature of adaptive management is the continuous loop involving scientific enquiry that is specifically designed to inform policy and management, and the periodic monitoring and evaluation of the success, or not, of the new or modified approaches (Bormann et al. 2007, Steffen 2009).

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Appendix A Auckland's terrestrial ecosystems

National distribution of the indigenous terrestrial ecosystem types (*sensu* Singers and Rogers 2014) present in the Auckland region (summarised from Singers et al. 2017) and notes on their vulnerability to climate change.

Ecosystem type {code} (IUCN THREAT RANK) [risk of negative climate change effects]	**Habitat type and distribution in New Zealand**	**Potential vulnerabilities of this ecosystem type to climate changes and the severity of these effects. Overall risk of negative impacts <u>from climate change</u>**
1. Pohutukawa-puriri broadleaved coastal forest {WF4} (ENDANGERED) [Overall moderate risk]	Frost free areas from the far north (Three Kings) to Mahia on the east coast and New Plymouth on the west coast of the North Island.	Effects from change in general climate seem less likely as frosts will decrease further and this ecosystem may expand south. Potentially more vulnerable to increased frequency and intensity of disturbance events. The recent detection of myrtle rust in northern NZ in 2017 is a significant development and climate change interactions that increase the spread and/ or virulence of this pathogen may present a significant threat to pohutukawa, one of the main component species of this ecosystem type.
2. Totara-kanuka broadleaved dune forest {WF5} (CRITICALLY ENDANGERED) [Overall moderate-low risk]	Stabilised sand dunes from North Cape to Kawhia, Coromandel, Matakana Island and Bay of Plenty coast to East Cape.	Not at climatic limit in Auckland and ecosystem is based on geology not climate. Probably more vulnerable to increased frequency and intensity of disturbance events (esp. storms and drought) due to coastal and droughty substrate. The recent detection of myrtle rust in northern NZ in 2017 is a significant development and climate change interactions that increase the spread and/ or virulence of this pathogen may present a significant threat to kanuka; which is the dominant species within the regenerating variant of this ecosystem type.
3. Puriri forest {WF7} (CRITICALLY ENDANGERED) [Overall low risk]	Predominantly frost-free, warm and sub-humid areas from Northland to northern Waikato (west coast), Bay of Plenty and Poverty Bay (east coast).	Effects from change in general climate seem less likely as frosts will decrease further and this ecosystem may expand south. Potentially more vulnerable to increased frequency and intensity of disturbance events.
4. Kahikatea-pukatea swamp forest {WF8} (CRITICALLY ENDANGERED) [Overall low risk]	Predominantly the west of the North Island from Northland to Wellington, and the upper South Island. Found on poor-draining soils in warm to mild and humid to sub-humid areas.	Widespread outside Auckland and ecosystem is based on geology not climate. Auckland climate will remain within the ecosystem's climatic envelope. Potentially more vulnerable to increased frequency and intensity of disturbance events.
5. Tairare-tawa podocarp forest {WF9} (ENDANGERED) [Overall low risk]	Predominantly frost-free areas, below 450m, from the lower Waikato northwards.	Effects from change in general climate seem less likely as frosts will decrease further and this ecosystem may expand south. Potentially more vulnerable to increased frequency and intensity of disturbance events.

Ecosystem type {code} (IUCN THREAT RANK) [risk of negative climate change effects]	Habitat type and distribution in New Zealand	Potential vulnerabilities of this ecosystem type to climate changes and the severity of these effects. Overall risk of negative impacts from climate change
6. Dense kauri forest {WF10} (ENDANGERED) [Overall moderate-low risk]	North of 38 degrees south latitude (approx. Raglan to Tauranga harbours).	Effects from change in general climate seem less likely as this is a warm climate ecosystem that has had a more southerly distribution in the past. The highly fragmented and reduced distribution of this ecosystem from its historic extent means it is probably more vulnerable to pests, pathogens and increased frequency and intensity of disturbance events.
7. Mixed kauri-podocarp-broadleaved forest {WF11} (ENDANGERED) [Overall low risk]	North of 38 degrees south latitude (approx. Raglan to Tauranga harbours) on predominantly hill-slopes with acidic leached soils.	Not at climatic limit in Auckland and ecosystem is partially based on geology. Effects from change in general climate seem less likely as this is a warm climate ecosystem that has had a more southerly distribution in the past. Probably more vulnerable to pests, pathogens and increased frequency and intensity of disturbance events.
8. Mixed kauri-podocarp-broadleaved-beech forest {WF12} (ENDANGERED) [Overall low risk]	Warm and sub-humid areas, generally below 600m, north of 38 degrees south. Occurs almost exclusively on steep gradient hill-slopes.	Not at climatic limit in Auckland and ecosystem is partially based on geology. Effects from change in general climate seem less likely as this is a warm climate ecosystem that has had a more southerly distribution in the past. Probably more vulnerable to pests, pathogens and increased frequency and intensity of disturbance events.
9. Tawa-kohekohe-rewarewa-hinau-podocarp forest {WF13} (VULNERABLE) [Overall low risk]	Upper North Island across a wide geographical area and altitudinal range in warm and sub-humid to humid climates, on a wide range of moderately fertile soil types.	Widespread ecosystem type that is not at climatic limit in Auckland and appears able to tolerate a wide climatic range. Probably relatively resilient to changes in general climate. Potentially more vulnerable to increased frequency and intensity of disturbance events.
10. Kahikatea flood plain forest {MF4} (CRITICALLY ENDANGERED) [Overall low risk]	Sub-humid to semi-arid climates on lowland Holocene flood plains with poor-draining soils. Eastern parts of north and south islands. Found as small remnants in frost-prone lowland areas of the Auckland Region.	Widespread ecosystem that can tolerate a range of drier climate types. However, its Auckland distribution is noted as being at least partly determined by frosts. Frosts are likely to decrease in frequency and intensity because of climate change and this has the potential to negatively affect kahikatea flood plain forest in Auckland.

Ecosystem type {code} (IUCN THREAT RANK) [risk of negative climate change effects]	Habitat type and distribution in New Zealand	Potential vulnerabilities of this ecosystem type to climate changes and the severity of these effects. Overall risk of negative impacts from climate change
11. Rimu-towai rain forest {MF24} (CRITICALLY ENDANGERED) [Overall moderate risk]	Low fertility steepland and plateaux above 450m – between Coromandel and Kaitaia – that have high rainfall, frequent cloud cover and high winds. Restricted to Hunua Ranges above 450m in Auckland	This ecosystem has a relatively restricted national distribution and a highly restricted distribution in Auckland that is largely determined by climate (in this case precipitation). It is likely to be vulnerable to changes in general climate that alter rainfall patterns. However, the 'tipping point(s)' and/ or effects of climate change on this ecosystem are poorly understood.
12. Kauri-towai-rata-podocarp montane cloud forest {MF25} (ENDANGERED) [Overall high risk]	A higher altitude ecosystem with a very limited extent that is restricted to predominantly rugged volcanic summits of the northern Kaimai and Coromandel Ranges, Aotea (Great Barrier Is.) and Hauturu (Little Barrier Is.).	This ecosystem has a highly restricted distribution, both nationally and in Auckland, that is largely determined by climate (in this case precipitation). It is likely to be vulnerable to changes in general climate that alter rainfall patterns. However, the 'tipping point(s)' and/ or effects of climate change on this ecosystem are poorly understood.
13. Pohutukawa coastal cliff forest {CL1} (VULNERABLE) [Overall moderate risk]	Steep, erosion and drought-prone coastal cliffs exposed to salt and strong winds from the far North to north Taranaki (west coast) and Poverty Bay (east coast). Pohutukawa cliff forest is widespread in the Auckland region; around 2600ha is mapped in the CEL, in around 1000 different polygons. However, many of these remnants are highly modified by weeds. The best examples occur on the Waitakere coast and on Hauraki Gulf islands (Singers et al. 2017).	Not at climatic limit in Auckland and ecosystem is based on landform, not climate. Probably more vulnerable to increased frequency and intensity of disturbance events (especially storms and drought) due to exposed coastal, erosion prone, droughty substrate. This ecosystem type is also highly vulnerable to the impact of browsing mammals (especially possums (Payton 2000)) and introduced weeds (Wiser and Allen 2006). The impact of new pathogens, such as myrtle rust, also have the potential to cause widespread devastation. Climate change impacts that increase the severity of one or more of these threats could have a severe impact on the long-term health of pohutukawa cliff forest.

Ecosystem type {code} (IUCN THREAT RANK) [risk of negative climate change effects]	**Habitat type and distribution in New Zealand**	**Potential vulnerabilities of this ecosystem type to climate changes and the severity of these effects. Overall risk of negative impacts <u>from climate change</u>**
14. Hebe-wharariki cliff scrub {CL2} (LEAST CONCERN) [Overall moderate-low risk]	This ecosystem occurs on cliffs, rock outcrops, highly erodible steep slopes and colluvial slopes at the bases of these features (Singers et al. 2017). It occurs on a range of parent materials throughout the North Island, and is most common on steep inland cliffs, especially along rivers (ibid.).	Despite its 'least concern' ranking, this ecosystem type has a very restricted distribution within the Auckland region; just 42ha is mapped in the CEL, with an average 'patch size' of around one hectare. In Auckland, the best examples of this ecosystem lie within the regions four largest and best tracts of intact indigenous forest; Waitakere Ranges, Hunua Ranges, Aotea (Great Barrier) and Hauturu (Little Barrier) islands. Its steep and erosion prone habitat probably makes this ecosystem more vulnerable to the impact of more frequent and severe storms and erosion. However, many of the species are adapted to these disturbances and the ecosystems relatively widespread distribution within the Auckland region reduces the risk of stochastic disturbance affecting a significant proportion of remnants in a single event.
15. Pohutukawa scrub and forest {VS1} (ENDANGERED) [Overall moderate risk]	Frost free locations along the coastline of the northern North Island and in localised places around the Rotorua lakes (Singers et al. 2017). Often abundant on very raw soils or parent rock exposed to salt-laden winds (Bergin and Hosking 2006). The best Auckland region example is on Rangitoto Island.	Direct effects from change in general climate are probably less likely to negatively affect this ecosystem type as it is a 'warm-climate' ecosystem that is well adapted to coastal disturbance. However, potential indirect threats include changes in the interactions between pohutukawa forest and animal pests, plant pests and/ or pathogens. The best and largest examples of this ecosystem in Auckland are now free of animal pests, but the ecosystem is invaded by a wide range of weeds which can displace natives and alter successional pathways (Singers et al. 2017). Myrtle rust, which was recently detected in New Zealand, also has the potential to severely affect pohutukawa (Galbraith and Large 2017) and the interactions of climate change with the effects of this pathogen are currently unclear.

Ecosystem type {code} (IUCN THREAT RANK) [risk of negative climate change effects]	**Habitat type and distribution in New Zealand**	**Potential vulnerabilities of this ecosystem type to climate changes and the severity of these effects. Overall risk of negative impacts <u>from climate change</u>**
16. Kanuka scrub and forest {VS2} (LEAST CONCERN) [Overall moderate risk]	Found throughout NZ from North Cape to Otago in locations where former native forest cover has been removed by disturbance (both natural and human-induced). Thrives in warm to cool semi-arid climates	Low vulnerability. Increases in drought stress and more regular climate-related disturbance may benefit this ecosystem type at the expense of mature forest. This is because some species of kanuka are particularly well adapted to drought stress (Burrows 1973, Smale 1994, Meurk 2008) and commonly replace tall forest in New Zealand following frequent fires (Wardle 1991). Very widespread throughout Auckland (comprising 31% of the area of all scrub and forest) and NZ. The recent detection of myrtle rust in northern NZ in 2017 is a significant development and climate change interactions that increase the spread and/ or virulence of this pathogen may present a significant threat to kanuka, the main component species of this ecosystem type.
17. Manuka – kanuka scrub {VS3} (LEAST CONCERN) [Overall moderate risk]	Occurs throughout most of NZ's sub-humid climate zones from Northland to coastal Otago and coast to montane areas. Abundant in the Waitakere Ranges and on Aotea (Great Barrier Is.)	Low vulnerability. More regular climate-related disturbance may benefit this ecosystem type at the expense of mature forest. Very widespread throughout NZ. Low susceptibility to pest animals, however the future impact of myrtle rust – which may interact with climate effects – is uncertain.
18. Broadleaf forest and scrub {VS5} (LEAST CONCERN) [Overall low risk]	Northland to Stewart Is. Most abundant on low fertility hill-slopes that were formally forested, particularly in wetter areas although it is present locally in semi-arid regions. Found throughout Auckland, especially on south-facing slopes	Low vulnerability, although in the long-term a drier climate may favour other scrub types (e.g. manuka-kanuka) over this ecosystem More regular climate-related disturbance may benefit this ecosystem type at the expense of mature forest. Very widespread throughout NZ. More vulnerable to pest animal impacts than other scrub types due to its high proportion of palatable species.
19. Manuka gumland {WL1} (CRITICALLY ENDANGERED) [Overall moderate-low risk]	Occurs across the same range as kauri forest; north of 37 S latitude. Greatly reduced in extent to small pockets (Clarkson et al. 2011). Just one true gumland site in Auckland (Waikumete), although there are other induced examples in Albany, Orewa and Whangaparaoa.	Gumlands occupy some of the lowest fertility soils in New Zealand and are well adapted to water and drought stress. Their distribution is determined by edaphic factors, not climate, so they may be less vulnerable to general climate change. Their very restricted distribution means Auckland's gumlands are more vulnerable to severe, localised, climate-related disturbances. However, the most important threats are weeds and clearance for development.

Ecosystem type {code} (IUCN THREAT RANK) [risk of negative climate change effects]	Habitat type and distribution in New Zealand	Potential vulnerabilities of this ecosystem type to climate changes and the severity of these effects. Overall risk of negative impacts <u>from climate change</u>
20. Manuka - wire rush rushland {WL2} (CRITICALLY ENDANGERED) [Overall moderate-low risk]	This ecosystem occurs as part of inland wetlands in northern NZ on older (1500- 7000 years) organic parent material (Clarkson et al. 2004). Found on the margins of some dune lakes in Auckland (Singers et al. 2017) it has a highly restricted distribution.	Less than 13ha of this ecosystem has been mapped in the Auckland region which makes it vulnerable to severe, localised, climate-related disturbances that happen to negatively affect the few small fragments that remain. Drainage and development for agriculture means there are few places for the ecosystem to go. May be affected by drought but this ecosystem is tolerant of extended dry periods (Singers et al. 2017).
21. Bamboo rush - wire rush rushland {WL3} (COLLAPSE) [Overall low risk]	This ecosystem is found in older (>7000 years), raised, rain fed (i.e. low nutrient) bogs in warm and sub-humid northern NZ (Clarkson et al. 2004). Historical presence in the Auckland region, but all examples have been drained.	This ecosystem' distribution is determined by edaphic factors (i.e. poor-draining, highly acidic nutrient-poor soils), not climate, so it may be less vulnerable to general climate change. The ecosystem once covered 100,000+ha of northern NZ but 95% of this has gone (de Lange et al. 1999). Highly vulnerable to regular fires, but occasional fires are probably necessary to retain this ecosystem in the face of competition from taller stature vegetation.
22. Oioi rushland and reedland {WL10} (ENDANGERED) [Overall high risk]	These moderate fertility wetlands are located within the freshwater zones of estuaries, and also shoreline wetlands of some inland lakes. They have not been comprehensively mapped in Auckland, but are likely to be present at the mouths of many streams discharging into estuaries.	Just over 100ha of this ecosystem is mapped in the CEL, although it is probably more extensive than this (Singers et al. 2017). However, its coastal distribution means oioi rushland is likely to be particularly vulnerable to the impacts of climate change; including increasing salinity due to storm surges and/ or sea level rise, and physical damage from more frequent and intensive storm events.
23. Machaerina sedgeland {WL11} (CRITICALLY ENDANGERED) [Overall moderate-low risk]	Common throughout New Zealand. In Auckland this moderate fertility wetland ecosystem is mostly found in shallow depressions and around the margins of dune lakes. It is widely distributed, but most patches are very small. Just over 400ha of this ecosystem type is mapped in the CEL, although the average size of individual patches is just 1.09 ha.	Small, fragmented ecosystems are more vulnerable to being severely impacted by climate-related physical disturbance, although the widely distributed nature of this ecosystem throughout the region somewhat mitigates this risk. As a wetland ecosystem Machaerina sedgelands are inherently vulnerable to any increase in the frequency and/ or severity of droughts and floods. Weed invasion and eutrophication are probably the biggest threats to this ecosystem (Singers et al. 2017) and any climate change effects that increase the severity of these threats are therefore key for Machaerina sedgeland.

Ecosystem type {code} (IUCN THREAT RANK) [risk of negative climate change effects]	Habitat type and distribution in New Zealand	Potential vulnerabilities of this ecosystem type to climate changes and the severity of these effects. Overall risk of negative impacts <u>from climate change</u>
24. Manuka-tangle fern fen {WL12} (CRITICALLY ENDANGERED) [Overall moderate-low risk]	Manuka fens are medium fertility wetlands that occur in places that are seasonally wet and dry. Common throughout New Zealand, the most extensive examples of this ecosystem in Auckland occur on Aotea. With concentrations at Kaitoke Swamp and wetlands in the Claris and Whangapoua area.	This ecosystem type has been severely reduced in extent due to fire and drainage over the last 800 years. Around 390ha are mapped in the CEL, but the large wetlands on Aotea contribute 66% of the regional total. This makes this manuka fen more vulnerable to localised severe storms or climatic events that effect Aotea. As a wetland ecosystem manuka fens are inherently vulnerable to any increase in the frequency and/ or severity of droughts and floods which increase sediment and nutrient input. Weeds and fires are probably the biggest current threats to manuka fens (Singers et al. 2017), and climate effects that exacerbate these threats are a key risk for this ecosystem type.
25. Lakeshore turf {WL15} (CRITICALLY ENDANGERED) [Overall moderate-high risk]	This ephemeral wetland ecosystem occupies a narrow band of habitat on shallow-gradient, fluctuating lake shorelines (Johnson 1972). Knowledge of its distribution is Auckland is incomplete, although we know it is very sparsely distributed as the environmental conditions in which it grows are very rare.	Across the whole Auckland Region just 5ha of lakeshore turf is mapped in the CEL. Although this is almost certainly and under-estimate of its true extent it is a very rare ecosystem type. Its limited distribution may make it more vulnerable to climatic disturbances, however the ephemeral nature of lakeshore turf wetlands means they are well adapted to moving around the landscape in 'search' of habitat. If suitable habitat remains, then it is likely that this ecosystem will also remain.
26. Flaxland {WL18} (CRITICALLY ENDANGERED) [Overall moderate risk]	Flaxlands are swamps which occur on young landforms that regularly flood or receive surface flow from surrounding land (Bagnall and Ogle 1981). They are widespread throughout NZ, although their extent has been severely reduced by draining in most regions, including Auckland.	Their regional distribution is very patchy; a total of only 54ha of flaxland is mapped in the current ecosystem layer, with an average size of just 0.7 ha. Many flaxland remnants are associated with coastal lakes and duneland wetlands, which means they are in an area that is particularly exposed to disturbance from increased frequency and/ or severity of storms, and sea-level rise. However, the relative vulnerability of individual remnants likely to be highly site specific.

Ecosystem type {code} (IUCN THREAT RANK) [risk of negative climate change effects]	Habitat type and distribution in New Zealand	Potential vulnerabilities of this ecosystem type to climate changes and the severity of these effects. Overall risk of negative impacts <u>from climate change</u>
27. Raupo reedland {WL19} (ENDANGERED) [Overall moderate-high risk]	In more 'natural' settings raupo reedland is the dominant indigenous wetland ecosystem in high nutrient or eutrophic sites and/ or wetlands on recent mineral soils. Raupo reedland occurs on the margins of lakes, lagoons, ponds and river oxbows, and in flooded valleys. These wetlands are particularly common in coastal regions and coastal duneland areas (ibid.), such as the South Kaipara Peninsula and Hauraki Gulf islands, in the Auckland region.	Raupo (*Typha orientalis*) reedland is one of the most distinctive and commonly seen wetland ecosystems within Auckland's rural landscape. It is often found as small patches in the bases of gullies, surrounded by exotic pasture. This ecosystem is adapted to deal with a widely fluctuating water table and it may therefore be better able to tolerate future drought stress than some other wetland ecosystem types. Raupo's ability to disperse widely in throughout landscape and take advantage of the patchy availability of suitable habitat mean this ecosystem type is likely to remain throughout the region. However, Auckland's best and largest examples of raupo reedland are in low-lying coastal locations that are particularly vulnerable to the impacts of climate change.
28. Mangrove forest and scrub {SA1} (LEAST CONCERN) [Overall moderate-high risk]	This variable ecosystem occurs within tidal estuaries, inlets, rivers and streams north of 38 degrees south latitude in the North Island. There are seven species-poor but distinct communities (variants) of this general ecosystem type; with variants distributed according to salinity and the substrate on which they grow (Singers et al. 2017). Mangroves are a prominent feature of most of the Auckland region's eastern coastline, all harbours, and the estuaries of major rivers. The overwhelming majority of this this type is the SA1.2 variant; mangrove forest and scrub.	Almost 10,200ha of mangrove forest and scrub is mapped in the CEL and around 90% of this is dominated by mangrove (*Avicennia marina* subsp. a*ustralasica*) scrub and forest (SA1.2). Other mapped variants include sea rush rushland (SA1.3; c.5% of total), sea grass grassland (SA1.1; c.4% of total), and shell barrier beaches (SA1.5; c.1% of total). Only trace amounts of the other three variants are mapped. The impact of climate change, in particular sea level rise, on mangrove distribution is unclear and is likely to vary in response to local topography, coastline development and sediment budgets (Morrisey et al. 2007). Rising sea level may reduce the range of mangroves. However, in locations where rates of sediment accumulation are high, expansion may keep pace with, or even exceed, the rate of sea-level rise (ibid.). Migration of both mangroves and saltmarshes will be restricted where coastal defences are present and climate change could result in the SA1.2 variant displacing much rarer 'saltmarsh' (SA1.3, SA1.4 and SA1.6) and 'substrate driven' (SA1.5 and SA1.7) variants of this ecosystem type.

Ecosystem type {code} (IUCN THREAT RANK) [risk of negative climate change effects]	**Habitat type and distribution in New Zealand**	**Potential vulnerabilities of this ecosystem type to climate changes and the severity of these effects. Overall risk of negative impacts <u>from climate change</u>**
29. Shore bindweed - knobby club rush gravelfield {SA4} (ENDANGERED) [Overall moderate-high risk]	This ecosystem type is associated with gravel and boulder beaches and the estuarine areas of large rivers (Singers et al. 2017). It is very local in the North Island and while Auckland region knowledge is incomplete small areas are found at Matingarahi, Tapapakanga, Waiheke and Hauturu (Little Barrier) (ibid.).	This historically rare ecosystem (Williams et al. 2007) is very limited in extent within the region; just 56ha are mapped in the CEL and more than 90% of this is associated with the margins of Hauturu (Little Barrier) Island. Key ecosystem processes are the landform, raw soil and high salinity (Singers et al. 2017) and these probably have some resilience to climate change impacts – provided they are not entirely submerged by rapid sea-level rise. This ecosystem was never common, but has been reduced by a wide range of threats including vehicles, development, grazing and weeds (ibid.). Drought tolerant weeds are a particularly threatening (Wiser et al. 2010) and these will probably increase with climate change.
30. Coastal turf {SA5} (CRITICALLY ENDANGERED) [Overall high risk]	Coastal turf or herbfield occurs where persistent salt-laden winds prevent any vegetation taller than about 50mm from becoming established (Singers et al. 2017). Coastal turf is found on coastal promontories of hard rock and, infrequently, consolidated sand and gravel (Rogers and Wiser 2010).	Less than 12ha of coastal turf has been mapped in the Auckland region, and this is probably an overestimate of the total area of this ecosystem type as most of the mapped locations include the surrounding vegetation as part of the 'coastal turf' (Stanley 2018). Coastal turf is highly vulnerable to stochastic effects – particularly coastal erosion effects - due to the highly exposed nature of its habitat and the very small size and highly fragmented nature of the remaining patches of this ecosystem.
31. Iceplant - glasswort herbfield {SA7} (CRITICALLY ENDANGERED) [Overall moderate-high risk]	This coastal ecosystem is strongly influenced by salinity in association with physical disturbance and guano from seabirds and is also known as 'petrel scrub' (Wright 1980, Singers et al. 2017). It was formerly on coastal sites throughout NZ, but has become extinct from the mainland and most offshore islands. Restoration of seabird colonies on predator free coastal habitat may assist future expansion of petrel scrub. This ecosystem provides habitat for several nationally threatened plant species (see Appendix C).	This historically rare ecosystem (Williams et al. 2007) is very limited in extent within the region; around 60ha are mapped in the CEL, almost all of which is on the Mokohinau Islands. However, there are very small remnants in other locations with active seabirds (e.g. coastal rock stacks at Te Henga Beach). Petrel scrub requires active seabird burrows to arrest succession to tall forest, and its biggest threat is therefore predatory mammals that have exterminated or supressed seabird populations (Jones et al. 2008). The elevation of currently mapped locations mean they are not threatened with inundation but would be highly exposed to more frequent and intensive storms. The impact of climate change on seabird populations is probably the primary factor determining the long-term persistence of petrel scrub, although this ecosystem is also highly vulnerable to invasion by herbaceous weeds (Singers et al. 2017).

Ecosystem type {code} (IUCN THREAT RANK) [risk of negative climate change effects]	Habitat type and distribution in New Zealand	Potential vulnerabilities of this ecosystem type to climate changes and the severity of these effects. Overall risk of negative impacts <u>from climate change</u>
32. Spinifex – pingao grassland {DN2} (ENDANGERED) [Overall moderate-high risk]	This native ecosystem grows on active dunelands where there is an abundant supply of wind-blown sand. It is found along the coast – where conditions allow – from Northland to Farewell Spit. However, availability of habitat limits its total extent and it is classified as an uncommon ecosystem by Williams et al. 2007).	Active dunelands provide a harsh, nutrient-poor, droughty and exposed habitat for plant growth. Dunelands are a feature of the coastal environment throughout the Auckland region, on both the mainland, Waiheke Island and Aotea (Great Barrier Island). The loose unconsolidated nature of the sand that comprises active dunelands, and their exposed coastal location, means this ecosystem could be quite vulnerable to disturbances from increased storm severity and frequency. However, the region-wide distribution of dunelands means it is likely that severe damage would be relatively localised. Therefore, the overall impact of climate change on the health and distribution of this ecosystem, while likely to be negative, is still uncertain.
33. oioi – knobby clubrush sedgeland {DN5} (CRITICALLY ENDANGERED) [Overall moderate-high risk]	This ecosystem occupies dune plains or coastal plains (Esler 1969 and 1970) and has a patchy distribution throughout mainland New Zealand and offshore islands. In Auckland, good quality, extensive examples of this ecosystem type are found at Whatipu and Papakanui Spit. Very similar vegetation also occurs in Auckland on wind-swept coastal hillslopes with raw sandy soils and this variant of the ecosystem type is particularly notable along the western coastal edge of the Awhitu Peninsula (Singers et al. 2017).	The low-lying, coastal and highly exposed nature of the locations where oioi-knobby clubrush sedgeland grows means this ecosystem type could be particularly vulnerable to disturbance from an increased frequency and/ or intensity of storm events. This ecosystem is adapted to stresses such as salt deposition, inundation and physical disturbance from the mass movement of its sand dune substrate. However, very severe erosion has the potential to completely remove the physical habitat (i.e. dunelands) on which this ecosystem depends. While there is a relatively large area of this ecosystem type, more than 85% of the region's oioi-knobby clubrush sedgeland is concentrated in two low-lying coastal sand plains that are vulnerable to storm damage (Whatipu and Papakanui Spit).
34. Geothermally heated water and steam {GT2} (DATA DEFICIENT) [Overall low risk]	There are two geothermal ecosystem types recognised nationally. Historically, in Auckland, there were small areas of habitat at Parakai and Waiwera that have now been lost as a result of development. Auckland's single remaining geothermal ecosystem is Kaitoke hot springs on Aotea (Great Barrier) island.	Highly restricted and specialised habitat type. This ecosystem is unlikely to be affected by climate change impacts.

Ecosystem type {code} (IUCN THREAT RANK) [risk of negative climate change effects]	Habitat type and distribution in New Zealand	Potential vulnerabilities of this ecosystem type to climate changes and the severity of these effects. Overall risk of negative impacts <u>from climate change</u>
35. Cave ecosystems {CV1} (DATA DEFICIENT) [Overall low risk]	Caves occur in association with basaltic volcanoes in the Auckland region (Williams et al. 2007)	Highly restricted and specialised habitat type. This ecosystem is unlikely to be affected by climate change impacts.

Appendix B Threatened indigenous plants with an Auckland geographical limit

Nationally ‘threatened’ or ‘at risk’ indigenous plant species (de Lange et al. 2018) that reach their geographical limits within or very close to the Auckland region.

Scientific name	Common name	Threat status (de Lange et al. 2018)	Habitat and vulnerability to climate change impacts
Amphibromus fluitans	Water brome	Nationally endangered	Overall moderate risk, see Appendix C for more details of this species.
Anogramma leptophylla	Jersey fern or annual fern	Nationally vulnerable	Overall high risk, see Appendix C for more details of this species.
Carex litorosa	Sea sedge	At risk – declining	Overall moderate risk, see Appendix C for more details of this species.
Centipeda minima	Sneezeweed, centipeda	Nationally critical	Overall moderate risk, see Appendix C for more details of this species.
Clianthus puniceus	Kakabeak, kowhai ngutu-kaka, kakabeak	Nationally critical	Overall severe risk, see Appendix C for more details of this species.
Cyclosorus interruptus	None known	At risk – declining	Overall moderate-low risk, see Appendix C for more details of this species.
Dactylanthus taylorii	Wood rose, pua o te reinga, flower of hades	Nationally vulnerable	Overall low risk, see Appendix C for more details of this species.
Daucus glochidiatus	Native carrot, New Zealand carrot	At risk – declining	Overall moderate-low risk, see Appendix C for more details of this species.
Dichelachne micrantha	Purple plume grass	Nationally vulnerable	Overall moderate-low risk, see Appendix C for more details of this species.
Eleocharis neozelandica	Sand spike sedge, spikesedge	Declining	Overall moderate-high risk, see Appendix C for more details of this species.

Scientific name	Common name	Threat status (de Lange et al. 2018)	Habitat and vulnerability to climate change impacts
Epilobium hirtigerum	Hairy willowherb	Nationally critical	Overall low risk, see Appendix C for more details of this species.
Epilobium insulare	Willowherb	Declining	Overall low risk, see Appendix C for more details of this species.
Euphorbia glauca Euphorbiaceae	Shore spurge, Sea spurge, waiu-atua, sand milkweed	Declining	Overall moderate-high risk, see Appendix C for more details of this species.
Geranium retrorsum	Turnip-rooted geranium	Nationally vulnerable	Overall moderate risk, see Appendix C for more details of this species.
Hebe bishopiana	Waitakere rock koromiko	Nationally vulnerable	Overall moderate-low risk, see Appendix C for more details of this species.
Hebe speciosa	Napuka, Titirangi	Nationally vulnerable	Overall high risk, see Appendix C for more details of this species.
Juncus pauciflorus	Leafless rush	Declining	Overall moderate-low risk, see Appendix C for more details of this species.
Kunzea sinclairii	Great Barrier Island kanuka	Nationally critical	Overall moderate-high risk, see Appendix C for more details of this species.
Lepidium oleraceum	Nau, Cooks scurvy grass	Nationally vulnerable	Overall moderate-high risk, see Appendix C for more details of this species.
Machaerina complanata	None known	Nationally vulnerable	Overall high risk, see Appendix C for more details of this species.
Mazus novaezeelan diae subsp. *impolitus f.*	Impolitus dwarf musk	Nationally vulnerable	Overall moderate-high risk, see Appendix C for more details of this species.

Scientific name	Common name	Threat status (de Lange et al. 2018)	Habitat and vulnerability to climate change impacts
Myosotis petiolata var.	Pansa forget-me-not	Nationally endangered	Overall high risk, see Appendix C for more details of this species.
Myriophyllum robustum	Stout water milfoil	Declining	Overall low risk, see Appendix C for more details of this species.
Ophioglossum petiolatum	Stalked adders tongue	Nationally critical	Overall moderate-low risk, see Appendix C for more details of this species.
Paspalum orbiculare	Native paspalum, scrobic	Declining	Overall low risk, see Appendix C for more details of this species.
Peraxilla tetrapetala	Red mistletoe, pikirangi, pirita	Declining	Overall low risk, see Appendix C for more details of this species.
Picris burbidgeae,	Oxtongue native	Nationally endangered	Overall low risk, see Appendix C for more details of this species.
Pimelea tomentosa	None	Nationally vulnerable	Overall low risk, see Appendix C for more details of this species.
Pittosporum kirkii	Kirks kohuhu	Declining	Overall low risk, see Appendix C for more details of this species.
Plumatichilos tasmanicum	Plumed greenhood	Nationally endangered	Overall low risk, see Appendix C for more details of this species.
Poa billardierei	Sand tussock, hinarepe	Declining	Overall moderate-high risk, see Appendix C for more details of this species.
Pterostylis paludosa	Swamp greenhood	Declining	Overall low risk, see Appendix C for more details of this species.
Ptisana salicina	King fern, para	Declining	Overall low risk, see Appendix C for more details of this species.

Scientific name	Common name	Threat status (de Lange et al. 2018)	Habitat and vulnerability to climate change impacts
Rorippa divaricata	New Zealand watercress, matangaoa	Nationally vulnerable	Overall moderate-low risk, see Appendix C for more details of this species.
Schoenus carsei	Carses schoenus	Nationally endangered	Overall moderate risk, see Appendix C for more details of this species.
Senecio scaberulus	Fireweed	Nationally critical	Overall high risk, see Appendix C for more details of this species.
Spiranthes novaezelandiae	Lady's tresses, spiranthes	Nationally vulnerable	Overall moderate-low risk, see Appendix C for more details of this species.
Tupeia antarctica	Taapia, pirita, white mistletoe, tupia	Declining	Overall low risk, see Appendix C for more details of this species.
Utricularia australis	Yellow bladderwort	Nationally endangered	Overall low risk, see Appendix C for more details of this species.

Appendix C Auckland's threatened plants

Threatened plants (de Lange et al. 2018) that grow within the Auckland region. Growth form and habit information from NZPCN (2019).

Scientific (and common) name(s)	Growth form and habit (from NZPCN 2019)	Threat status (de Lange et al. 2018)	Habitat and vulnerability to climate change impacts and overall risk of adverse effects from climate change.
Agathis australis (kauri)	Stout, coniferous forest tree, 30-60m tall, with trunk up to 7m diameter	Nationally vulnerable	Endemic tree occurring in the northern North Island from Te Paki south to Pukenui (near Kawhia) in the West and near Te Puke in the East (NZPCN 2019). Largely cleared by fire and for timber, just 1% of pre-human kauri forest remains today. Kauri is unpalatable to pest animals and kauri forest is resistant to weed invasion, although it is vulnerable to fire (Singers et al. 2017). Kauri is a warm forest species that requires disturbance for seedling establishment. Therefore, kauri might have some resilience to increased mean temperature and storm frequency. However, if increased drought frequency results in more fires this would be a negative effect. Kauri's recent listing as a threatened species (de Lange et al. 2018) is based on its vulnerability to PTA, which is emerging as a serious threat to the species and wider ecosystem (Jamieson et al. 2014). Climate change effects that increase the spread and/ or virulence of PTA – e.g. by transport of water borne spores during more intensive rainfall events - are a significant threat to this species. Overall moderate risk.
Amphibromus fluitans (water brome)	Weakly tufted, stolon-iferous, semi-aquatic grass.	Nationally endangered	Wide potential distribution in seasonally dry wetlands and shallow lakes and lagoons (de Lange et al. 2010). Actual restricted distribution increases vulnerability to stochastic disturbance, but this species can disperse readily and widely. Possible effects from changes in rainfall and drought. Biggest threats remain habitat loss, stock and weeds (ibid.). Overall moderate risk.
Anogramma Leptophylla (Jersey fern, annual fern)	Small (1-6cm tall) winter dormant fern, which dries off mid-late summer, appearing dead.	Nationally vulnerable	Wide potential distribution on sparsely vegetated, seasonally dry banks and rock faces (ibid.). Actual restricted distribution increases vulnerability to stochastic disturbance; this species is only found at one site in Auckland and at that site only on south facing rock walls. It is possible, but unclear if annual fern will benefit from increased drought and/ or disturbance of taller vegetation. Other threats include habitat loss and weed competition (ibid.). Overall moderate-high risk.

Scientific (and common) name(s)	**Growth form and habit (from NZPCN 2019)**	**Threat status (de Lange et al. 2018)**	**Habitat and vulnerability to climate change impacts and overall risk of adverse effects from climate change.**
Brachyglottis kirkii var. kirkii (kohurangi or Kirk's daisy)	Small, usually epiphytic shrub bearing large white daisy-like flowers.	Nationally vulnerable	This species has 5000- 20,000 mature individuals in NZ but is predicted to decline by 10-70% in future due to possum browse and has severely declined in the last 10 years (de Lange et al. 2013, 2018). It is common enough in Auckland to have been recorded in 13 of the c.250 grid squares with forest plots (i.e. 5%), almost all on possum free islands in the Hauraki Gulf. This species is identified as a data poor species. No special climate risks identified and this species is quite widespread on islands. Overall low risk.
Carex litorosa (sea sedge)	Small (to 80cm but usually smaller) upright, endemic sedge species	At risk – declining	Coastal in salty, brackish marshes and on sandy, tidal river banks from throughout North, South and Stewart islands (NZPCN 2019). 5000-20 000 mature individuals, but a predicted decline of 10-30% (de Lange et al. 2018). This species is relatively widely distributed, but its coastal location and relatively narrow ecological niche make it more vulnerable to habitat disturbance and storm effects. Overall moderate risk.
Centipeda minima (sneezeweed, Centipeda)	Aromatic, usually prostrate, annual spreading herb up to 20cm high	Nationally critical	An opportunistic plant that will grow in any suitable, seasonally damp, sparsely vegetated site (de Lange et al. 2010). Actual restricted distribution increases vulnerability to stochastic disturbance, but sneezeweed might benefit from increased drought and/ or disturbance of taller vegetation. Biggest threats remain habitat loss and weed competition (ibid.). Overall moderate risk.
Clianthus puniceus (kakabeak, Kowhai Ngutu-Kaka)	Rare small bushy shrub with drooping clusters of pink, red or white sharp-tipped flowers	Nationally critical	The only known wild population grows in low coastal scrub on talus at the base of mudstone cliffs on the Kaipara Harbour shoreline where it is vulnerable to summer drought, weed competition and browsing animals (ibid.). Coastal location, restricted distribution and the inability of this species to recolonise new sites – probably due to the impact of plant and animal pests – means it is in serious risk of extinction in the wild and is overall risk to the impacts of climate change is severe.
Cyclosorus interruptus	Creeping fern with harsh, hairless, olive-green fronds to 80cm long	At risk – declining	A species of geothermal habitats, and frost-free, coastal and lowland wetlands, especially those dominated by raupo and swamp millet (NZPCN 2019). Relatively large population but its specialised habitat requirements mean total area of occupancy is ≤ 10 000ha (de Lange et al. 2018). The species is secure overseas and is more common in other regions of NZ. Overall moderate-low risk.

Scientific (and common) name(s)	**Growth form and habit (from NZPCN 2019)**	**Threat status (de Lange et al. 2018)**	**Habitat and vulnerability to climate change impacts and overall risk of adverse effects from climate change.**
Dactylanthus taylorii (Wood rose, pua o te reinga, flower of Hades)	Perennial root-parasite with rhizomes mostly buried just below soil surface.	Nationally vulnerable	This species is relatively widely distributed through the North Island amongst different tree hosts and forest types, and from lowland to montane locations (De Lange et al. 2010). Its wide – mostly non-coastal - distribution and ecological tolerances make it less vulnerable climate change affects than many other species. Its main threats are possum browse and the lack of pollinators (ibid.) Overall low risk.
Daucus glochidiatus (native carrot, New Zealand carrot)	Erect, biennial herb, 30-80cm high. Annual in harsh conditions.	At risk – declining	Coastal and lowland to montane locations on cliff faces, rock outcrops, talus slopes, and in open forest (ibid.). Native carrot may benefit from increased disturbance of taller vegetation and/or grassland which compete with it. However, its rapid decline over the last 30 years (ibid.) mean the small number of sites are vulnerable to being 'wiped-out' by stochastic disturbance events. Its biggest threat is weed competition (ibid.). Overall moderate-low risk.
Dichelachne micrantha (purple plume grass)	Stout, rigid, tufted grass with rigid 'leaves' up to 20cm long.	Nationally vulnerable	Coastal to lowland, usually in open shrubland or grassland, or clay pans. Often on cliff faces, among talus and at the back of boulder beaches. Mostly found on remote northern offshore islands (ibid.); including Aotea (Great Barrier), Rangitoto, Pakihi and Kaikoura islands, and several mainland sites, in Auckland region. The biggest threats to purple plume grass are loss of habitat due to development and the spread of weeds which out-compete and overtop it (ibid.). May benefit from increased disturbance but coastal location and patchy distribution increases exposure to stochastic events. Overall moderate-low risk.
Eleocharis neozelandica (sand spike sedge, spike sedge)	Rhizomatous widely creeping and mat-forming spike-sedge of damp sandy flats. Leaves 3-8cm long.	At risk – declining	Damp sand flats, often near streams or in places where fresh water filters through the sand at depth or where it is temporarily ponded (NZPCN 2019). An endemic species that is only found in the North Island (and one South Is site). Moderate- large population of 5000-20 000 mature individuals, but a predicted decline 10-30% (de Lange et al. 2018). This obligate coastal species needs to be closely monitored as it has been shown to vulnerable to extreme fluctuations in population size in the past (ibid.), its distribution is not well known, and is very exposed to coastal climatic disturbances and storms. Overall moderate-high risk.

Scientific (and common) name(s)	Growth form and habit (from NZPCN 2019)	Threat status (de Lange et al. 2018)	Habitat and vulnerability to climate change impacts and overall risk of adverse effects from climate change.
Epilobium hirtigerum (hairy willowherb)	Robust perennial, stoloniferous herb, 0.2-1.8m tall.	At risk – recover-ing	Coastal to montane in open, freshly disturbed, usually seasonally wet sites. Also found in ditches, drains and urban wasteland (De Lange et al. 2010). Its biggest threats are habitat destruction associated with development and taller stature fast-growing weed species (ibid.). Proven ability to disperse and adaptation to disturbed sites. Overall low risk.
Epilobium insulare (willow herb)	Loosely matted perennial herb, 3-40cm tall.	At risk – declining	Relatively open, marshy places, bogs, and about lake margins, from sea level to 900m (NZPCN 2019). Very rare in Auckland region but more common – although sparsely distributed through the rest of mainland NZ. Total area of occupancy ≤ 1000ha and a predicted decline of 10-30% (de Lange et al. 2018). Wide distribution from coastal to montane and open habitats suggest this species is more buffered against climate effects. Overall low risk.
Euphorbia glauca (shore spurge, sea spurge, waiu-atua, sand milkweed)	Perennial herb with multiple erect stems up to 1m tall and underground rhizomes.	At risk – declining	Coastal cliffs, banks and talus slopes, sand dunes and rocky lake shore scarps (NZPCN 2019). This relatively widespread species has a large population of >100,000 mature individuals, but it is predicted to decline (de Lange et al. 2018) due to a range of threats such as browsing and/ or trampling (cattle, sheep, pigs and possums), competition from taller vegetation, coastal development and erosion (NZPCN 2019). Obligate coastal distribution and range of threats mean this species is overall moderate-high risk.
Geranium retrorsum (Turnip-rooted geranium)	Perennial herb 15-40cm tall	Nationally vulnerable	Open habitats in coastal to lower montane locations, such as (in Auckland) lava fields, clay pans and rocky coastal headlands (De Lange et al. 2010). This species requires disturbance to regenerate, but its localised distribution may make it more vulnerable to stochastic events; more than 75% of the 26 Auckland region records comprise a single or handful of plants Biggest threats are browsing by hares and rabbits and competition from tall-growing weedy plants (ibid.). Overall moderate risk.

Scientific (and common) name(s)	Growth form and habit (from NZPCN 2019)	Threat status (de Lange et al. 2018)	Habitat and vulnerability to climate change impacts and overall risk of adverse effects from climate change.
Veronica bishopiana (Waitakere rock koromiko)	Low growing (perennial) shrub inhabiting rocky sites in the Waitakere area.	Nationally vulnerable	The Waitakere rock hebe is a regionally endemic species[19] whose natural distribution is confined to stream-sides, gorges, cliff faces and damp or partially shaded rock outcrops in the Waitakere Ranges. It has a very localised distribution; however, it is relatively widely distributed within its natural range and is presumably adapted to dealing with regular disturbance. Biggest threats are weed competition with pampas and Mexican daisy, and weed spraying of roadside populations. Overall moderate-low risk.
Veronica speciosa (Titirangi, Napuka)	Shrub up to 2 x 3m. Spreading to sprawling, rarely erect, and often layering on contact with ground.	At risk – declining	Natural populations of titirangi are known from only three sites in the North Island, one of which is in Auckland (Woodhill Forest near Muriwai). Its habitat is coastal volcanic rock headlines, cliffs and talus slopes (ibid.). The species very restricted distribution and coastal location mean it at high risk of being affected by climate change. Coastal erosion has been identified as a problem at one of the three natural sites where titirangi is found, and other threats include browsing animals and hybridisation with inappropriate plantings (ibid.)
Juncus pauciflorus (Leafless rush)	Perennial, slender, clumped rush with sprawling stems that spread widely from the base.	Nationally vulnerable	Found throughout mainland NZ and Australia (where its population is secure) in coastal to lowland environments on damp ground and hollows under light scrub, pasture, swamp margins, dune swales and coastal forest. Often found on northern offshore islands (NZPCN 2019). Sparse distribution includes many coastal sites – but it isn't restricted to these locations. Total area of occupancy ≤ 100 ha, and a predicted decline of 10-50% (de Lange et al. 2018). Overall moderate-low risk.
Korthalsella salicornioides (dwarf mistletoe)	Hemi-parasitic, succulent plant parasitising exposed branches and branchlets of host.	Nationally critical	This endemic species has a sparse distribution in coastal to sub-alpine locations throughout the three main islands of New Zealand within forest, scrub and shrublands. Dwarf mistletoe grows parasitically on manuka and species within the kanuka complex (NZPCN 2019), therefore it is highly dependent on these species. Given the recent re-classification of manuka and kanuka species as 'Nationally vulnerable' due to the detection of myrtle rust in northern NZ in 2017, dwarf mistletoe could be severely impacted by this pathogen (de Lange et al. 2018). Climate change interactions that increase the spread and/ or virulence of myrtle rust may present a significant threat to this species. Overall risk is unclear without further data

[19] Regionally endemic species means the Auckland region is the only place in the world (and the Universe!) where this species is found naturally.

Scientific (and common) name(s)	Growth form and habit (from NZPCN 2019)	Threat status (de Lange et al. 2018)	Habitat and vulnerability to climate change impacts and overall risk of adverse effects from climate change.
Kunzea amathicola (Rawiritoa, kanuka)	Shrubs or trees up to 15m tall	Nationally vulnerable	An endemic species found on coastal sites (especially active dune fields) in the western North and north-western South Island. In the Auckland region this species is present on duneland along the west coast and on Kawau and Hauturu (Little Barrier) islands (NZPCN 2019). This relatively widespread tree has recently been classified as a threatened species due to the detection of myrtle rust – a pathogen for which there is no known effective treatment – in northern NZ in 2017. Climate change interactions that increase the spread and/ or virulence of myrtle rust may present a significant threat to this species. Overall risk is unclear without further data.
Kunzea linearis (Rawiri, Manuka-Rauriki)	Erect shrubs or small tree up to 12m.	Nationally vulnerable	Coastal shrublands and cliff faces, usually on sand, sand podzols, and/or sandy peats. Rarely on podzolised clays or sandstone bluffs (NZPCN 2019). This obligate coastal species is restricted to northern NZ (north Waikato northwards) and while its population is large (20,000-100,000 mature individuals) it is in rapid decline (predicted 50-70% decline) (de Lange et al. 2018). Primary threats are loss of habitat to coastal development, farming and for firewood as very few populations occur on protected land (NZPCN 2019). Overall moderate-high risk.
Kunzea robusta (Rawirinui, kanuka)	Trees 8-30m tall.	Nationally vulnerable	Endemic tree, common throughout the North and South Islands in coastal to lowland shrubland, regenerating forest and forest margins, also present in montane forest (NZPCN 2019). This very wide-spread tree has recently been classified as a threatened species due to the detection of myrtle rust – a pathogen for which there is no known effective treatment – in northern NZ in 2017. Kanuka is present in almost 60% of RIMU forest SOE monitoring plots. Climate change interactions that increase the spread and/ or virulence of myrtle rust may present a significant threat to this species. Overall risk is unclear without further data.
Kunzea sinclairii (Great Barrier Island kanuka)	Shrubs up to 3 × 1m, very rarely forming trees up to 6m tall	Nationally critical	This sprawling silvery-grey shrub (rarely a small tree) is endemic to Aotea (Great Barrier) Island where it is largely confined to exposed outcrops of rhyolitic lava rock on the central portion of the island (de Lange and Norton 2004). Its restricted distribution, vulnerability to weed impacts, the potential impact of fire with increased drought and the possible impact of myrtle rust mean this species is overall moderate-high risk from climate change effects.

Scientific (and common) name(s)	Growth form and habit (from NZPCN 2019)	Threat status (de Lange et al. 2018)	Habitat and vulnerability to climate change impacts and overall risk of adverse effects from climate change.
Lepidium oleraceum (Nau, Cooks scurvy grass)	Glabrous, much-branched, perennial, herb up to 1 x 1m, usually less.	Nationally vulnerable	Found throughout New Zealand. Nau is usually found in exposed coastal sites such as rock stacks, islets, headlands and even sea walls (De Lange et al. 2010). Its most significant threat is probably the decline of seabird manured soils, where it seems to thrive (ibid.). The synergistic effect of climate- related disturbance and highly exposed nature of its habitat mean this species is probably more vulnerable; overall moderate-high risk. The ongoing attempts at re-establishment of seabird colonies on animal-pest free islands and planting of nau may help to mitigate any climate-related impacts on this species.
Leptinella tenella	Soft, widely creeping, perennial herb.	Nationally vulnerable	Lowland, usually on stream margins where they enter estuaries, coastal lake margins, and wetlands bordering saltmarsh. It favours sites that are kept open through periodic disturbance from high tides and flooding (NZPCN 2019). This sparsely distributed endemic species has a total area of occupancy ≤ 100 ha, and predicted population decline of 10-50%. Mostly coastal distribution, but the species appears well adapted to, and may benefit from, increased coastal disturbance and flooding. Overall low risk.
Leptospermum scoparium var. scoparium (manuka, kahikatoa)	Shrub, sub-shrub, or small tree up to 5m in height.	At risk – declining	Found throughout New Zealand, and in Australia, manuka is abundant from coastal situations to low alpine habitats (NZPCN 2019). This very wide-spread tree has recently been classified as a threatened species due to the detection of myrtle rust – a pathogen for which there is no known effective treatment – in northern NZ in 2017. Manuka is present in c.26% of RIMU forest SOE monitoring plots. Climate change interactions that increase the spread and/ or virulence of myrtle rust may present a significant threat to this species. Overall risk is unclear without further data.
Lophomyrtus bullata (ramarama)	Bushy shrub or tree up to 6m tall or more.	Nationally critical	Endemic species of coastal to montane forest and shrubland in the North and South islands (NZPCN 2019). Climate change interactions that increase the spread and/ or virulence of myrtle rust may present a significant threat to this species. This species has been shown to have very high susceptibility to myrtle rust in planted and nursery grown specimens, but the impact of this pathogen on wild populations is less certain. Sparsely distributed in the Auckland region. Overall risk is moderate-high.

Scientific (and common) name(s)	Growth form and habit (from NZPCN 2019)	Threat status (de Lange et al. 2018)	Habitat and vulnerability to climate change impacts and overall risk of adverse effects from climate change.
Lophomyrtus obcordata (rohutu)	Shrub up to c.6m tall.	Nationally critical	Endemic plant with a patchy distribution throughout the North and South islands (NZPCN 2019). Climate change interactions that increase the spread and/ or virulence of myrtle rust may present a significant threat to this species. Overall risk is unclear without further data. This species has been shown to have very high susceptibility to myrtle rust in planted and nursery grown specimens, but the impact of this pathogen on wild populations is less certain. Sparsely distributed in the Auckland region. Overall risk is moderate-high.
Machaerina complanata (None known)	Dark green, tufted and leafy sedge, up to 1.3m tall.	Nationally vulnerable	This NZ endemic species has a scattered distribution north of the Kaipara Harbour. There are <15 known sub-populations (de Lange et al. 2018) and only two sites are known within the Auckland region; both are within manuka fens near the coast. It is found in saltmarsh and dune swale wetlands plus (De Lange et al. 2010) open forest and scrub. It thrives in recently disturbed habitats and probably requires disturbance to persist in the landscape. Very restricted coastal distribution in Auckland makes this species vulnerable to stochastic events and possible impacts of prolonged drought. Overall high risk.
Mazus novaezeelandiae subsp. impolitus (Dwarf musk)	Perennial, creeping herb, forming compact leafy patches.	Nationally endangered	Dwarf musk usually grows in damp sand hollows and sand flats, where its biggest threats are habitat clearance and stock damage (ibid.). Although stock damage has also been cited as necessary to reduce weed competition and over-topping my native species (NZPCN 2019). Dwarf musk is probably more vulnerable to the impact of climate change due to its low-lying coastal habitat, although the actual impact of different types of disturbance on the demographics of this species is uncertain. Overall moderate-high risk.
Metrosideros albiflora (akatea, white flowering rata)	Stout, Woody long-climbing vine up to 20 m.	Nationally vulnerable	Endemic to coastal to montane forest habitats in the northern portion of the North Island. This species is virtually confined to kauri (Agathis australis) forest associations. Sparsely distributed in Auckland, akatea is vulnerable to multiple threats including browsing, myrtle rust and kauri dieback. Climate change interactions that increase the spread and/ or virulence of myrtle rust or kauri dieback may present a significant threat to this species. Overall moderate-high risk.

Scientific (and common) name(s)	Growth form and habit (from NZPCN 2019)	Threat status (de Lange et al. 2018)	Habitat and vulnerability to climate change impacts and overall risk of adverse effects <u>from climate change</u>.
Metrosideros carminea (carmine rata)	Woody long-climbing vine up to 15m (usually less).	Nationally vulnerable	Endemic plant found throughout the upper half of the North Island in mainly coastal to lowland locations. Carmine rata is most common in closed forest and forest margins and is often found on rock outcrops and cliff faces (NZPCN 2019). Much less common than some climbing rata in Auckland, it is still present in c.2% of RIMU forest SOE monitoring plots.
Metrosideros colensoi (climbing rata)	Woody long-climbing vine with a slender stem up to 10m.	Nationally vulnerable	Endemic. New Zealand: North Island (from central Northland south), South Island (Nelson and Marlborough to Westland and southern Marlborough / North Canterbury (Napenape). Lowland to montane forest (particularly a vine seen in riparian and alluvial forest). Especially common in limestone areas on rock outcrops, in gorges, cliff faces and around cave entrances.
Metrosideros diffusa (white rata)	Woody, long-climbing vine.	Nationally vulnerable	Endemic. Found throughout the North, South and Stewart Islands (NZPCN 2019). Common in lowland forest and along forest edges, particularly in Canterbury and Westland (Wilson and Gallaway 1993). White rata is present in c.16% of RIMU forest SOE monitoring plots. This very wide-spread climber has recently been classified as a threatened species due to the detection of myrtle rust – a pathogen for which there is no known effective treatment – in northern NZ in 2017. Climate change interactions that increase the spread and/ or virulence of myrtle rust may present a significant threat to this species. Overall risk is unclear without further data.
Metrosideros excelsa (pohutukawa)	Large sprawling tree up to 10m tall with a spread of 10- 50m	Nationally vulnerable	Endemic tree of coastal forest and inland lake margins, common in the northern half of the North Island (NZPCN 2019). Pohutukawa is present in c.6% of RIMU forest SOE monitoring plots. This widespread coastal tree has recently been classified as a threatened species due to the detection of myrtle rust – a pathogen for which there is no known effective treatment – in northern NZ in 2017. Climate change interactions that increase the spread and/ or virulence of myrtle rust may present a significant threat to this species. Possum browse is also a risk to this tree and climatic changes that operate synergistically with browse damage (such as drought) may also be important. Overall risk is unclear without further data.

Scientific (and common) name(s)	**Growth form and habit (from NZPCN 2019)**	**Threat status (de Lange et al. 2018)**	**Habitat and vulnerability to climate change impacts and overall risk of adverse effects <u>from climate change</u>.**
Metrosideros fulgens (climbing rata)	Woody, long-climbing vine	Nationally vulnerable	Climbing rata is endemic to New Zealand and is common throughout lowland and montane forests in Auckland and the North Island (Poole and Adams 1994). This species is present in c.24% of RIMU forest SOE monitoring plots. This very wide-spread climber has recently been classified as a threatened species due to the detection of myrtle rust – a pathogen for which there is no known effective treatment – in northern NZ in 2017. Climate change interactions that increase the spread and/ or virulence of myrtle rust may present a significant threat to this species. Overall risk is unclear without further data.
Metrosideros parkinsonii (Parkinson's rata)	Much branched shrub or small tree up to 10m tall.	Nationally vulnerable	Endemic shrub of montane (in the North Is.) cloud forests. Restricted to Hauturu and Aotea (Little Barrier and Great Barrier islands) in the North Island and the west coast of the South Island (NZPCN 2019). Limited distribution and 'wet forest' habitat makes this species more susceptible to climate change effects such as warming, drought and stochastic disturbances, especially if these act synergistically with myrtle rust. Overall risk is unclear without further data.
Metrosideros perforata (akatea)	Woody long-climbing vine up to 20m.	Nationally vulnerable	Endemic climber in coastal to montane habitats throughout New Zealand. Akatea is an abundant plant of open scrub, dense forest or rock-land (NZPCN 2019) and is common throughout Auckland; it is present in c.42% of RIMU forest SOE monitoring plots. This very wide-spread climber has recently been classified as a threatened species due to the detection of myrtle rust – a pathogen for which there is no known effective treatment – in northern NZ in 2017. Climate change interactions that increase the spread and/ or virulence of myrtle rust may present a significant threat to this species. Overall risk is unclear without further data.

Scientific (and common) name(s)	Growth form and habit (from NZPCN 2019)	Threat status (de Lange et al. 2018)	Habitat and vulnerability to climate change impacts and overall risk of adverse effects from climate change.
Metrosideros robusta (northern rata)	Tall forest, epiphytic 'strangler tree' 25-40m tall	Nationally vulnerable	Endemic tree of coastal and lowland forest found throughout the mainland islands of New Zealand (NZPCN 2019). Northern rata is sparsely distributed throughout mature primary forest associations in Auckland and is present in c.4% of RIMU forest SOE monitoring plots. The species is vulnerable to the impact of possum browse and climatic effects that act synergistically with possum damage, drought and/ or myrtle rust may be important. This common tree has recently been classified as a threatened species due to the detection of myrtle rust – a pathogen for which there is no known effective treatment – in northern NZ in 2017. Climate change interactions that increase the spread and/ or virulence of myrtle rust may present a significant threat to this species. Overall risk is unclear without further data.
Metrosideros umbellata (southern rata)	Shrub or tall tree reaching 20m	Nationally vulnerable	Endemic tree that is found in forest and scrub throughout the main islands of New Zealand, and the sub-Antarctic islands, in lowland to sub-alpine environments. Southern rata is quite sparsely distributed in the upper North Island, and this is especially the case within the Auckland region where it is present in just c.1% of RIMU forest SOE monitoring plots. This tree has recently been classified as a threatened species due to the detection of myrtle rust – a pathogen for which there is no known effective treatment – in northern NZ in 2017. Climate change interactions that increase the spread and/ or virulence of myrtle rust may present a significant threat to this species. Possum browse is also a risk to this tree and climatic changes that operate synergistically with browse damage (such as drought) may also be important. Overall risk is unclear without further data.
Myosotis petiolata var. pansa (Forget-me-not)	Stout, robust to weakly erect, short-lived perennial herb.	Nationally endangered	This almost purely coastal species is found in open coastal forest on banks, cliffs, ledges and colluvial slopes within 300m of the sea (De Lange et al. 2018). Muriwai beach is the northern limit of this species, which is now confined to the Waitakere coast (NZPCN 2019). There are 377 site records from the Auckland west coast and most of these are very exposed to the impact of climate-related coastal disturbances. Overall high risk. Other threats are browsing, coastal development and weed competition; especially from gorse pampas and exotic ruderal species.

Scientific (and common) name(s)	**Growth form and habit (from NZPCN 2019)**	**Threat status (de Lange et al. 2018)**	**Habitat and vulnerability to climate change impacts and overall risk of adverse effects from climate change.**
Myriophyllum robustum (Stout water milfoil)	Perennial aquatic herb which if in pools of water is firmly rooted to the bottom.	At risk – declining	This species grows in shallow peaty lakes, slow flowing streams, dune ponds, and in muddy or seasonally flooded ground in alluvial forest (NZPCN 2019). It is sparsely distributed through parts of both the North and South islands. Probably >100 000 mature individuals, with a predicted decline 10-70% (de Lange et al. 2018). Not confined to coast, distribution is sparse, but relatively widespread which reduces vulnerability to stochastic events. Biggest threats are drainage and degradation of wetlands with open water features (NZPCN 2019). Overall low risk.
Neomyrtus pedunculata (Rohutu)	Shrub or small tree up to 8m tall.	Nationally critical	Endemic of coastal to montane forest and shrubland in the three main islands of New Zealand. Sparsely distributed in the Auckland region. Climate change interactions that increase the spread and/ or virulence of myrtle rust may present a significant threat to this species. Overall risk is unclear without further data.
Ophioglossum petiolatum (Stalked adders tongue)	Perennial, seasonally dormant fern.	Nationally critical	Coastal and lowland ephemeral wetlands, sandy margins of coastal lagoons, lake margins and damp hollows (De Lange et al. 2010). Few records in Auckland, but this species is easily overlooked. Susceptible to a range of threats, included displacement by other native plants. This species may benefit from higher intensity and frequency disturbance to 'over-crowding' vegetation, but its patchy distribution makes it more vulnerable to stochastic events. Land development is a particular risk as it is often found in modified habitat that isn't recognised as having high natural values (ibid.) Overall moderate-low risk.
Paspalum orbiculare (Native Paspalum, scrobic)	Perennial grass. Leaves stiffly erect. Leaf-blade up to 20cm (rarely 30cm) long.	Nationally vulnerable	Scrobic is found in coastal to lowland environments, in seasonal wetlands (often with Baumea juncea), on lake margins, in gumland scrub, and along track sides (NZPCN 2019). Indigenous. Native to northern New Zealand, with a particular stronghold on Aotea (Great Barrier) Island, this species is common in the wider Pacific and Australia (ibid.); therefore, extirpation from the Auckland region would not necessarily be critical for the global distribution of the species. Within NZ scrobic 'habitat' is ≤ 1000ha in extent and the species has a predicted decline 30-70% (de Lange et al. 2018). There is little information on it threat, but overtopping by taller, faster growing grass and shrub species (including natives) is suggested by NZPCN (2019). This species may benefit from increased disturbance, although as a wetland species it could also be vulnerable to the impact(s) on increased drought. Overall low risk.

Scientific (and common) name(s)	Growth form and habit (from NZPCN 2019)	Threat status (de Lange et al. 2018)	Habitat and vulnerability to climate change impacts and overall risk of adverse effects from climate change.
Peraxilla tetrapetala (Red mistletoe, Pikirangi, pirita)	A hemi-parasitic shrub that can grow up to 2m across.	At risk – declining	Red mistletoe has a relatively wide range, from coastal to montane environments in the North and South Islands, but is less common in the North (NZPCN 2019). Its main hosts are four species of NZ beech trees – of which only one (black beech) is present in the region and is confined to Hauturu (Little Barrier) Island (Te Ara 2019). But it has also been recorded as a parasite on a further 17 species including puriri and pohutukawa (ibid.), which are widespread in Auckland. Climate change has not been identified as a direct threat to this species; possum browse, rat-browse and lack of pollinators are most commonly identified (DOC 2019). Overall low risk.
Picris burbidgeae (Native oxtongue)	Annual to perennial herb 0.5-1.2m tall with a basally woody stem.	Nationally endangered	Coastal and lowland on ground recently disturbed by fire, slips or wind, including highly modified habitat such as road margins, rubbish dumps and gravel pits (De Lange et al. 2010). Formerly widespread in northern New Zealand, including Auckland and the Hauraki Gulf islands, the species has rapidly declined (ibid). Its ecological traits make it well adapted to more intensive climate-related disturbance, provided it can be protected from habitat loss through coastal development. Overall low risk.
Pimelea tomentosa	An erect, grey-green, leafy shrub up to 1m tall.	Nationally vulnerable	Coastal to montane open habitats such as rock stacks, cliff tops, coastal forest and scrub margins, tracks and roadsides (ibid.). The species relatively widespread distribution – in comparison to many other nationally threatened plants – and proven adaptations to disturbance means it is overall low risk.
Pittosporum kirkii (Kirk's kohuhu)	Small shrub, usually epiphytic on other trees.	At risk – declining	Common enough in Auckland to have been recorded in two random located forest monitoring plots (on Hauturu and Aotea islands). Endemic within coastal to montane forest in the northern half of the North Island (NZPCN 2019). Population consists of >100,000 mature individuals, with a predicted decline of 10-70% (de Lange et al. 2018) which means it is relatively secure from stochastic threats. Main threats are possum browse and habitat loss (NZPCN 2019). Overall low risk.

Scientific (and common) name(s)	Growth form and habit (from NZPCN 2019)	Threat status (de Lange et al. 2018)	Habitat and vulnerability to climate change impacts and overall risk of adverse effects from climate change.
Pterostylis tasmanica (Plumed Greenhood)	Tuberous, terrestrial orchid, found either solitary or growing in loose groups.	Nationally vulnerable	Growing on scrub or forest margins, and within gumland scrub and sedgeland, this orchid species requires frequent disturbance, usually fire, to maintain its open habitat. Its precipitous decline in the last 100 years is probably due to fire control ((De Lange et al. 2010). Increased drought and fire frequency seem likely to favour this species. However, it is vulnerable to weed competition so climate changes that decrease the relative fitness of the orchid against co-occurring weed species could still have a negative effect. Overall low risk.
Poa billardierei (Hinarepe, sand tussock)	Yellow-green tussocks up to about 70cm tall.	At risk – declining	Coastal dunes and sandy and rocky places near the shore, especially foredunes and dune hollows (NZPCN 2019). Relatively widespread through the main islands of New Zealand, and also Australia (ibid.). NZ population comprises 20,000-100,000 mature individuals, with a predicted decline of 10-50% (de Lange et al. 2018). Mammalian browsing, competition from marram grass, coastal development and vehicles are the biggest threats to this species (NZPCN 2019). However, its coastal location makes it more vulnerable climate change impacts. Moderate-high risk.
Pterostylis paludosa (Swamp greenhood)	Terrestrial tuberous orchid growing in dense colonies.	At risk – declining	Swamp greenhood grows in peat bogs and heathlands, usually in well-lit sites amongst mosses and sedges (NZPCN 2019). It is endemic to NZ and has a somewhat restricted distribution on the three mainland islands. There are around 5000-20,000 mature individuals, with a predicted decline 10-30% (de Lange et al. 2018). Distribution includes coastal zone sites – including Aotea island in Auckland – but it is likely to benefit from increased disturbance, particularly fire disturbance that removes the threat of overtopping and shading by taller stature native vegetation. Drainage of habitat and over-collection are the current primary threats (NZPCN 2019) and if rainfall is sufficient to maintain wetland habitat this species is overall low risk.
Ptisana salicina (King fern, Para)	A large, robust fern with fronds to 5m tall arising from a stout, starchy base.	At risk – declining	Para favours lowland, karst habitats and dark stream sides, often amongst supplejack and parataniwha (NZPCN 2019). Widespread in the north-western North Island this species is found in a number of locations throughout the Auckland region, as is not particularly exposed to coastal hazards or other climate-related disturbance. Feral and domestic stock browse is the most serious threat to this species throughout its range - large specimens are only found where there has been intensive animal control, or in locations inaccessible to stock (NZPCN 2018). Overall low risk.

Scientific (and common) name(s)	Growth form and habit (from NZPCN 2019)	Threat status (de Lange et al. 2018)	Habitat and vulnerability to climate change impacts and overall risk of adverse effects from climate change.
Rorippa divaricata (New Zealand water cress, Matangaoa)	Annual to perennial herb (depend-ing on local growing conditions), 0.3-2m tall.	Nationally vulnerable	Disturbed habitats such as slips or open locations along tracksides, and lake and river margins. Including coastal scrub and lakes. Often associated with petrel colonies on offshore islands (De Lange et al. 2010). This species requires disturbance – competition from weeds and succession to tall native vegetation are its primary threats (ibid.). May benefit from increased disturbance, although not if its fitness was reduced in relation to co-occurring weed species. May benefit from seabird conservation efforts. Overall moderate-low risk.
Scandia rosifolia (Koheriki)	Semi-erect to somewhat openly sprawling, woody, aromatic shrub up to 1 x 1m.	Nationally critical	Koheriki is a North Island endemic with a wide climatic range from coastal to subalpine locations. It is usually found on cliff faces, clay banks or amongst boulders, often found along cliffs lining river gorges (NZPCN 2018). The threat status of this species has recently been significantly upgraded in recent years. This is based on its extreme palatability to browsing mammals (esp. goats and possums) and it has undergone a significant decline of >70% (de Lange et al. 2018). The Waitakere Ranges were a former stronghold (ibid.). While its main threats are not related to climate change, scattered remaining populations are vulnerable to stochastic effects, especially given the erosion prone nature of its habitat. Overall moderate risk.
Schoenus carsei (Carse's Schoenus)	Stout rush-like sedge up to 1m tall.	Nationally critical	Relatively wide ecological range; from moderately fertile to acidic wetlands from the coast to montane climates. It favours open sites that have been frequently burned (de Lange et al. 2010). Occasionally associated with ephemeral dune ponds. Its sparse distribution makes this species more vulnerable to stochastic events. Threatened by wetland drainage and eutrophication, displacement by weeds and overtopping by native vegetation. Overall moderate risk.

Scientific (and common) name(s)	Growth form and habit (from NZPCN 2019)	Threat status (de Lange et al. 2018)	Habitat and vulnerability to climate change impacts and overall risk of adverse effects from climate change.
Senecio scaberulus (Fireweed)	Annual or short-lived perennial herb up to 1.5m tall.	Nationally critical	This coastal species is found in sparsely vegetated sites under pohutukawa, on lava fields, rock outcrops, cliffs or banks near the sea (Ibid.). Once widespread in the north of the North Island it has declined dramatically due to urbanisation and weed competition (ibid.). Coastal location and multiple threats mean this species is overall high risk.
Spiranthes novae-zelandiae (Lady's tresses, spiranthes)	Terrestrial, perennial herb (orchid). Plant at flowering up to 1m tall.	Nationally vulnerable	Acidic peat bogs and lake margins. Rare in Auckland, there is just a single contemporary, and several historical, records. But it is more common rest of New Zealand (de Lange et al. 2018). Vulnerable to stochastic effects but may benefit if fire frequency increases. Overall moderate-low risk.
Syzygium maire (Swamp maire, Maire tawake, Waiwaka)	Tree to c.16m high, frequently bearing pneumato-phores	Nationally critical	Endemic tree of coastal and lowland riparian habitats that was formerly common in the north and south islands. Maire tawake is now scarce or absent over large parts of its former range due to the clearance of swamp forest, which increases its vulnerability to stochastic effects and the impacts of altered hydrology and drought due to climate change. Climate change interactions that increase the spread and/ or virulence of myrtle rust may also present a significant threat to this species. Overall moderate-high.
Tupeia antarctica (Taapia, pirita, white mistletoe, tupia)	A shrubby semi-parasitic shrub to 1m diameter.	At risk – declining	Tupia is endemic to the North and South islands and grows in regenerating forest or scrub, where it is parasitic on a wide range of hosts (NZPCN 2019). It has a relatively large population of >100,000 mature individuals, which is secure in locations where the main threats to this species are absent (de Lange et al. 2018). That is, possums and lack of pollinators (NZPCN 2019). Overall low risk.
Utricularia australis (Yellow Bladderwort)	Wholly submerged, floating carnivorous aquatic plants dying down to resting buds in winter.	Nationally critical	Shallow water (to 1m deep) in peat lakes and pools, and streams within peat bogs, from Te Paki to Lake Taupo (de Lange et al. 2010); yellow bladderwort is also found in Australia and Europe population. This species is severely threatened by competition from the aquatic weed *U. gibba*, other introduced aquatic weeds, and habitat modification and drainage (NZPCN 2019). The NZ population has a predicted decline of > 70% (de Lange et al. 2018). Not directly threatened by climate change and therefore an overall low risk.

Appendix D Plants potential vulnerability to myrtle rust or kauri dieback

Statement from de Lange et al. (2018) outlining the reasons for the re-classification of kauri and 19 widespread Myrtaceous species as threatened plants:

"Following the arrival of myrtle rust (*Austropuccinia psidii*) to Raoul Island (Kermadec Islands group) and northern New Zealand in April and May 2017 respectively, the panel has also reviewed the conservation status of the indigenous Myrtaceae. As with kauri dieback, there is currently no known effective treatment for myrtle rust.

On advice from Australian botanists (David Cantrill, Tom May, M.A.M. Renner, N.G. Walsh pers. comm.) familiar with this rust, a reassessment of the New Zealand Myrtaceae and those plants intimately associated with them is warranted. Current evidence suggests that species within the endemic genera *Lophomyrtus* and *Neomyrtus* are the most likely to be seriously affected (Makinson 2014; M.A.M. Renner pers. comm.). *Lophomyrtus* and *Neomyrtus* are closely allied to Australian *Austromyrtus* and *Rhodomyrtus*, genera that are severely, often mortally impacted by myrtle rust ([Carnegie] et al. 2016; M.A.M. Renner pers. comm.) Furthermore, the severe effect of myrtle rust on the Kermadec Islands endemic *Metrosideros kermadecensis* was not foreseen, while the debilitating impact (often terminal) caused by the rust on New Zealand Myrtaceae cultivated in Australia, or their close congeners, suggests that we have yet to see the full impact of myrtle rust here.

The panel is also concerned over the potential devastation that could be caused to *Metrosideros* if the *Ceratocystis fimbriata* strain responsible for 'Rapid Ohia decline' in Hawai'i (Mortenson et al. 2016) became established in New Zealand. Therefore, as a precautionary measure the panel has designated all the New Zealand Myrtaceae previously considered to be Not Threatened as 'Threatened' and elevated the status of those previously assessed as At Risk to Threatened. The sole non-myrtaceous plant known to be intimately associated with New Zealand Myrtaceae, the endemic hemiparasitic *Korthalsella salicornioides* has also been assessed as 'Threatened – Nationally Critical'."

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