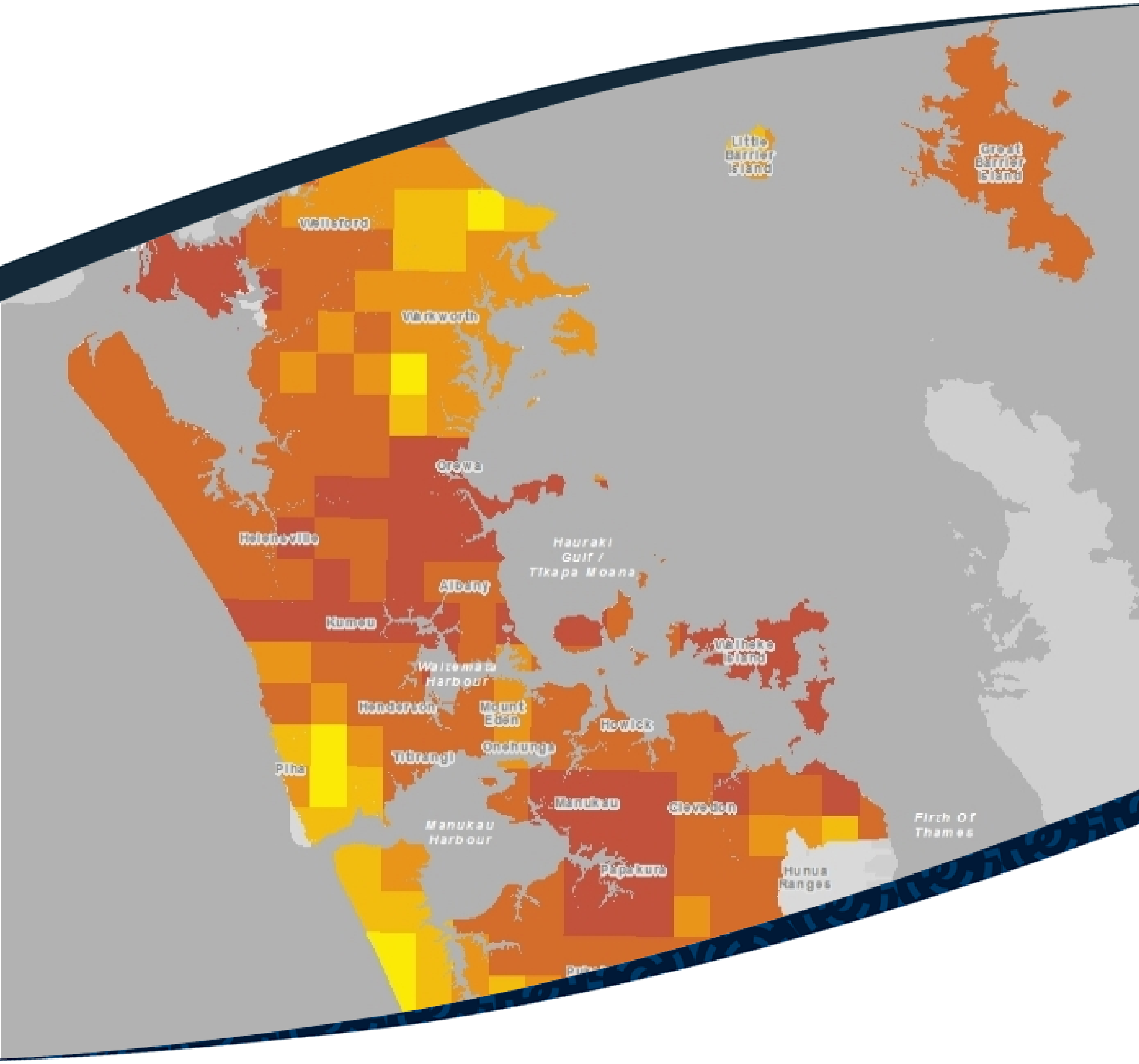
Development of the Auckland Heat Vulnerability Index

Jennifer L R Joynt and Nancy E Golubiewski

March 2019

Technical Report 2019/012



RIMU Research and Evaluation Unit

Auckland Council
Te Kaunihera o Tāmaki Makaurau

Development of the Auckland Heat Vulnerability Index

March 2019 | Technical Report 2019/012

Jennifer L. R. Joynt

Nancy E. Golubiewski

Research and Evaluation Unit, RIMU

Auckland Council
Technical Report 2019/012

ISSN 2230-4525 (Print)
ISSN 2230-4533 (Online)

ISBN 978-1-98-858962-6 (Print)
ISBN 978-1-98-858963-3 (PDF)

This report has been peer reviewed by the Peer Review Panel.
Review completed on 13 March 2019 Reviewed by two reviewers
Approved for Auckland Council publication by: Name: Eva McLaren Position: Manager, Research and Evaluation (RIMU)
Name: Regan Solomon Position: Manager, Land Use and Infrastructure Research and Evaluation
Name: John Mauro Position: Chief Sustainability Officer, Auckland Council
Date: 13 March 2019

Recommended citation

Joynt, Jennifer L. R. and Nancy E. Golubiewski (2019). Development of the Auckland Heat Vulnerability Index. Auckland Council technical report, TR2019/012

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
Foley, M. M. and M. Carbines (2019)

Flooding risk in a changing climate
Golubiewski, N. E., J. L. R. Joynt and K. Balderston (2019)

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

The following work contributes to the Auckland Council Climate Change Risk Assessment (CCRA) undertaken at Auckland Council's Research and Evaluation Unit (RIMU), and also contributes to the Auckland Climate Action Plan (ACAP).

According to projections developed by the National Institute of Water and Atmospheric Research (NIWA) based on a representative concentration pathway (RCP) 8.5, climate change will have numerous impacts on Auckland. By the end of this century extreme heat events are predicted to increase by a factor of four. Increasing hot days pose a considerable risk to the health and well-being of the population, particularly for those either more sensitive to heat or with less capacity to adapt to their surroundings. The following work develops a heat vulnerability index (HVI) which identifies areas of increased vulnerability to heat due to the resident population's inherent sensitivity and adaptive capacity.

Mortality and morbidity figures can be used to inform the development of a HVI by increasing understanding of which socio-economic groups are most affected by extreme heat events. Threshold levels for heat vulnerability vary, with threshold levels in the tropics being markedly higher than for more temperate climates. Despite variation in threshold levels, the impact of extreme heat on the population is common across case studies presented in the literature. Therefore, utilising recommended variables from the evaluations of case studies of real extreme heat events in France, Spain, China, South Korea, USA, Canada, Australia and the UK, and adapting them to the local context, is a pragmatic way to address this current research gap in New Zealand.

The following groups are identified as being at higher risk to heat-related mortality: females, persons living alone (socially isolated), households without vehicles (limited access), over 65s, under 5s, limited comprehension of the local language, ethnic minorities, low income households, renter households – particularly occupants of housing with poor thermal performance, – limited educational attainment, the chronically ill and mentally ill.

The literature informs the development of an Auckland specific heat vulnerability index (HVI) using 10 dependent variables that exacerbate heat vulnerability mapped using GIS at the census area unit level. The 10 variables include the multifactorial indicator, New Zealand Indices of Multiple Deprivation (Exeter, et al., 2013) (IMD); and the 2013 census-based variables: one-person households; rental tenure; residents over 65; children under 5; English language skills; household rent burden; Māori and Pacific population distribution (as a proxy for the chronic health conditions

– diabetes, cardiovascular disease, renal disease, respiratory disease and mental illness) (Ministry of Health/ Manatū Hauora, 2015, 2016, 2017; Statistics New Zealand, 2013). Green infrastructure is included from the New Zealand Land Cover Database (LCDB) (Ministry for the Environment, 2018). The result of the HVI is a spatial representation of census area units with heightened vulnerability to extreme heat. The introduction of the HVI illustrates that the effects of climate change may be felt beyond the more widely understood risks of sea level rise and affect the most vulnerable in society.

An acknowledged omission from this research is the significant role social infrastructure plays in mitigating vulnerability to extreme heat. Social infrastructure is both the physical buildings that enable social interactions and provide functions such as cool spaces. These include but are not restricted to community centres, places of worship, marae, libraries and community cafes. As well as the community connections that are fostered within the buildings, such as manaakitanga, support for the socially isolated, buddy systems, and community support groups. Existing social infrastructure within the communities identified in this research could mitigate the vulnerability of the identified communities considerably. Quantifying and including social infrastructure in this iteration of the HVI is out of scope but presents a significant future research opportunity to refine this work.

The majority of at risk areas identified using the HVI are in Māngere-Ōtāhuhu, Ōtara-Papatoetoe, Manurewa and Papakura local board areas, collectively known as the Southern Initiative (TSI). The population of the TSI has high social, economic and health-based risks, as well as some of the highest projections in increased hot days. For example, over 90 extra hot days by 2110. To the east, the local board area of Maungakiekie-Tāmaki has high vulnerability to heat according to the HVI and a slightly lower projection of number of hot days than the TSI. To the west, the Henderson-Massey Local Board area shows high heat vulnerability with slightly lower projections of increased hot days than the eastern areas in 2090 and the same as the areas to the east by 2110.

Land cover has a significant impact on mitigating or exacerbating extreme heat. Where an area has significant greenspace and tree canopy, evapotranspiration and shading offer significant passive ecosystem services, likewise where areas are urbanised the thermal mass of construction materials creates an urban heat island effect. Community scale green infrastructure is therefore particularly beneficial in areas of low income where residents can be restricted by limited resources to adapt to extreme heat. Land cover maps demonstrate that many heat vulnerable areas also have very limited green cover compounding the risk of extreme heat. Prioritising preservation and increase of greenspace in these areas could considerably improve the heat vulnerability of the population.

Occupational groups that are vulnerable to extreme heat include labourers, farm workers and outdoor construction workers. In addition to the HVI, occupations vulnerable to heat have been mapped to illustrate occupational exposure to extreme heat. Occupational heat risk will potentially emerge as a growing issue as Auckland is exposed to increasing hot days.

Mitigation strategies for extreme heat include the development of Heat Management Plans which have been widely adopted by cities around the world, particularly in regions of the world where extreme heat has resulted in significant loss of life. The plans often include heat wave warning systems (HWWS), using social media, media and community facilities. The plans also collate and promote an inventory of social infrastructure (community cool spaces) and green infrastructure available to communities during extreme heat events, including existing civil defence centres. In addition, the plans support the provision of information and education, providing practical advice and outreach to residents on how to prepare and protect themselves (and their neighbours) before and during an extreme heat event. For example, by using a buddy system, and by utilising existing services such as health and social network and community groups.

This report illustrates the first iteration of the Auckland HVI using the best available data at the time. It is envisaged that as new data is generated, i.e. 2018 census, new vegetation cover data and more in-depth social infrastructure analysis, the HVI will be refined and improved and could potentially yield new data on the location of vulnerable sectors of the population. This tool is intended to illustrate the heterogeneity of impacts of the anticipated rise in hot days and stimulate discussion on potential adaptation strategies.

Table of contents

1.0 Introduction

As the climate changes over the coming decades, increasing hot days could pose a significant health risk to the population of Auckland. The National Institute of Water and Atmospheric Research (NIWA), defines hot days as days where the daily maximum temperature exceeds 25 degrees Celsius because temperatures above this threshold are considered ‘hot’ given New Zealand’s temperate maritime climate (Pearce et al., 2018).

According to regional climate projections (Pearce et al., 2018), under a business as usual projection (Representative Concentration Pathway RCP 8.5), nearly all the Auckland region (with the exception of the Waitākere Ranges) could experience at least 10-15 extra hot days per year by 2040; and up to 25 extra hot days in the south and north of the region. By 2090, most of the region could experience 60-70 extra hot days with areas to the south and north of the region experiencing up to 90 extra hot days. By 2110, this could increase so that most of the region will experience 70-80 extra hot days, with the south and north of the region experiencing over 90 more hot days than baseline conditions[1]. Essentially, Aucklanders will be exposed to three months of extra hot days, which will elevate the risk of heat-related morbidity and mortality considerably (Royal Society/Te Apārangi, 2017)

Several researchers globally have developed spatial heat vulnerability index (HVI) maps by mapping socio-economic vulnerability factors related to heat morbidity/ mortality against known socio-economic, health, household and neighbourhood variables such as green infrastructure, and social infrastructure (Eisenman et al., 2016; Johnson, et al., 2012). The HVIs are tested for reliability against known morbidity/mortality data following extreme heat events (Chuang, 2015; Eisenman et al., 2016; Hondula, 2015; Reid et al., 2009). Although HVI conceptualisation and measurement differ from study to study, there are commonalities amongst most (Chuang, 2015). Developing heat vulnerability maps to inform heat emergency plans are increasing internationally and can aid a city in targeting resources to those most at risk (Reid et al., 2009). The epidemiological literature was used to inform the development of a heat vulnerability index for Auckland using the “business as usual” scenario (RCP8.5) where emissions continue unabated for the years 2040, 2090 and 2110 (Pearce et al., 2018).

This work has been undertaken to complement the social vulnerability assessment also being developed under Auckland Council’s climate change risk assessment programme (CCRA). The work presented here, and throughout the CCRA reports,

[1] Changes relative to the baseline climate of 1986-2005 (termed ‘1995’).

defines vulnerability as the nexus between exposure to a hazard, sensitivity to that hazard and adaptive capacity to mitigate the impacts of the hazard.

Fernadez & Golubiewski (2019) compiled a non-weighted indicator of social vulnerability; adaptive capacity (including natural capital); and climate risks (including sea level rise, increased hot days, drought, mean temperature change, relative humidity, precipitation days, and increased rainfall projections) into a single indicator. This work focuses on one of the projected climate change risks, namely increased hot days over 25°C, and provides a nuanced picture of at-risk groups within census area units (CAU). As with the work by Fernadez & Golubiewski (2019), sensitivity and adaptive capacity are measured using socio-demographic indicators. In addition, proxies are used for heat-sensitive chronic illness distribution in the population. Urban heating and cooling potential is also captured with the inclusion of the New Zealand Land Cover Database. The outcome of this work is a spatial heat vulnerability index (HVI).

2.0 Background

There is now robust evidence that climate change is affecting the frequency, intensity and duration of extreme heat events globally, and that these events have been linked to excess morbidity and mortality (Ebi, Ogden, Semenza, & Woodward, 2017), even within temperate climates such as the UK, France and Canada (Dong et al., 2018; Fouillet et al., 2006; Graham, 2016).

The effect of hot days is not uniformly felt and vulnerability to climate change is not homogenous in its definition. The Intergovernmental Panel on Climate Change (IPCC) (2001) defined vulnerability from a biophysical perspective, in that biological vulnerability was a function of the character, magnitude, and rate of climate variation to which a system is exposed, the systems sensitivity to that risk, and its capacity to adapt. To define social vulnerability to climate change more accurately, risk itself needs to be considered as a function of hazard exposure and vulnerability (Auckland Council, 2019). This definition reflects that those with greater disadvantage are inherently at greater risk of the effects of climate change. Furthermore, the reason for disadvantage, such as, poor health or low income, can create greater vulnerability to some climate change risks over others.

Cutter (2003) recommended that by overlaying hazard exposure with population data, social vulnerability could be spatially presented. This work attempts to define the relevant vulnerable communities in the Auckland region, based on findings of factor analyses of victims of extreme heat events globally. In addition, vulnerable communities are presented spatially using Geographic Information Systems (GIS).

2.1 Defining an extreme heat event

It is the relative change of heat and the duration that defines an extreme heat event or hot day. The effects of heat exposure on individuals vary relative to the normal range of temperatures to which the population is acclimatised (Hajat & Kosatky, 2010). For example, it was the 11-12°C difference from the seasonal norm, raising the temperature above 30°C for 10 consecutive days, that caused the 15,000 excess deaths in France in 2003 (Fouillet et al., 2006). This heat event, although extreme for France, would not be expected to cause the same impact in a city such as Dubai, where average temperatures exceed 30°C for six months of the year and the population and built environment are adapted to cope (World Weather Online, 2018). The World Health Organisation reports that temperate cities have higher rates of heat-related deaths than tropical cities (Berry, 2013; Johnson et al., 2012). Furthermore, the effects of hot days can be exacerbated by high humidity levels, as humidity impacts the way heat is experienced with higher humidity levels impairing the body's ability to sweat and cool itself (Barreca, 2012). This is significant for Auckland as, in addition to increasing hot days, absolute humidity levels are projected to increase (Talbot, 2019).

The point at which heat stress is felt is known as the 'threshold value' which is the point at which the population is put under heat stress during a heat event[2]. Research undertaken in seven US cities (Hondula, 2015:446) defined threshold temperature as 'the lowest temperature at which mortality is significantly different than observed for normal summer conditions'. They found that this threshold varied geographically between cities and within cities. For example, Atlanta, Georgia, which has high temperatures and humidity throughout the summer months, was found to have no threshold temperature (Hondula, et al., 2015). Threshold values are thus a measure of a population's tolerance to its local climate (Hajat & Kosatky, 2010; Gronlund, et al., 2018).

Variability also exists within populations, and the impacts of hot days are not homogenous spatially or demographically. Certain population groups and environments are more vulnerable than others to extreme heat events/ hot days. The geographical variation is attributed both to the distribution of populations with low socio-economic status, underlying health conditions susceptible to heat as well as varied built and natural environments.

According to NIWA the criteria for a 'hot day' in Auckland is days with maximum temperatures greater than 25 degrees (Tmax >25°C) (Lorrey, Pearce, Barkus, Anderson, & Clement-Jones, 2018). Auckland currently experiences 20 hot days each year, which contribute to a proportion of the 14 heat-related deaths per annum recorded for the over 65 age group in Auckland and Christchurch (Royal Society/Te Apārangi, 2017). The NIWA projections for Auckland predict that the number of hot days experienced will increase fourfold (to over 90 days per annum) by the end of the 21st century (Pearce et al., 2018). Heat-related deaths will increase significantly in line with average temperature rises; from the current baseline of 14 heat-related deaths per year up to 88 deaths per year with a three-degree rise in global temperatures (Royal Society/Te Apārangi, 2017).

[2] Heat events can be calculated as follows: temperatures that are (a) the 97.5th historical percentile of daily maximum temperature for summertime months (t1) and (b) the 81st historical percentile of daily maximum temperature for summertime months (t2). So extreme heat events are based on 1) maximum daily temperatures above t1 for 3 consecutive days and 2) average maximum daily temps must be above t2 for every day in the period (Eisenman et al, 2016).

2.2 Health effects of extreme heat

Exposure to extended periods of extreme heat can have severe physiological consequences (Eisenman et al., 2016; Fouillet et al., 2006; Gronlund et al., 2018; Hondula, 2015; Reid et al., 2009). Extreme heat has a significant impact on the human body's ability to regulate internal systems. During heat-waves, the most common hospital admission is due to heat exhaustion and heat stroke (Knowlton, et al., 2009). The human body has a highly sophisticated mechanism to thermoregulate, with a healthy body responding to high temperatures through blood vessel widening (vasodilation), increases in the rate that blood is pumped through the heart (cardiac output), and sweating (Gronlund et al., 2018), where exposed populations have underlying health conditions, the ability for the body to activate these coping mechanisms is diminished (Nitschke et al., 2011). In particular the thermoregulatory, physiological and circulatory adjustments required to cope with extreme heat can put stress on the kidneys, so where people with underlying renal conditions are exposed to extreme heat it can cause dehydration, electrolyte disorders as well as acute renal failure (Alana et al., 2008; Chuang, 2015). The correlation found between reports of acute renal failure and extreme heat events in California in 2006 (Knowlton et al., 2009) and numerous extreme heat events recorded in Australia between 1995-2006 (Hansen 2008; Knowlton, et al., 2009) demonstrate this causal effect.

Other underlying health conditions of concern include cardiovascular disease and secondary cardiovascular failure because of heat-related renal failure (Hajat & Kosatky, 2010) and respiratory illness (Kjellstrom, 2010; Royal Society/Te Apārangi, 2017). Evidence of the link between an increase in the severity of cardiovascular disease and heat events varies. Many studies have found a strong correlation between the exacerbation of cardiovascular disease and extreme heat (Åström, et al., 2011). A study undertaken on the elderly in the UK reported no association between high temperatures and myocardial infarction hospitalisations (Bhaskaran et al., 2010). Whereas an investigation in 12 European cities found that high temperatures increase cardiovascular mortality but not cardiovascular admissions (Michelozzi et al., 2009). The New Zealand Royal Society reports the correlation of extreme heat and cardiovascular disease exacerbation (Royal Society/Te Apārangi, 2017). Hajat & Kotatsky (2010) inform that renal failure can lead to cardiovascular failure in some patients. For this report, cardiovascular disease has an assumed link with heat-related morbidity and mortality.

Research undertaken around the world comparing hospital admissions to extreme heat events link increasing morbidity relative to each degree of temperature above the heat threshold for that region (Åström et al., 2013; Åström et al., 2011). As reported by Lin et al., (2012), studies have demonstrated that the correlation causes between a 2.7 per cent and 4.5 per cent increase in respiratory admissions for the over 75 age groups for each one-degree exceedance of the temperature threshold. Considering a globally ageing population, with the proportion aged over 65 years in Auckland projected to increase by 155 per cent by 2043 (Statistics New Zealand 2013), projections of the impact of increasing hot days are estimated to be conservative (Åström et al., 2013). For those with pre-existing health conditions nearing death, hot days can expedite their deterioration which affects the inter-temporal distribution of mortality. This phenomenon is known as ‘‘harvesting’’ (Barreca, 2012).

Hot day effects are not confined to physiological impacts. Mental health conditions also deteriorate under heat stress conditions. The thermoregulatory disruption caused by extreme temperatures compromises the effectiveness of psychotropic medication usage, psychiatric illness, and various behaviour symptoms (Hansen et al., 2008; Nitschke et al., 2011; Page,et al., 2012; Wang, et al., 2014). In addition to underlying health conditions which increase sensitivity to heat, socio economic and environmental factors play a considerable part in mortality and morbidity outcomes (Maller & Strengers, 2011).

2.3 Factors influencing vulnerability to extreme heat

The projection of increasing extreme heat events are not consistent across the Auckland region (Pearce et al., 2018). Likewise, the impact of the hot days will not be the same across Auckland as heat-related deaths are closely related to both social vulnerability and the local natural and built environment (Eisenman et al., 2016; Reid et al., 2009). Increasing hot days pose a considerable risk to the health and well-being of the population. Particularly for those either more sensitive to heat or with less capacity to adapt their surroundings (Maller & Strengers, 2011). Research undertaken across the globe, including from France, USA, Canada, Australia and the UK, identifies the following groups to be of higher risk to heat-related mortality: females[3], persons living alone (socially isolated), households without vehicles (limited access), over 65s, under 5s, limited comprehension of the local language, ethnic minorities, low income households, renter households: particularly occupants of housing with poor thermal performance, limited educational attainment and the chronically and mentally ill (Borrell et al., 2006; Eisenman et al., 2016 ; Fouillet et al.,

[3] Gender is only thought to be a factor in so much that females are more likely to live alone over 65 years, therefore gender is a proxy for social isolation in this age group making them more vulnerable (Eisenman et al., 2016). In research undertaken on the Chicago heat wave (Klinenberg, 2003) and Barcelona heat wave (Borrell, et al, 2006, more male victims were recorded.

* *Equivalisation: methods used to control for household composition

2006; Hajat & Kosatky, 2010; Hondula, 2015; Reid et al., 2009; Royal Society/Te Apārangi, 2017).

2.3.1 Housing type, tenure and condition and heat vulnerability

Studies undertaken after extreme heat waves have found that most heat-related deaths occur in the home (Klinenberg, 2003; Maller & Strengers, 2011). The type and tenure of a building can impact on sensitivity and adaptive capacity to extreme heat, with the following factors all influencing outcomes for residents: orientation and thermal performance of the building, the location of the resident within the building, with residents located on higher floors at more risk than those with direct access to the outdoors (Klinenberg, 2003; Kovats & Ebi, 2006). Lack of access to passive ventilation[4] and mechanical ventilation systems (air conditioning units) also influences vulnerability in the home (Eisenman et al., 2016). As building regulations change, properties are becoming more airtight, which although effective at retaining heat in winter can lead to overheating in summer where adequate ventilation is not also fitted (Gupta & Greggs, 2012; White, 2017). Even when available, both passive and mechanical ventilation use can be moderated by other factors, for example willingness to open windows may be limited by security concerns (McNeil, et al., 2015) and the use of air-conditioning units can be moderated by cost implications (Eisenman et al., 2016). Tenure also plays a role in determining vulnerability, as those in private rental tenure have more limited scope to make physical adaptations to a property and are reliant on landlords and or property managers to implement physical changes (Instone, et al., 2015; Joynt, 2017; Witten et al., 2017).

In New Zealand rental properties are of considerably lower thermal and quality standard than private properties (White, 2017). Recent changes under the Health Homes Guarantee Act 2017 will require all tenanted properties to be insulated to building code standards. However, without a requirement for a warrant of fitness, compliance with this legislation is reliant on tenants holding landlords and property managers accountable to implement the necessary adaptations. In the Auckland context this has been shown to be a less effective method of implementing changes, as tenants fear reprisals for ensuring compliance with legislation (Joynt, 2017).

The ability to physically adapt a rental house is also limited due to restrictions in most private tenancy agreements (Joynt, 2017). Tenants thereby have reduced capacity to undertake preventative steps to reduce vulnerability to extreme heat events, such as adapting windows and ventilation (Maller & Strengers, 2011).

[4] Passive ventilation takes advantage of wind and orientation of windows to cool or warm a property (BRANZ, 2015).

Overcrowded houses reportedly increase vulnerability to extreme heat events as overcrowding is strongly correlated to low income, which reduces adaptive capacity. In addition, overcrowded occupants are more likely to have chronic conditions such as depression (Pierse, et al., 2016) and respiratory problems, which are compounded by poor housing quality (Joynt, Tuatagaloa, & Lysnar, 2016). Multi-generational or multi-family occupancy is a cultural norm for many in New Zealand. Multi-occupancy should not be conflated with overcrowding which is a significant problem in Auckland. Multi-occupancy households which are not overcrowded would in fact mitigate some risk to extreme heat by reducing social isolation.

2.3.2 Underlying chronic health conditions and heat vulnerability

Chronic health conditions can be made worse by extreme heat. Cardiac, renal, diabetes and respiratory disease, as well as mental health conditions are caused or aggravated by high temperatures (Alana et al., 2008; Eisenman et al., 2016; Fouillet et al., 2006; Hajat & Kosatky, 2010; Hondula, 2015; Reid et al., 2009; Royal Society/Te Apārangi, 2017). Distribution of these diseases also has a spatial and ethnic dimension, as demonstrated by the prevalence of the diseases within specific communities. The ethnic and, by association, spatial patterns of diseases with a causal factor in heat vulnerability are described below.

One in 20 adults in New Zealand live with cardiovascular disease (Heart Foundation, 2018) and Māori adults are more than twice as likely to die from this cause as European New Zealanders (Heart Research Institute, 2018). Data from the New Zealand Health Survey 2015[5] showed some spatial variation in the incidence of cardiovascular disease in the Auckland population. The ischaemic heart disease indicator, which covers: strokes, angina, previous heart attacks and hardening of the arteries, was used to evaluate prevalence and distribution of cardiovascular disease in Auckland (Ministry of Health/ Manatū Hauora., 2015). The results showed that 4.2 per cent of the populations served by both Auckland District Health Board (DHB) and Counties Manukau DHB had diagnosed ischaemic heart problems, whereas 3.1 per cent of the population in Waitematā DHB was diagnosed as such. There was a statistically greater number of Māori than non-Māori women with heart disease in Counties Manukau, and statistically more Māori than non-Māori across genders with cardiovascular disease in the Auckland DHB (Ministry of Health/ Manatū Hauora, 2015, 2016, 2017). In all three DHBs, the over 65 age group had four times the diagnosis of ischaemic heart disease than the 45-64 year old group (Ministry of Health/ Manatū Hauora., 2015).

[5] Regional data sets from the 2016/2017 survey were not publically available.

Diabetes affects seven per cent of New Zealanders, and nearly 100,000 people live with diabetes in Auckland (Diabetes Auckland, 2018). Research reported in 2016 indicated a statistically significant relationship between diabetes prevalence and geographic location in Auckland. A fivefold difference was found in patient numbers having diabetes between the North Shore (3.4%) and Māngere (17.3%). The research also found that Māori, Pacific and Asian cohorts were disproportionately represented in patient groups (Warin, et al., 2016).

Diabetes is a precursor for renal disease. Of the 485 adults and 18 young adults and children starting renal replacement therapy in New Zealand in 2015, nearly half (47%) had kidney disease caused by diabetes (New Zealand Nephrology, 2015). Counties Manukau had one of the highest incidences per million, of end-stage kidney disease in the country with 1501 patients, as compared to Auckland (1202) and Waitematā (782) (New Zealand Nephrology, 2015).

In Auckland, hospitalisation due to 'total serious respiratory diseases' has been found to have a geographic as well as demographic determinant. Research undertaken on District Health Board (DHB) areas in 2015 reported the following numbers of hospitalisation per 100,000 people, Auckland DHB (#1839); Waitematā DHB (#1713) admissions; and Counties Manukau DHB (#2308) (Telfar-Barnard & Zhang, 2016). Demographic data at the DHB level is not available on respiratory health. However, research indicated that nationally respiratory hospitalisation rates were highest for children under 15 years and adults over 65, more males than females in the under 15 and over 65 categories, and more females in the 15-64 age group. These groups can therefore be used as a proxy indicator of respiratory illness distribution.

There is also an ethnic dimension to respiratory hospitalisations. Pacific people had 3.1 times higher rates than non-Māori. Māori rates of hospitalisation were also significantly higher than non-Māori rates. Income was also correlated significantly with respiratory disease with the most deprived quintile demonstrating three times higher hospitalisation rates than the least deprived quintile (Telfar-Barnard & Zhang, 2016).

People with underlying mental health conditions are also more vulnerable than the general population to extreme heat events (Bolton, 2018; Page, et al., 2012; Royal Society/Te Apārangi, 2017; Wang, et al., 2014). The Office of the Director of Mental Health reports annually on the distribution and demography of patients with mental health conditions across Auckland. Data on diagnosed psychological distress in adults in the Annual Health Report 2016 showed significantly greater numbers of patients with mental health conditions than the national average in Counties Manukau DHB and significantly less in Waitematā DHB; Auckland DHB had a similar occurrence of mental health conditions in the population to the national rate (Ministry of Health/ Manatū Hauora, 2016).

The 2016 report (Ministry of Health/ Manatū Hauora, 2016) showed that Māori access rates to mental health services exceed those of other groups significantly (Māori 6.1% vs non-Māori 3.1%). This was attributed in part to both the relatively young population and high levels of deprivation of Māori in Auckland (two-thirds living in deprivation) (Ministry of Health/ Manatū Hauora, 2016). These factors do not, however, fully account for the disproportionate use of mental health services by Māori as demonstrated in research undertaken by Oakley Browne et al., (2006) in Royal Society/Te Apārangi (2017).

The data reflects findings by the Ministry of Health in 2017 that people living in the most socio-economically deprived areas were nearly three times more likely to experience psychological distress as people living in the least deprived areas, after adjusting for age, gender and ethnicity as the Counties Manukau DHB has a high level of deprivation (Ministry of Health/ Manatū Hauora., 2017).

Finally, pregnant women are a group not mapped on the HVI due to the temporary nature of the condition; however, being pregnant is identified as a risk factor in heat-related morbidity (Harlan, 2006). The birth-rate in all ethnicities is expected to decline over the next century. However, the current high birth rate of Pacific peoples will continue (Statistics New Zealand., 2018). Support for pregnant women through access to ventilation at home, in a community cool space, or potentially through primary care centres or antenatal clinics will be required during a hot event.

2.3.3 Socio-economic indicators of vulnerability to heat events

Adaptive capacity is the ability to cope with the impacts and aftermath of a hazardous event (Chuang, 2015). Adaptive capacity is influenced by demographic and socio-economic characteristics (age, gender, family status), health status (pre-existing illness), access to resources, support and information (e.g. with regard to heat protection measures) and mobility (Chuang, 2015; Johnson et al., 2012; Reid et al., 2009; Wolf & McGregor, 2013).

Many measures of social vulnerability and deprivation also relate to heat vulnerability. A useful indicator to quantify social vulnerability due to its multifaceted inputs is the New Zealand Indices of Multiple Deprivation (IMD). An alternative deprivation index is also available the New Zealand Deprivation index (NZDep), which combines the following census data:

- Communication – people aged <65 with no access to the Internet at home.
- Income – people aged 18-64 receiving a means tested benefit.

- Income – people living in equivalised[*] households with income below an income threshold.
- Qualifications – people aged 18-64 without any qualifications.
- Owned home – people not living in own home.
- Support people aged <65 living in a single parent family.
- Living space – people living in equivalised* households below a bedroom occupancy threshold.
- Transport – people with no access to a car (Atkinson, Salmond, & Crampton, 2014).

Although the NZDep is comprehensive, the IMD more closely captures the types of indicators related to vulnerability to extreme heat using administrative datasets to measure area-level deprivation, for example crime statistics are not captured in the NZDep but are in the IMD. High mortality rates in the Chicago heat wave were attributed to fear of crime and breakdown of community which prevented vulnerable residents from leaving their apartments and seeking help or cool sanctuary in public parks and community centres (Klinenberg, 2003; Klinenberg, 2018). Likewise, the IMD captures access to places such as medical centres, supermarkets, service stations, schools and other childcare facilities, all of which can present potential areas of refuge from extreme heat (Eisenman et al., 2016).

Other variables included in the IMD and identified in the literature as causing heightened heat vulnerability include: low income, rental tenure, overcrowding, respiratory related hospital admissions, infectious diseases, low-educational attainment and limited private vehicle access (Chuang, 2015; Eisenman et al., 2016; Hansen et al., 2008; Hansen, et al., 2013; Royal Society/Te Apārangi, 2017; Salmond & Crampton, 2012).

In total, the IMD combines 28 indicators of deprivation from national health, social development, taxation, education and police databases, geospatial data providers and the 2013 Census, all of which represented seven domains of deprivation: Employment; Income; Crime; Housing; Health; Education and Geographical Access (Exeter et al., 2017). The 28 indicators of deprivation are normalised as a range from 1-10, with 1 indicating the least deprived and 10 the most deprived areas. The spatial area used to present the data is a ‘datazone’ developed for the indices at a scale between a mesh block and CAU level.

Low education attainment in itself does not preclude an individual from understanding a risk. However, low educational attainment is linked to low income which can

[*] Equivalisation: methods used to control for household composition

impede a person's ability to prepare for, or recover from, a possible disaster (Chuang, 2015; Flanagan, et al., 2011; Reid et al., 2009; Wolf & McGregor, 2013).

Access to a private vehicle is also captured in the IMD. In terms of heat vulnerability limited access to private vehicles can increase isolation and reduce a person's capacity to seek refuge in a cool site or to access medical attention during a hot event (Eisenman et al., 2016). In a study in Arizona, access to community cool space within walking distance was found to have a positive correlation with reduced heat-related mortality, even when controlling for social vulnerability indicators (Eisenman et al., 2016). In the Auckland region, seven per cent of people reported having no access to a vehicle in the 2013 census (Statistics New Zealand., 2013). Not all those without vehicles will be isolated as having no vehicle can be a positive choice where all services or public transport is within easy reach. However, the combination of other socio-economic factors captured in the IMD means that those represented without vehicles in the IMD are also vulnerable due to other socio-economic, demographic or health factors.

2.3.4 Census data

The IMD alone does not comprehensibly capture all the indicator variables associated with vulnerability to extreme heat as there are other factors that impact significantly. The remaining indicators, derived directly from the 2013 census, are described below.

Data on one-person households is used as a proxy for social isolation, as demonstrated in the heat vulnerability indices established by Eisenman et al., (2016) and Wolf and McGregor (2013). Research undertaken on causal factors of high morbidity and mortality rates, found that social isolation had a considerable bearing on well-being during a heat event (Eisenman et al., 2016; Klinenberg, 2003; Reid et al., 2009). Exclusion from access to recourses needed to protect health in an extreme heat event is more prevalent for the socially isolated or those with low levels of social capital (Cheng & Berry, 2013; Cutter et al., 2003). For example, the socially iolated are less likely to seek refuge in a community cool space than the socially connected.

In New Zealand, rental tenure can be used as a proxy for housing thermal performance. Research undertaken by White (2017) and Witten et al., (2017) established that rentals are of significantly poorer thermal performance in New Zealand, with a greater incidence of no or limited insulation, single glazing as well as limited or poorly maintained ventilation systems. Rental tenure is captured in the IMD, but as this is a composite measure, census data specifically on rental tenure was also mapped, as a proxy for housing stock quality[6]. Even with the implementation of the Healthy Homes Guarantee Act 2017, glazing and window condition will not be addressed, except for windows being openable, and the inclusion of ventilation systems in the form of extractor fans with the intention of controlling moisture content of the air and mould prevention, rather than cooling. Therefore airtightness and winter warmth may be improved under the Healthy Homes Guarantee Act, but cooling which is a function of both insulation, reduction in solar gain and ventilation may not (Gupta & Greggs, 2012).

Both the young and elderly are identified in the literature as sensitive to the effects of extreme heat. Children under five (in particular infants), are vulnerable to extreme heat as they have less ability for thermoregulation leading to heat exhaustion. This is due to children having higher metabolic rates, a lower cardiac index[7] than adults, and a greater tendency for more behavioural impacts such as intense physical activity outside. They are also less able to recognise a need to moderate their behaviour by seeking shade and cool drinks, making them sensitive to heat exhaustion (Xu et al., 2014). Data on age distribution is available at the census area unit level from the 2013 census.

Elderly populations are amongst the most vulnerable to extreme heat due to both medical and social causal factors (Åström et al., 2011). Social isolation is more prevalent in elderly populations and the elderly have an increased vulnerability to hyperthermia, due to the prevalence of heat sensitive chronic health conditions, including cardiovascular disease, respiratory, renal and diabetes (Åström et al., 2011; Reid et al., 2009). The elderly are also less able to regulate their body temperature due to decreased blood circulation, inefficient sweat glands and increased use of high blood pressure medication that is associated with an inability to perspire (MedicineNet.com, 2003). Other risk factors in the elderly include greater prevalence of decreased motor function due to illness such as Parkinson's disease or declining mental functions, which can compromise an individual's ability to assess risk and modify behaviour by moving to cooler areas or drinking more fluids (Johnson et al., 2012).

The reliability of ethnicity as an indicator of heat-related mortality is less well understood (Eisenman et al., 2016; Hondula, 2015). Differences in ethnicity are more likely attributable to the different environments and socio-economic conditions affecting representatives of different ethnic communities. The large number of Pacific

[6] Rental figures are included twice, but as the weighting of rental within the IMD housing indicator is relatively low weight (9%), the spatial distribution of rental tenancies is unclear (Exeter et al., 2017). The use of the specific rental data in this research is as a proxy for housing condition and therefore does not present a significant double counting error.

[7] The cardiac index is an assessment of the cardiac output value based on the patient's size (nursingcenter.com)

people on low-incomes living in poorly adapted houses is a more likely risk factor for Pacific people, rather than their origin. English language proficiency, which affects a resident's ability to understand risks conveyed in English (for English speaking countries), was found to be a causal factor in understanding the risk of heat extremes (Hansen, et al, 2013). Auckland is an ethnically diverse city, and according to the 2013 census seven per cent of the community define themselves as unable to speak English[8]. Currently the Auckland Emergency Management Plan is made available in several languages other than English which may mitigate the risk for Aucklanders. However, the plan currently does not cover extreme heat as a hazard. Consequently, for this report, the non-English speaking community is assumed to have heightened vulnerability.

As noted in the literature, excess mortality and morbidity during heat events is closely associated with underlying health conditions, particularly type 2 diabetes, chronic renal disease, cardiovascular disease, respiratory disease and mental health conditions (Chuang, 2015; Eisenman et al., 2016; Fouillet et al., 2006; Gronlund et al., 2018; Hondula, 2015; Knowlton et al., 2009; Nitschke et al., 2011; Reid et al., 2009). As health data in New Zealand is carefully controlled to protect patient confidentality, proxies for health data distrbution are required. In New Zealand, Māori and Pacific populations are over-represented in health statistics for all of the heat susceptible conditions (Page, et al., 2012, Wang, et al., 2014; Ministry of Health/ Manatū Hauora, 2015, 2016, 2017; Royal Society, 2017). Using proxies in the absence of fine grain data is an established method for estimating population risk (Managan et al., 2014) and therefore Māori and Pacific population distribution can be used to coarsely demonstrate the spatial distribution of patients with underlying heat sensitive conditions.

A low household income relative to household outgoings (rent burden) can limit the occupant's adaptive capacity to hazards. Rent burden is defined as requiring no more than 30 per cent of gross household income for rent or to buy a property in Auckland in the lower quartile of house prices. This is an internationally accepted level of affordability often referred to as the burden of rent (MBIE, 2018). Even those with relatively high incomes can be in a rent burden scenario as demonstrated currently in Auckland in the so-called 'intermediate housing market'[9] (Mitchell, 2015), which includes an estimated 85,000 households unable to affordably service a mortgage. Housing rental burden is more useful than modelling household income

---

[8] Total people stated in the Auckland region 1,316,262, minus English speakers 1,233,633 equals 82,629 non English speakers or 6 % of Auckland population (Statistics New Zealand., 2013)

[9] Intermediate market definition "private renter households with at least one person in paid employment, unable to affordably purchase a house at the lower quartile house sale price for the local authority area at standard bank lending conditions"(Mitchell, 2015)

alone, as income is relative to outgoings. Rent burden is available at the census area unit level from the household economic survey based on the 2013 census.

In summary, there are several socio-demographic factors that create greater vulnerability to extreme heat events, but not being represented by the aforementioned characteristics does not remove risk associated with heat waves completely. Findings from the 2003 European heatwave indicated elevated numbers of excess mortality in all sectors of the community and in all regions exposed to the heatwave (Fouillet et al., 2006).

2.3.5 Social infrastructure and vulnerability to heat events

Social infrastructure plays a critical role in community resilience to hazard, Eric. Klinenberg (2018) suggests that social infrastructure is invisible, and crucially only becomes visible when it breaks down. During a hazard event, and when traditional hard infrastructure such as roads, utilities and health systems are overloaded and fail, it is the softer socially established infrastructure that promotes actions such as neighbours checking on neighbours, community groups offering shelter and provisions, and connection of alienated individuals that determines people's fate.

It is however much more difficult to measure the extent of social infrastructure in an area and consequently it is generally not included in the development of vulnerability indices. Social infrastructure such as parks, libraries, community cafes and childcare centres have a critical role in the vulnerability of communities during a heat event. Klinenberg (2003) found that during the Chicago heat wave in 1995 which claimed 800 lives (Hayhoe, et al., 2010), communities with identical socio-economic conditions but poor social infrastructure had significantly higher mortality rates, demonstrating that being economically or physically disadvantaged does not alone dictate your fate during a heat wave.

Community cohesion leads to better outcomes for the vulnerable during extreme events as it raises awareness of where more vulnerable individuals are located and supports activities which encourage neighbourliness, thus reducing social isolation. Community cohesion is enabled by the presence of places to foster connectivity, such as parks, schools, libraries, church groups and play centres. Where this enabling infrastructure is accessible and inviting there is reduced likelihood of social isolation (Klinenberg, 2018).

The inherent resilience of some communities due to their social infrastructure is recognised in the New Zealand National Disaster Resilience Strategy (2019). The Strategy recognises the inherent resilience provided by manaakitanga, demonstrated through Māori moral and relational attributes, including the promotion of a collaborative response to disaster response and recovery, commitment to environmental restoration, and the extension of hospitality to others experiencing adversity. The report notes that Māori also have assets and places which have often and will again be mobilised to secure community well-being in the aftermath of disasters. Auckland has a large Māori population, both mana whenua and matawaka so it can be assumed that the social and cultural infrastructure embedded for this population will mitigate some risk to heat vulnerability.

Auckland has a good provision of social infrastructure with parks, schools, community cafes, places of worship, marae, community gardens, libraries and play centres distributed throughout the city. Arguably some areas with high social deprivation have the most advanced social infrastructure due to their active and inclusive community groups. At present however, there is no specific compiled inventory of the social infrastructure and its distribution available in Auckland. It is therefore impossible to include social infrastructure in the HVI, despite acknowledgement that some of the areas identified as at risk due to the underlying socio-demographic characteristics may have significant adaptive capacity due to their established social infrastructure.

2.3.6 Environmental indicators of vulnerability to heat events

In dense urbanised areas, the lack of greenspace contributes to the urban heat island effect (UHI) (Oliveria, 2011). The UHI is recognised as a climatic phenomenon whereby the urban fabric, dominated by heat retaining construction materials and limited greenspace modifies the urban temperature (Lee et al., 2017). Urban centres can experience temperatures up to four or five degrees higher than surrounding non-urban areas due to the UHI (Oke, 1973). Greenspace as small as 0.24ha can reduce temperatures in densely urbanised areas by up to 6.9 °C compared to an urbanised space without green cover (Oliveria, 2011). As such, greenspace can contribute to a decrease in heat-related deaths and illness (Reid et al., 2009). Both open greenspace and urban tree canopy play a role in reducing heat (Hiemstra, Saaroni, & Amorim. (2017). Open greenspace effects change through evapotranspiration which cools the surrounding air. Urban tree canopy also impacts evapotranspiration rates and has the added function of providing shading from the sun (Bowler, et al., 2010).

Research undertaken in Toronto, Canada, identified that heat-related morbidity is reduced by 80 per cent as tree canopy cover increases beyond five per cent and that heat-related morbidity is reduced by 75 per cent as hard surface cover decreases below 75 per cent (Graham, 2016:2). Consequently, greenspace can more than mitigate the intensity of impacts of extreme heat events.

At an economic level, increasing tree canopy cover is one of the most cost-efficient ways of reducing the effects of hot days on internal buildings (McPherson, et al., 2011). For lower socio-economic groups, adaptive strategies at the neighbourhood scale reduce the cost burden of heat mitigation on individual households. Unfortunately, areas with a lower-socio economic level often have less greenspace and tree cover. Krafft and Fryd (2016) cited a Melbourne case study reporting tree cover was less available in neighbourhoods where people predominantly rented their homes and in areas of socio-economic disadvantage (Krafft & Fryd, 2016). In Auckland, green infrastructure also varies in its distribution, with low income areas having the poorer quality green infrastructure (Ma, 2016). As Auckland is growing and densifying, more pressure is put on not only open greenspace such as parks and vacant lots but also on private land as gardens are subdivided to make way for additional housing.

The urban tree canopy in the Waitematā Local Board area of Auckland is also declining. In a recent analysis undertaken at Auckland Council, more affluent suburbs were found to have been subject to piecemeal removal of individual or small groups of trees totalling the loss of 61.23ha of tree canopy over 10 years (Lawrence, Ludbrook and Bishop, 2018). Although it is acknowledged that across Auckland, measures to protect and enhance the tree canopy are being actively pursued (Auckland Council., 2018).

2.3.7 Occupational health and vulnerability to extreme heat events

Occupational health and productivity is compromised by extreme heat events (Eisenman et al., 2016:94; Royal Society/Te Apārangi, 2017). As Auckland's climate changes, sectors of the work force in outside manual labour will be exposed to increasing occupational health risks, including risks from increased ambient temperature, air pollution and ultraviolet exposure (Schulte & Chun, 2009).

The Health and Safety in Employment Act 1992 (HSE Act) requires that employers and others manage their safety and health hazards. The advice currently provided by Worksafe on working in extreme heat focuses on exposure to heat from high radiant heat (from dryers and ovens), high humidity (i.e. in kitchens and laundry's), through high metabolic load and from wearing protective clothing that prevents heat loss. The Worksafe guidelines written in 1997 for working in extremes of temperature currently state 'there is little risk of heat causing harm when heat is directly caused by the weather only' (Worksafe, 2017). This advice is unlikely to remain relevant in a changing climate. Workers in construction, agriculture, fisheries and forestry are those most likely to be affected by occupational health risks caused by extra hot days in Auckland. Construction is the largest growing sector of employment in New

Zealand with two-thirds of the growth in Auckland and Wellington (Statistics New Zealand, 2017).

3.0 Methods

The Auckland heat vulnerability index is a spatial model derived from methods used to develop HVIs around the world. Currently there are no published HVI methods available in New Zealand. Wolf and McGregor (2013) who developed a heat vulnerability index for London note that vulnerability is viewed as a latent, as opposed to a directly measurable variable represented by the synergistic effects of several variables. As noted in the literature review, threshold levels for heat vulnerability vary, with threshold levels in the tropics being markedly higher than for more temperate climates. Despite variation in threshold levels, the impact of extreme heat on the population is common across the case studies. Recommended variables have therefore been drawn from the evaluations of case studies of real extreme heat events. Adapting them to the local context goes some way to addressing this research gap in New Zealand.

This report illustrates the first attempt to develop a HVI using the best available data at the time. Data gaps are noted within the limitations section. As new data is generated, i.e. census 2018 data, new vegetation cover data and more in-depth social infrastructure analysis, the HVI will be refined and improved and could potentially yield new data on the location of vulnerable sectors of the population.

This tool is intended to illustrate the heterogeneity of impacts of the anticipated rise in hot days and stimulate discussion on potential adaptation strategies. The use of data at a fine grain scale enables the inherent level of risk associated with a particular place to be more fully expressed. Using more aggregate scales of analysis often masks the geographies of vulnerability that operate at finer spatial resolutions (Lindley, et al., 2006). As such, the census area unit (CAU) is the spatial scale at which all indicator variables were collected (or converted to). The CAU data is of a fine enough scale to demonstrate detailed spatial patterns, whilst not excluding sensitive data, as is the case with some variables at mesh block level.

Proxies are commonly used in the development of vulnerability indices (Rygel, O'sullivan, & Yarnal, 2006; Wolf & McGregor, 2013). For this research data on health and building quality data was unavailable at the CAU level so proxies were adopted. The HVI maps are overlaid on the hot day projections for 2040, 2090 and 2110, as well as over the green infrastructure map to illustrate where the community is potentially more sensitive to the predicted increase in hot days under RCP 8.5.

In addition to the HVI development, additional maps on occupational health were generated using GIS to develop a picture of the spatial distribution of the potentially vulnerable occupational groups.

3.1 Indicator variables

Auckland's Heat Vulnerability Index is a composite of 10 socio-economic, health and environmental variables that pertain to individual and community vulnerability to heat exposure.

Table 1: Ten variables comprising the heat vulnerability index

Variable	Data source	Variable definition	Proxy if applicable	Mean (range)	St.d
New Zealand Index of Multiple Deprivation (IMD)	University of Auckland data base (Exeter et al., 2013)	Ranked value reflecting 28 indicators of deprivation	Measure of social and material deprivation	Rank 1-10	n/a
One person household	2013 Census	Per cent of population in 1-person households	Social isolation	18% (0-47)	7.0
Rental tenure	2013 Census	Per cent of population in property not owned, or held in a family trust with rent paid	Housing with poor thermal performance	30.0% (0-80.0)	14
Over 65 years	2013 Census	Per cent of population over 65 years	Heightened heat sensitivity	11.9% (1.8-50.0)	6.0
Under 5 years	2013 Census	Per cent of population under 5 years	Heightened heat sensitivity	7.2% (1.5-22.2)	2.4
No English language	2013 Census	Per cent of population not able to speak English (not including those too young to speak)	Limited capacity to prepare and react to hazard	5.8% (0.0-21.3)	3.4
Burden rent (IMP)	Household Economic Survey (HES)	Ratio between average rent and average household income per CAU. (Burden rent = 30% or more income paid in rent)	Limited adaptive capacity	0.315 (0.00-0.569)[10]	0.114
Māori ethnicity	2013 Census	Per cent of population identifying as of Māori ethnicity[11]	Diabetes, renal, respiratory cardiovascular disease, and mental health conditions	10.3% (2.0-40.6)	6.8
Pacific ethnicity	2013 Census	Per cent of population identifying as of Pacific ethnicity	Diabetes, renal, respiratory cardiovascular disease, and mental health conditions	13.0% (0-0-79.2)	17
Non-greenspace	New Zealand Land Cover Database (LCDB)	Land cover classification	Shelter and urban cooling capacity	65.3% (0.1-100.0)	32.4

[10] The mean of the rent burden in each area unit could not be calculated due to a lack of data. Instead the total annual rent was divided over annual income to give the rent burden across each area unit overall.

[11] Respondents could choose to identify with multiple ethnicities in the 2013 Census

The 10 variables include the multifactorial indicator, New Zealand Indices of Multiple Deprivation (IMD), (Exeter et al., 2013, 2017). The IMD uses 'datazones', which bridge the scale of a meshblock and a census area unit. To align with the CAUs that this study uses, the IMD ranks assigned to each datazone were combined and averaged by weighted population to give the IMD rank by CAU.

The 2013 census-based variables included one-person households; rental tenure; residents over 65; children under 5; English language skills; household rent burden; and Māori and Pacific populations (Statistics New Zealand, 2013). Greenspace from the New Zealand Land Cover Database (LCDB) was also used (Ministry for the Environment, 2018).

Health data were unavailable at the CAU levels. As Māori and Pacific populations are disproportionately represented in statistics associated with all heat vulnerable diseases, including: diabetes, respiratory, renal, cardiovascular disease and mental health conditions (Ministry of Health/ Manatū Hauora, 2015, 2016, 2017; Page, et al., 2012; Wang, et al., 2014; Royal Society, 2017), the proportion of Māori and Pacific populations were used as proxies to identify populations prone to heat-related health risks. Proxies are commonly used in the development of vulnerability indices (Managan et al., 2014; Rygel et al., 2006; Wolf & McGregor, 2013).

The thermal performance of a building is dictated by the material components of the building, additional insulation and glazing cover. Insulation both traps heat during the winter and out during summer. However, if a building has large expanses of single glazed windows, without suitable ventilation, solar gain in summer can result in overheating of a property. Data on building composition and thermal performance is not available at the census area unit scale in New Zealand; however it is known that the private rental stock is of significantly poorer condition than the privately-owned stock (White, et al., 2017). As such, to identify properties of proportionately poorer thermal performance, data on the extent of private rental stock in Auckland is used as a proxy for housing thermal performance.

In addition to mapped socio-economic factors, the percentage of green cover was calculated and mapped across Auckland using the method described by Reid et al., (2009). The most recent Auckland land cover data from 2012 sourced from the New Zealand Land Cover Database (LCDB) (Ministry for the Environment., 2018) was clipped to the census area units (CAUs) to calculate the percentage of greenspace and vegetative land cover, as well as the proportion of each CAU consisting of water or non-vegetative types. For this purpose, LCDB classifications were grouped as follows:

- *Greenspace and vegetation:* broadleaved indigenous hardwoods; deciduous hardwoods; exotic forest; fernland; flaxland; forest – harvested; gorse and/or broom; herbaceous freshwater vegetation; herbaceous saline vegetation; high producing exotic grassland; indigenous forest; low producing grassland; mangrove; manuka and/or kanuka; matagouri or grey scrub; mixed exotic shrubland orchard; vineyard or other perennial crop; short-rotation cropland; urban parkland/open space.
- *Non-greenspace:* Built-up area (settlement); gravel or rock; landslide; sand or gravel; mine or dump; transport infrastructure.
- *Water:* lake or pond; river.

Land not classified as being within a census area unit were excluded from the calculations. The classification of green cover in the LCDB, does not distinguish between the quality and density of the coverage. Where tree canopies are more extensive they provide shelter and shade, however to be useful for this purpose they must also be accessible to the community. Likewise, where green cover is poorly maintained it can act as a deterrent to use (Klinenberg, 2018). Urban cooling through transpiration is also affected by the density and type of green coverage, as this is indeterminable using the LCDB, all green cover is assumed to provide equal cooling through evapotranspiration rates.

3.2 HVI compilation

Data from all 10 of the variables were converted to align with census area units and were inserted into Arc GIS layers on top of a regional base map of Auckland. The data were normalised into 10 ranks using the Jenks natural break function in ARC GIS[12]. The assigned ranks were 1-10 to align with the New Zealand Indices of Multiple Deprivation (IMD)(Exeter et al., 2013). Each census area unit was therefore ranked and summed with the IMD to produce an overall heat vulnerability index, with 0 reflecting low vulnerability and 100 reflecting high vulnerability across all variables.

Normalising the indicator variables into ranks enabled the opportunity to highlight areas with increased concentrations of risk indicators. The use of ranks is common in the development of heat vulnerability maps (Johnson et al., 2012; Reid et al., 2009). The IMD includes a weighted difference between the deprivation drivers. Further weighting of the impact of each of the variables on heat-related morbidity/ mortality

12 Natural breaks (Jenks) classes are based on natural groupings inherent in the data. Class breaks are identified that best group similar values and that maximize the differences between classes. The features are divided into classes whose boundaries are set where there are relatively big differences in the data values (see Univariate classification schemes in Geospatial Analysis—A Comprehensive Guide, 3rd edition; 2006-2009; de Smith, Goodchild, Longley).

using factor analysis could not be applied, as data on the relative impact of each variable were not available.

Spatial data for the 10 heat vulnerability ranked variables were summed and mapped in Arc GIS (version 10.2). This enabled spatial patterns of vulnerable communities to be identified, which could then be overlain on the NIWA projections for increasing hot days under the 8.5 scenario for the years 2040, 2090 and 2110 (Pearson et al., 2018).

3.3 Occupational health

In addition to the HVI, occupational health risks were also mapped. Occupational health risk is not combined into the HVI as the demographic data at CAU level would not be an accurate reflection of the workers exposure to risk, as the place a worker resides does not necessarily align with the same census area unit in which they work. Therefore, data was collected on the numbers of employees engaged in occupations at high risk of heat impact and the locations of these employment sectors.

To protect confidentiality, ANZSCO V1.2 (6-digit level) data which specifies jobs, are not available at the CAU level. Therefore, the broader group of Labourers was used to indicate patterns of occupation-related heat vulnerability, which is in most cases available at CAU level. It is accepted that labourers is a broad term and may capture some industries that work in temperature-controlled environments.

Infometrics (2018) reported employment by detailed (2-digit) occupation in Auckland and New Zealand (2017), and by local board in the two most at risk occupation categories, Farm, Forestry and Garden Workers and Construction and Mining Labourers.

Table 2: Regional statistics for vulnerable occupation

Occupation employment	**Number in employment in Auckland**	**Percentage of total employment in Auckland**
Farm, Forestry and Garden Workers	7,396	0.9%
Construction and Mining Labourers	8,235	1.0%

The Australian New Zealand Standard Classification of Occupations defines eight main groups. One of the groups 'Labourers' include, ANZSCO V1.2 (6 digit level) occupations of construction and mining labourers, farm, forestry and garden workers. These are the occupations most closely aligned to heightened occupational heat exposure risk (Schulte & Chun, 2009).

The locations for the at-risk occupations are mapped to give an additional insight into where employees may be vulnerable to hot days around the Auckland region in the period up to 2110.

Relative to population size, Māori and Pacific workers occupy the largest proportion of designated at-risk occupations. Māori and Pacific employee data (ANZSCO major group) from the 2013 census were plotted spatially for the resident population count aged 15 years and over. Notably this data includes some double counting as participants can affiliate to more than one ethnicity under the census.

4.0 Results

4.1 Presentation of the heat vulnerability index

The heat vulnerability index illustrates the relative risks of the population in each of the 408 census area units in the Auckland region (Figure 1a). It is noted that each of the CAUs may have mitigating factors not captured in the HVI, for example social infrastructure. Table 2 presents the CAUs with a HVI total score of 75 and above based on the factors assessed for this research as informed by the literature. The contributing factors vary between the CAUs, demonstrating that vulnerability is latent, as opposed to a directly measurable variable represented by the synergistic effects of several variables.

The areas with above average vulnerability to extreme heat events are located throughout the central urban corridor, rural settlements in the north and south, and Waiheke Island (Figure 1b).

Table 3 Indicators with the largest contribution to the heat vulnerability of the most sensitive populations

CAU	HVI rank total	Factors with greatest contribution to the most at risk populations (rank #9 or#10)
Fairburn	80	96% of CAU non-greenspace, a large Pacific population, large number in rental tenure with a high rental burden, IMD rank 10
Manurewa Central	78	98% of CAU non-greenspace, large number in rental tenure, Māori and non-English speakers, IMD rank 9
Manurewa East	77	High rent to income ratio burden, large number in rental tenure, large Māori population, IMD rank 10
Ranui Domain	77	High rent to income ratio burden, IMD rank 10
Point England	76	Large number in rental tenure, large proportion with no English language, IMD rank 10
Tāmaki	76	High rent to income ratio burden, IMD rank10, large Pacific population
Ōtāhuhu North	76	Large number in rental tenure, IMD rank 10, large proportion with no English language, 95% of CAU non-greenspace
Beaumont	76	IMD rank 10, large number in rental tenure, 93% of CAU non-greenspace, large Māori population,
Burbank	75	Large number in rental tenure with a high rental burden, IMD rank 10, large Māori and pacific populations, 100% of CAU non-greenspace
Ōtāhuhu West	75	Large number in rental tenure. IMD rank 10, 88% of CAU non-greenspace, large proportion with no English language
Wymondley	75	Large number in rental tenure with a high rental burden, IMD rank 10, large Pacific population

CAU	HVI rank total	Factors with greatest contribution to the most at risk populations (rank #9 or#10)
Ōtara South	75	Large Pacific population, large number in rental tenure, IMD rank 10, 91% of CAU non-greenspace
Homai West	75	Large Māori population, large number in rental tenure IMD rank 10
Ulrich	75	Large Māori population, high rental burden, IMD rank 10, 95% non-greenspace

The heat vulnerability index generated in this report plots the social, economic and environmental risk factors that could cause vulnerability to extreme heat spatially (Figure 1a). This approach highlights census area units with the greatest risk to the projected increase in hot days 1b), and the distribution of the most vulnerable communities with a HVI of 75+ (Figure 1c). The highest rated CAU on the HVI index was 80. A full list of the HVI data for all CAUs is available in the Appendix.

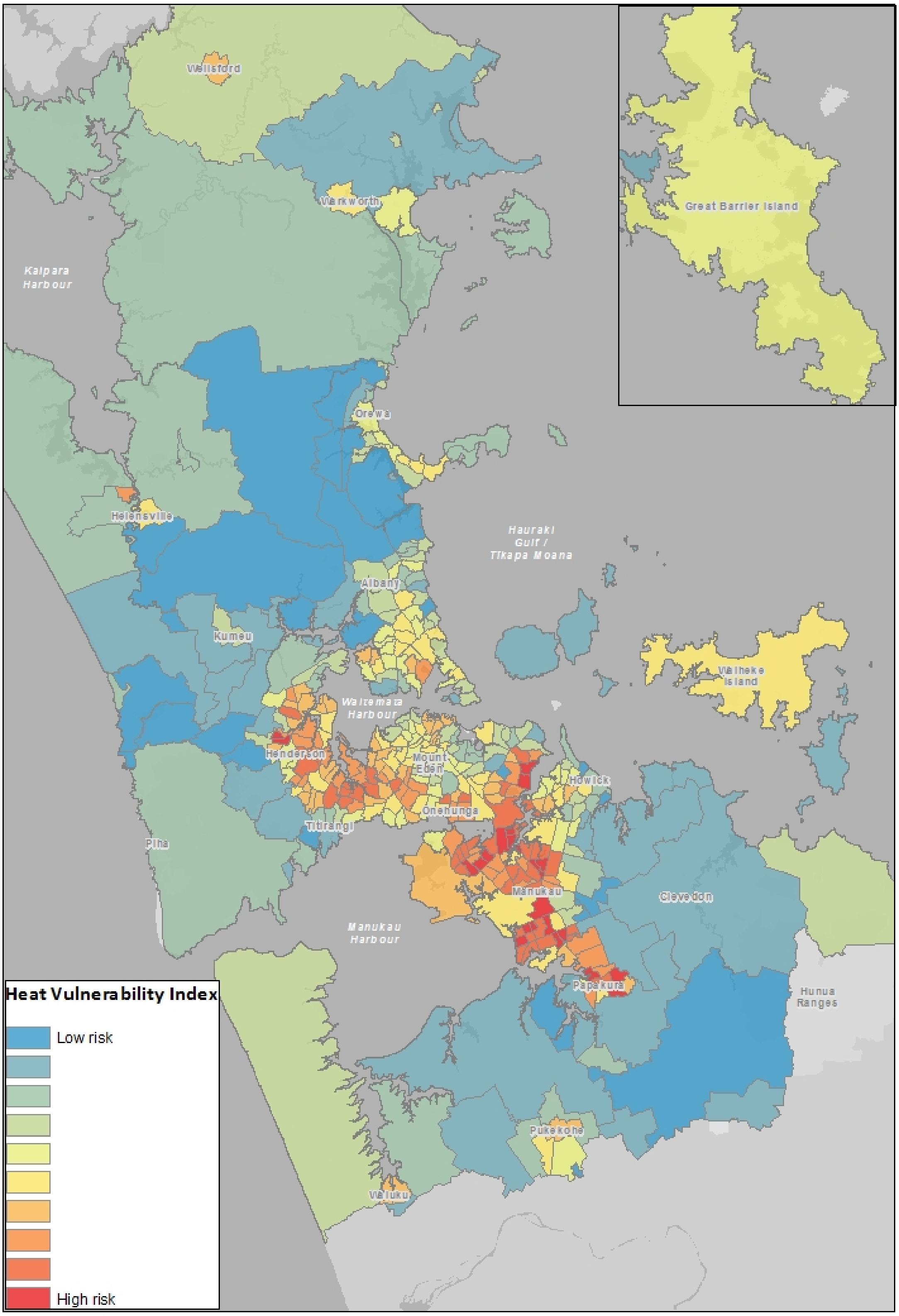


Figure 1a: HVI for Auckland of all ranked scores.

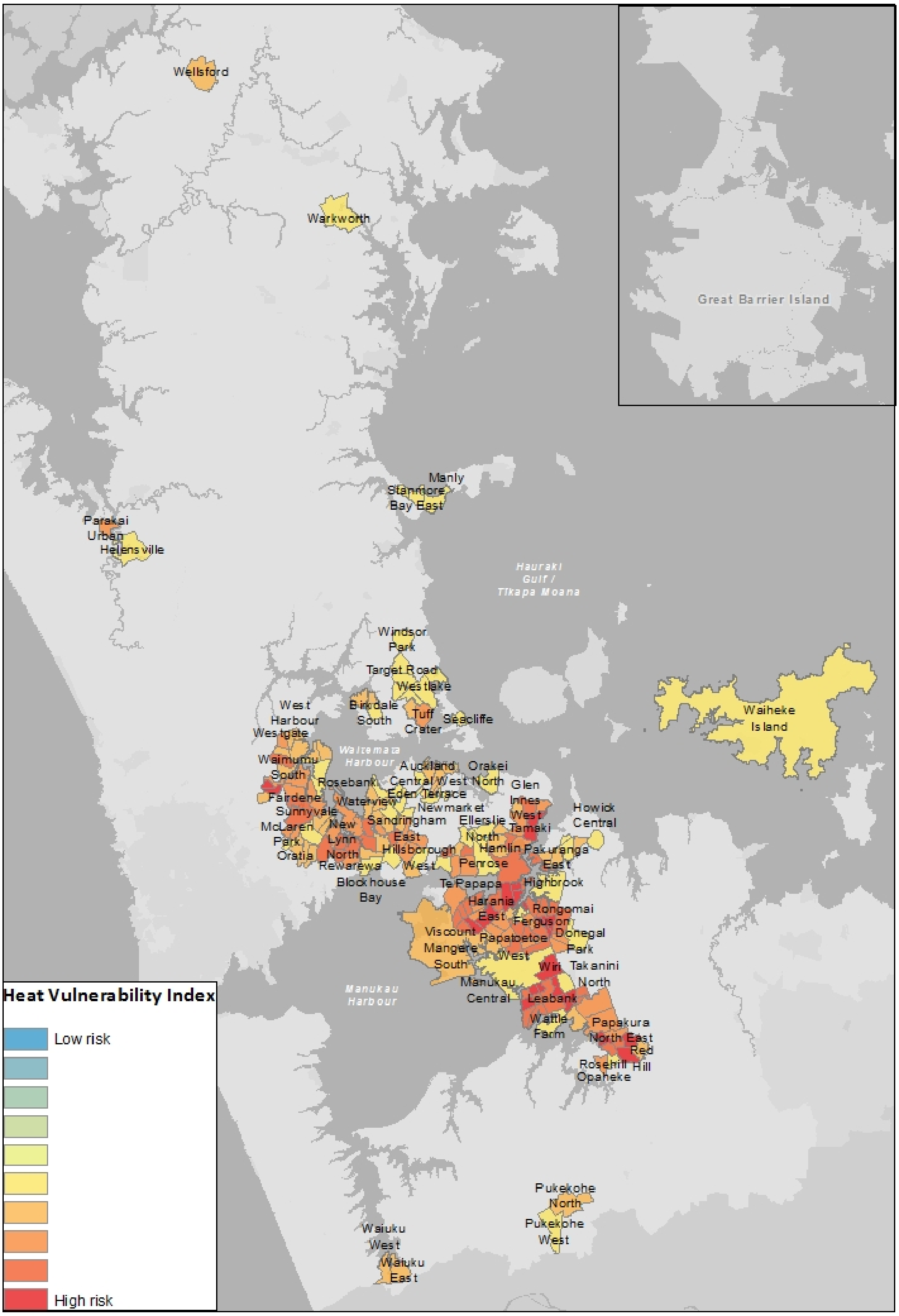


Figure 1b: HVI scores above the mean (52)

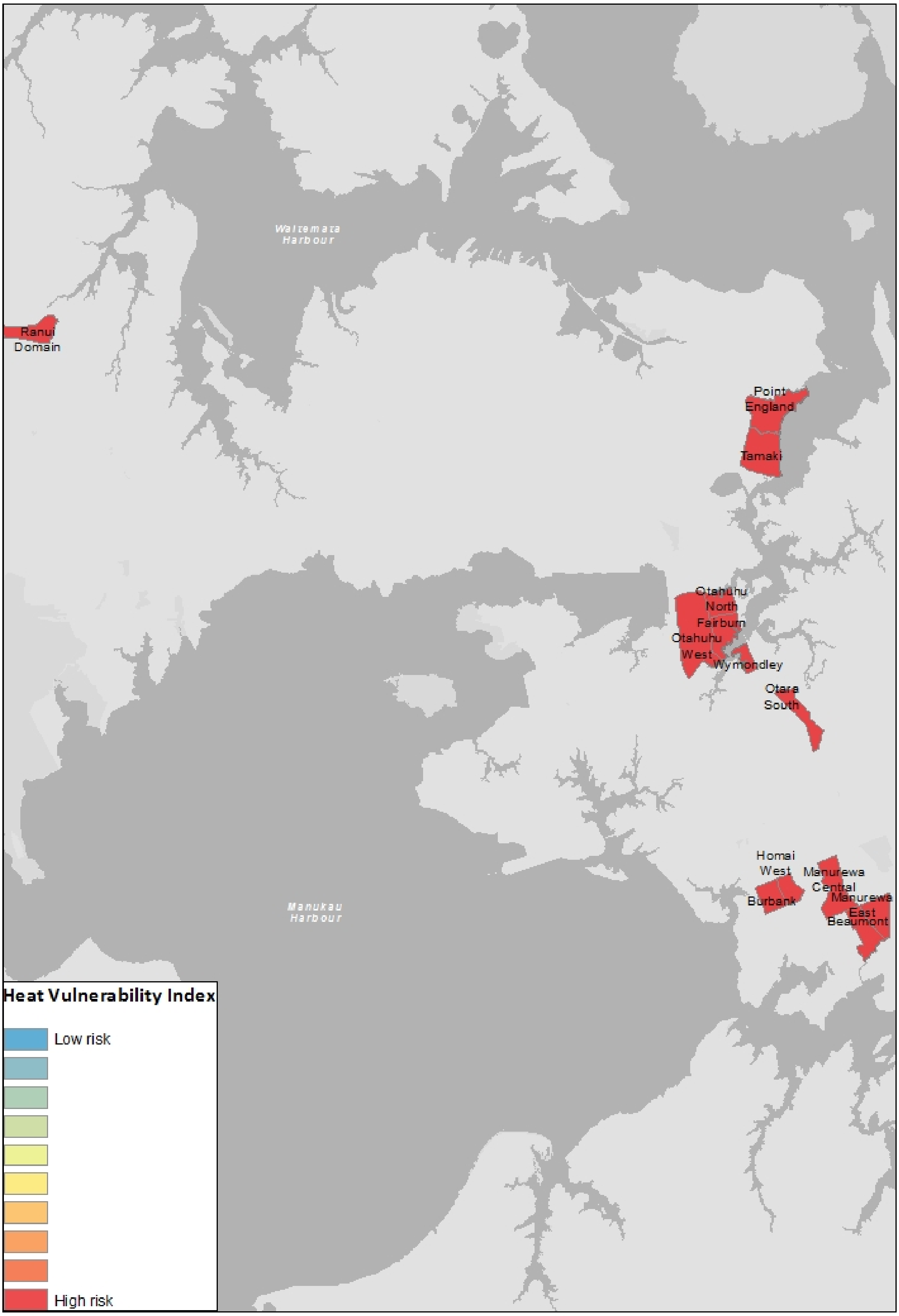


Figure 1C. CAUs with HVI ranking exceeding 75 points

4.2 HVI and projected climate change changes

The majority of at risk areas are located in the Southern Initiative area (TSI) of Auckland, which covers the local board areas of Māngere-Ōtāhuhu, Ōtara-Papatoetoe, Manurewa and Papakura. These areas not only have high social, economic and health-based risks, but also some of the highest projections in increased hot days, e.g. over 90 extra hot days by 2110 (Figure 4). To the east, Glen Innes West, Point England and Tāmaki within the local board area of Maungakiekie-Tāmaki have high vulnerability to heat and a slightly lower projection of number of hot days than the TSI. To the west, New Lynn north and south and Glenavon in Whau, Ulrich, Ranui Domain, Henderson north and south in Henderson-Massey Local Board area, show high heat vulnerability with slightly lower projections of increased hot days in 2090 and the same as the areas to the east by 2110 (Figure 4).

Population groups with the highest morbidity during extreme heat events are the elderly and the socially isolated (Eisenman et al., 2016). The following CAUs are identified as having the most at-risk socially isolated elderly: Papakura north, Great Barrier Island, Waiwera and Kawau.

The areas highlighted as most vulnerable using the heat vulnerability indicators are also areas expected to see some of the extreme increases in heat events for the periods 2040, 2090, 2110 (Figure 2 -4).

The increasing number of hot days will occur on top of an overall rise in annual average temperatures, 2.5-3.0°C by 2110 under RCP 8.5 (Pearce et al., 2018). In the shorter term the period 2040 is the central year of the period 2031-2050 interval, which means the impacts of the increased incidence of hot days will take effect within 11 years in Auckland. Within 11 years, the relative vulnerability of the highlighted census area units is unlikely to change significantly, meaning increased morbidity and mortality caused by extreme heat events will be felt within the policy timeframe of the Auckland Plan and Auckland Climate Action Plan.

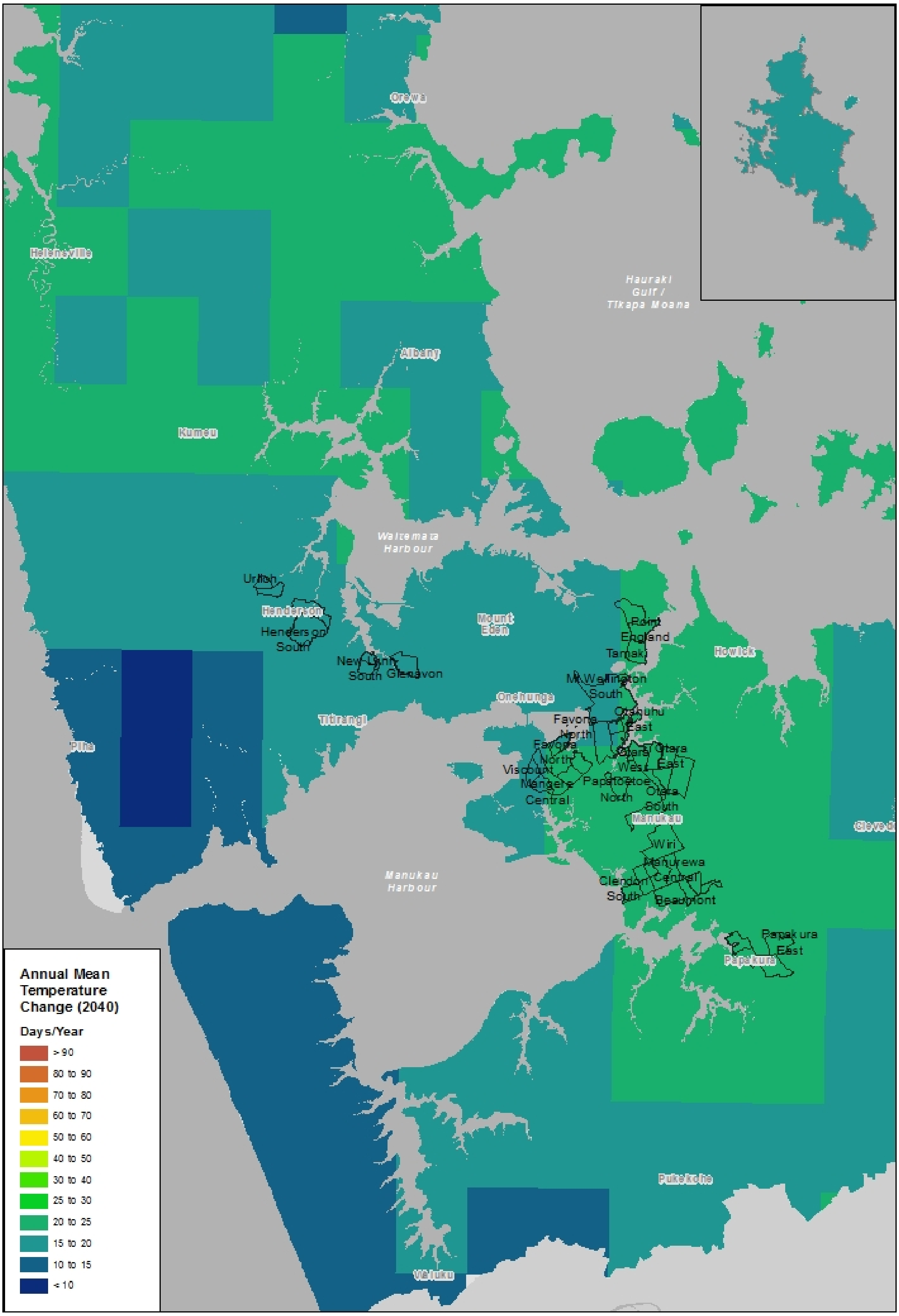


Figure 2: Most vulnerable communities to increased hot days per year (2040) calculated with the HVI (adapted from Pearce et al., 2018).

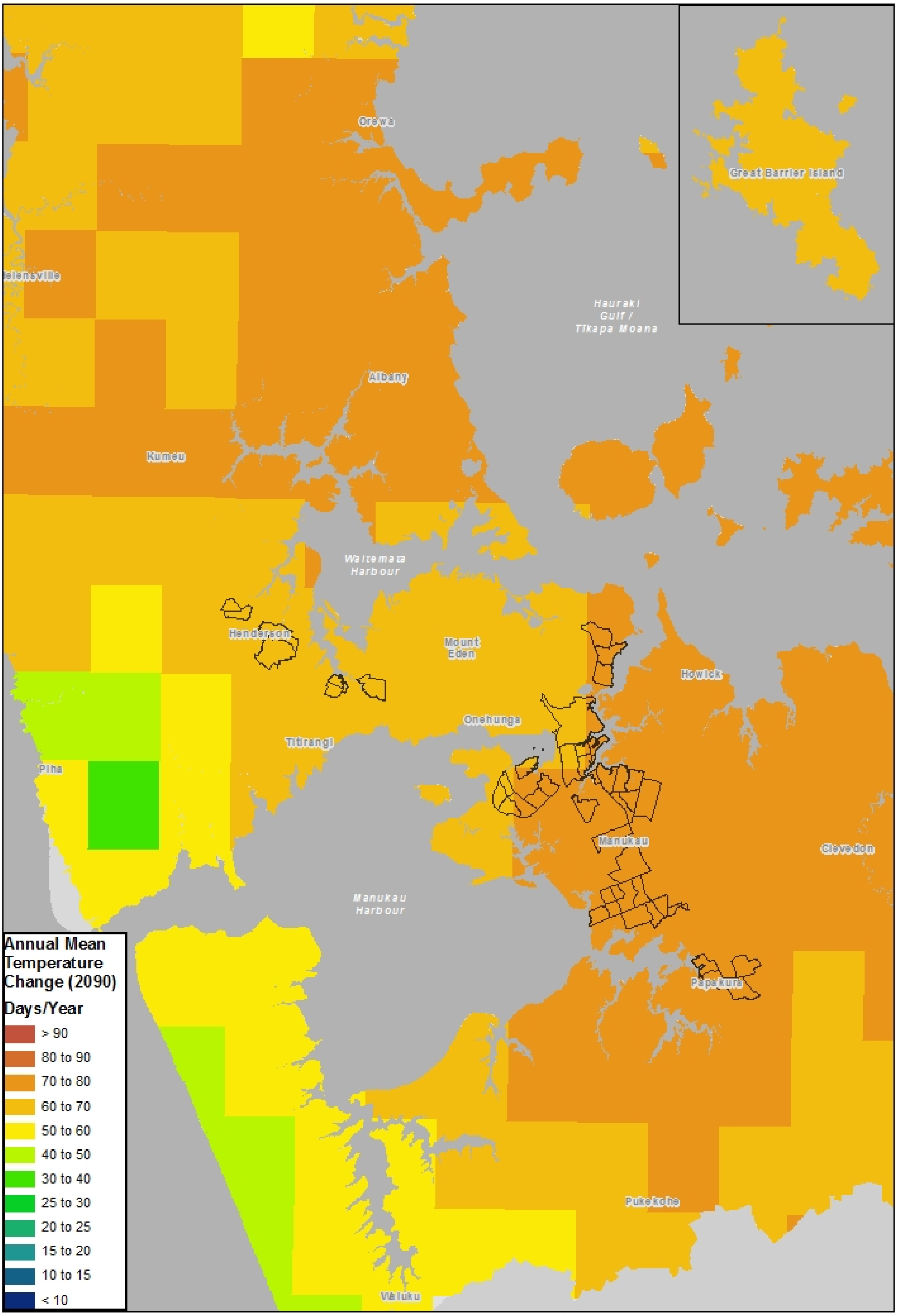


Figure 3: Most vulnerable communities to increased hot days per year (2090) calculated with the HVI (adapted from Pearce et al., 2018).

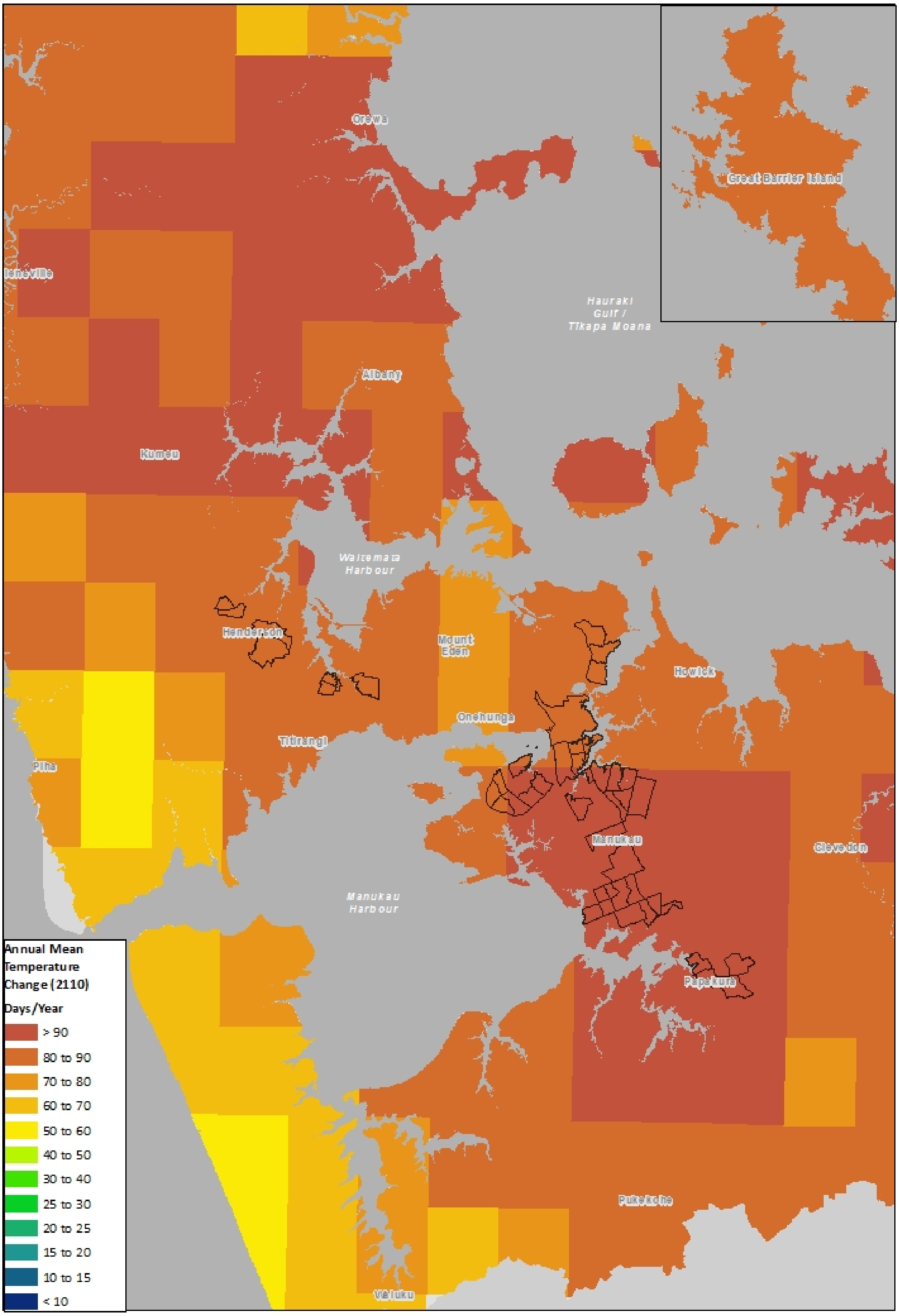


Figure 4: Most vulnerable communities to increased hot days per year (2110) calculated with the HVI (adapted from Pearce et al., 2018).

4.3 Heat vulnerability and land cover

Urban greening is recognised as a measure to mitigate human health impacts of increased temperatures resulting from climate change (Bowler et al., 2010). Unlike internal household scale adaptations to heat, such as air conditioning and improved thermal performance, green infrastructure is passive (neutral in terms of environmental emission of greenhouse gases). Green infrastructure also has the ability to cool at a community/ neighbourhood level rather than at an individual level, therefore benefitting a larger proportion of society. Implementing household adaptations is particularly challenging for low-income households and those in private rental properties. Research undertaken in the UK (Williams et al., 2013) on adapting suburbs to climate change found that respondents were unlikely to undertake preventative adaptations for climate change in low income areas. Recent research undertaken in New Zealand demonstrated the challenge of requesting adaptations in private rentals (Joynt, 2017; Witten et al., 2017). As 38 per cent of all Aucklanders and 58 per cent of low-income households in Auckland rent (Joynt, 2017), the lack of capacity to adapt their properties further demonstrates the importance of community scale adaptations to combat extreme heat. Therefore, green infrastructure within a low-income area has significant potential to reduce the risk to the local population.

Many of the areas identified as high risk in the HVI had proportionally less greenspace (Figure 5). The CAUs with the highest HVI ranks (73-80) are outlined in red, and the slightly lower HVI ranks in orange (68-72). There is therefore a correlation between areas with low green infrastructure and high deprivation indicators in Auckland. There are some exceptions, for example rural areas such as Parakai, and areas with large single-use industries, such as Māngere South, which contains the greenspace associated with the airport.

The land cover data used in this indicator were produced in 2012, and there have been notable changes in land use since that period. However, the synergy with the 2013 census data will allow for a relative comparison following release of the 2017 LIDAR data on greenspace and 2018 census data. It is noted that projecting green infrastructure forward to the period 2040-2110 is problematic. The future urbanisation projected under the Auckland Unitary Plan (Auckland Council, 2017) may reduce areas of green cover; however this may be mitigated by opportunities to expand green cover, with strategies such as the One Million Trees programme. The development of the HVI presents the best available data to date. However, it is recommended that as new data emerges on green infrastructure that the HVI is updated.

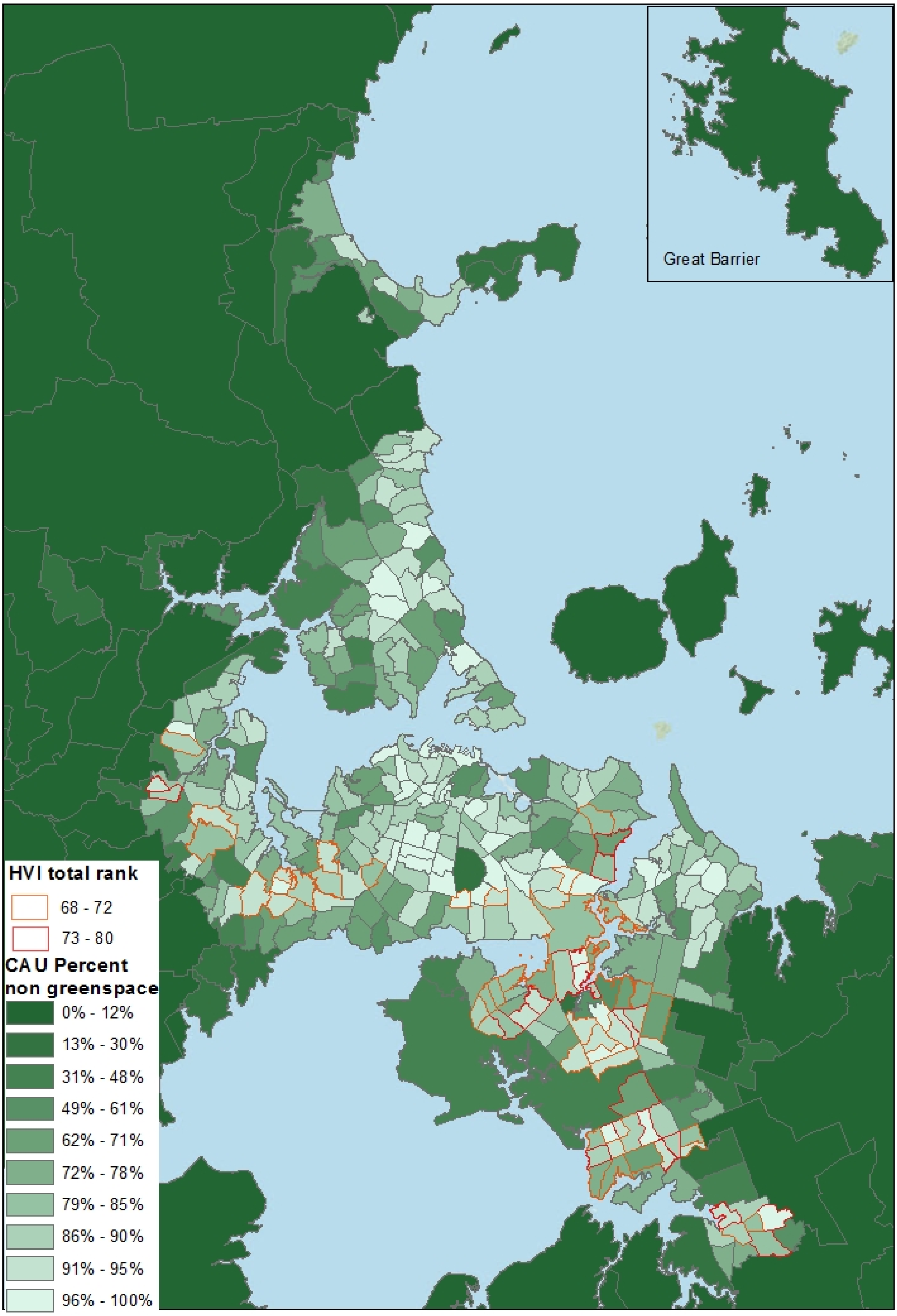


Figure 5: Intersection of HVI and proportion of greenspace.

4.4 Heat vulnerability and health

Due to the lack of health data at the CAU level, health indicators are captured in the HVI through the inclusion of proxies associated with either heightened sensitivity to extreme heat or to greater prevalence of chronic health conditions in certain populations. Proxies for sensitivity to heat are captured with the inclusions of the under 5s, and over 65s as variables in the HVI. Whereas heat-related chronic disease prevalence in the community is captured using census data on distribution of Māori and Pacific populations, these two population groups are over represented in statistics for diabetes, renal disease, cardiovascular disease, respiratory disease, and mental health conditions. Counties Manukau District Health Board areas (DHB) contain some of the most deprived areas in Auckland (Counties Manukau District Health Board, 2015). Table 4 demonstrates that Counties Manukau DHB also contains large numbers of patient groups with heat sensitive health conditions illustrating the spatial aspect of heat vulnerable disease distribution, with concentrations in areas with high socio-economic deprivation (Table 4).

Table 4 Proportion and numbers of patients with heat vulnerable chronic health problems in the three DHBs of Auckland.

District Health Boards (DHBs)	Diabetes %	Diabetes (n)	Psychological distress %	Psychological distress (n)	Ischemic heart disease[13] %	Ischemic heart disease (n)	Hospital discharges – respiratory system primary diagnoses
Waitematā	4.6	22,000	4.2	21,000	3.3	16,000	9,237
Auckland	4.3	19,000	5.1	22,000	2.4	12,000	7,512
Counties Manukau	7.2	34,000	6.8	32,000	2.9	15,000	10,564

In summary, chronic health conditions which are worsened with extreme heat have a spatial, ethnic and age specific profile. The District Health Board data (table 4) is not directly transferable to the heat vulnerability index which is presented at the finer grain CAU level. The data however validates the use of under 5s and over 65s and Māori and Pacific population statistics as proxies for poor health outcomes, as 58 per cent of all Counties Manukau Māori, and 76 per cent of Counties Manukau Pacific peoples, and 45 per cent of the 0-14 years old in Counties Manukau were living in decile 9 and 10 areas the 20 per cent relatively most deprived areas in New Zealand at the time of Census 2013 (Counties Manukau District Health Board, 2015).

[13] Ischaemic heart disease (diagnosed angina or admitted to hospital with heart attack)

4.5 Occupational health risks

Occupational health risks also have a spatial and demographic dimension. The highest numbers of vulnerable employees are in rural areas and urban areas with a concentration of manufacturing and labour activities (Figure 6). Manufacturing and labouring employment activities attract employees from lower socio-demographic backgrounds.

The rural areas of Rodney have high numbers of workers in farming and forestry, with pockets of heightened heat vulnerability in Wellsford and Warkworth. Likewise, in the south, Franklin has high numbers of population employed in manual labour, likely to be dominated by employment in farming. There is some concentration of heat vulnerability indicators and heat vulnerable occupations in the central western suburbs and within the Southern Initiative Area; this is due to a higher concentration of low skilled workers, a proportion of which are employed in outdoor occupations vulnerable to heat exposure such as the construction industry.

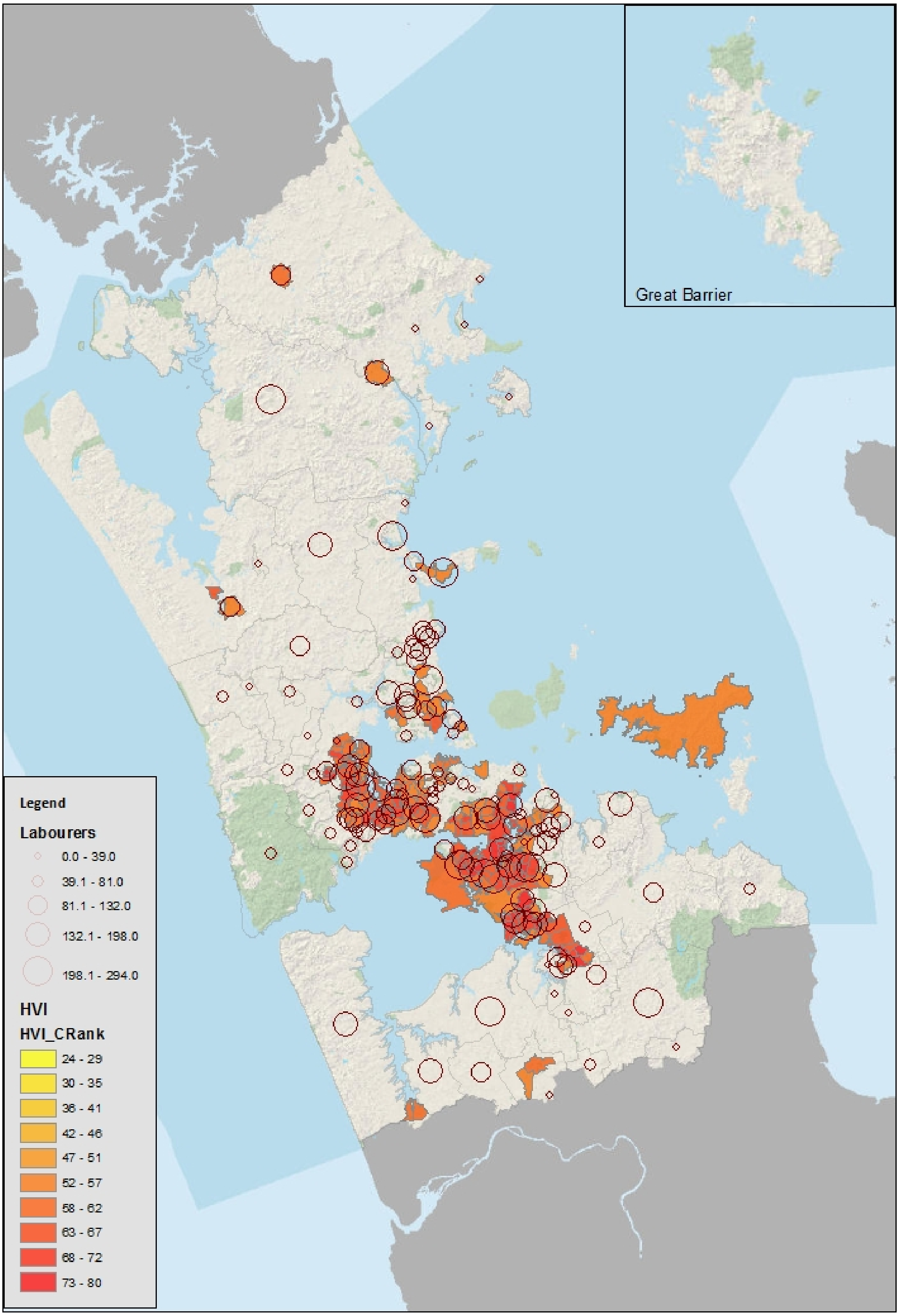


Figure 6 Employment in occupations vulnerable to heat events and HVI most at risk

When broken down by ethnicity, workers of European descent make up the largest group by number (#20,877) working as labourers. Proportionally, however, 15 per cent of Pacific people and 11 per cent of Māori are employed in high heat risk occupations, compared to five per cent of Europeans. This combined with other heat-related risks that disproportionately affect Māori and Pacific people, such as poor health, increase the risk of heat-related impacts these ethnic groups face because of their occupation. The current distribution of labourers from Māori and Pacific[14] ethnicities are represented in Figure 7a and b.

Notably there are larger proportions of Pacific people in at risk occupations in the Southern Initiative Area, which covers the local board areas of Māngere-Ōtāhuhu, Ōtara-Papatoetoe, Manurewa and Papakura. As noted, many of the respondents to the census may have affiliated with more than one ethnicity. There are, however, some areas where a difference is notable, such as large proportions of Māori labourers in the areas of Manurewa and Pukekohe and concentrations of Pacific people in Māngere, Papatoetoe, Manukau.

Being at risk to the effects of high heat events both at home, as indicated in the HVI, and at work could make Māori and Pacific groups particularly vulnerable.

14 Respondents to the census can identify with multiple ethnicities, so some of the counts of Māori and Pacific participants will be for the same respondent

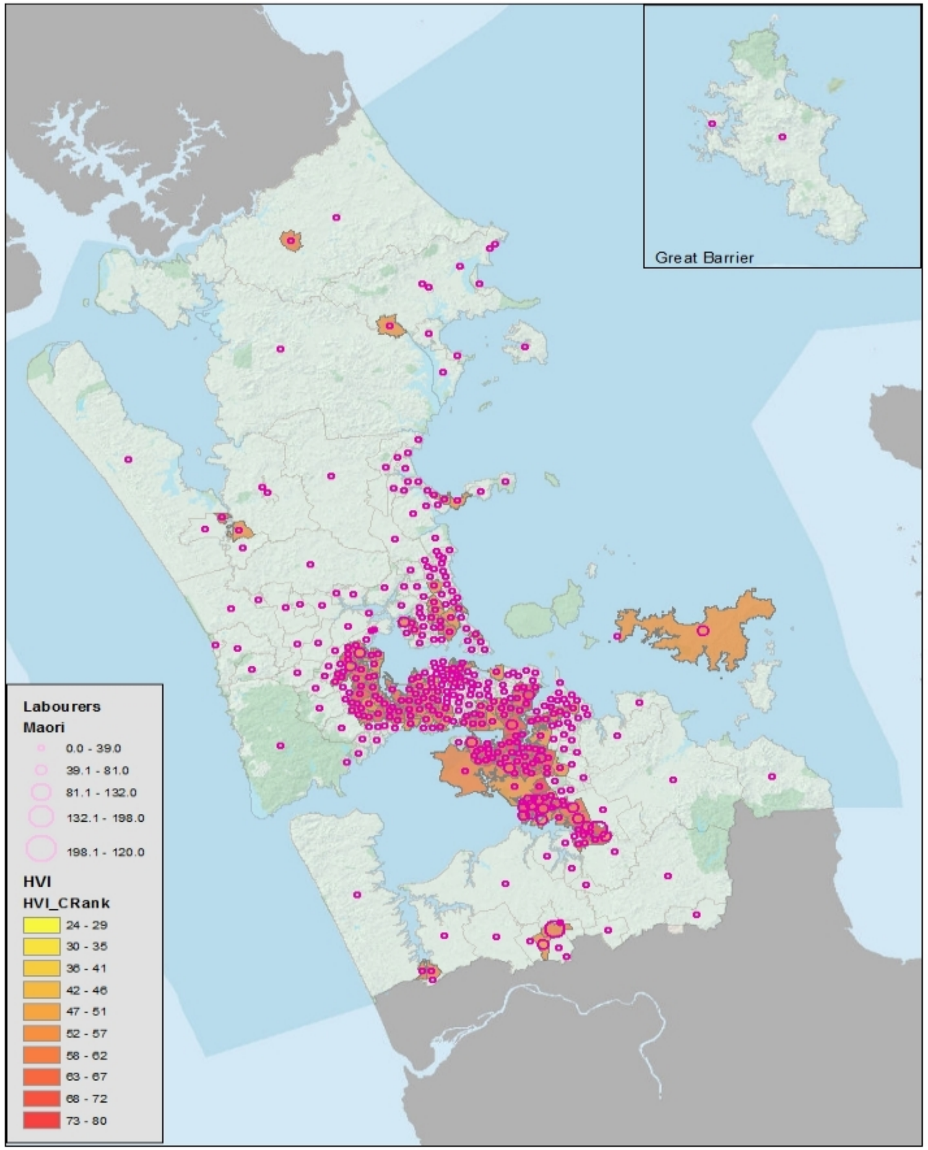


Figure 6b Distribution of Māori labourer employees and HVI

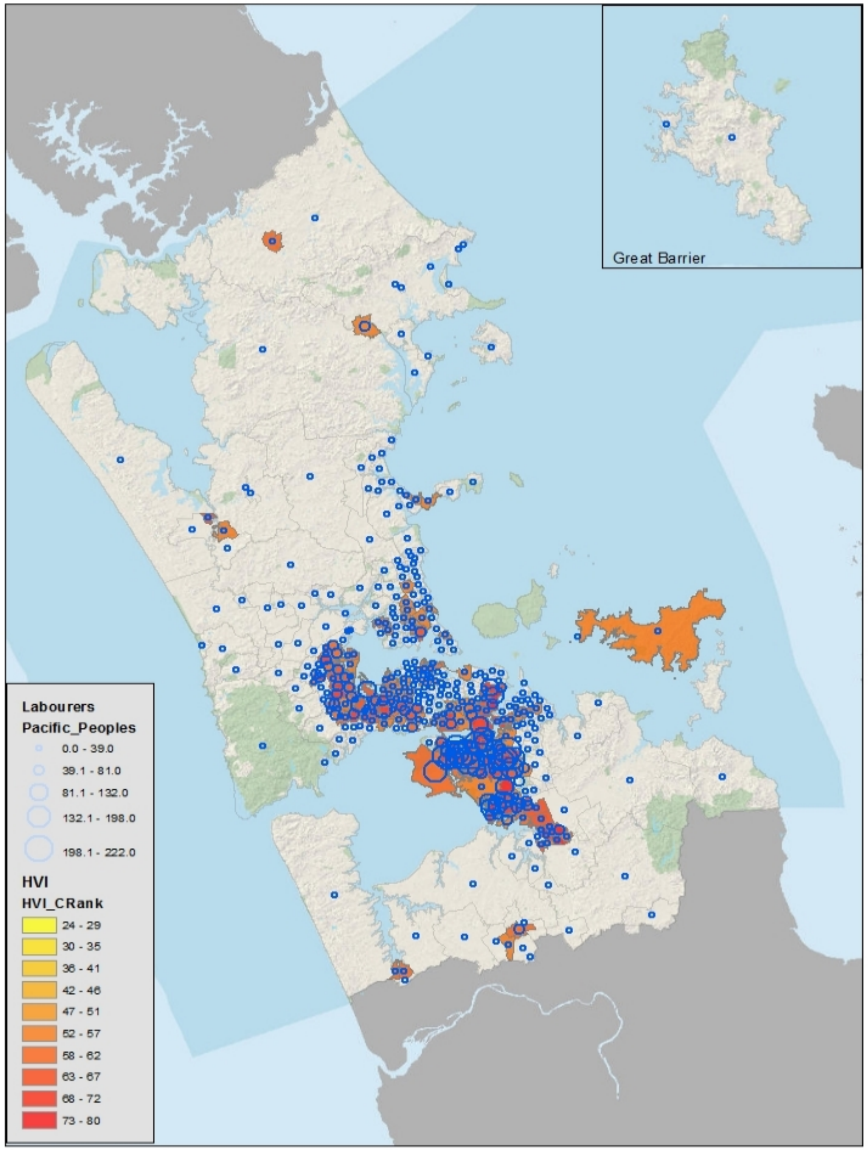


Figure 6c Distribution of Pacific labourer employees and HVI

4.6 Data limitations

Data for all the census-based indicator variables presented above were derived from the 2013 census. Predicting the vulnerability of a society based on present-day measures of social vulnerability indicators does have limitations. In effect, the analysis looks at changing environmental conditions against a static societal picture. There are methodological ways to counter this, such as using the Hamilton-Perry deterministic method to project population characteristics in the future (Hardy, 2018). For this analysis, present day societal and spatial characteristics are assumed to persist within the evaluation period years 2040-2100. Statistics New Zealand does offer some regional scale projections to 2043. These indicate increases in ageing populations, both because of a decreasing birth rate and increased life expectancy, and increased proportions of one-person households. The younger age structure of Māori and Pacific populations builds in greater capacity for population growth in these ethnic groups. Therefore, if current over representation of these groups in lower-socio economic and health statistics persist, the current projections for vulnerability will worsen in the future but are unlikely to change in location significantly (Statistics New Zealand, 2018).

In addition to the projected changes reported by Statistics New Zealand, there may also be changes in land use and spatial demographic profiles within Auckland because of climate change driven impacts, as areas become attractive for residents.

The population of New Zealand is also expected to grow because of climate change, with an influx of climate change refugees expected from the Pacific Islands. A resident of Kiribati became one of the world's first climate change refugee applicants when he sought refuge status in New Zealand in 2017 (Anderson, 2017). Refugees from other parts of the world may also start to apply to New Zealand as countries become less viable.

The data inputs in the HVI are also limited by the exclusion of social infrastructure, which in many areas and populations will be well established and provide a mitigative impact to the risk of increasing hot days. Quantifying social infrastructure presents a future research opportunity, which may involve cataloguing the location of existing community groups and the buildings which encourage greater community cohesion, such as community cafes and places of worship. The inclusion of social infrastructure has the potential to alter the HVI considerably.

The land cover database also has limitations as quality and density of the coverage is not presented. As LIDAR data on the urban tree canopy is completed in the coming years the HVI can be updated to represent more accurately the amount of urban cooling available through transpiration and the extent of available tree canopy shading available in each CAU.

5.0 Discussion

The following section has been divided into two sub-sections. The first focuses on the vulnerable populations in Auckland, and the second discusses how land use and social infrastructure can affect the population's vulnerability.

5.1 Vulnerable populations in Auckland

Projecting future vulnerability to climate change and implementing adaptation plans is becoming imperative. As the effects of climate change are becoming apparent through increased extreme events, the public and political rhetoric is shifting from just mitigating climate change to adapting to climate change impacts which is why the Auckland Climate Action Plan is timely.

The increased extreme heat events projected under the RCP 8.5 scenario will be felt by all members of society. The impacts however will be dependent on the ability of individuals and the community to adapt and protect themselves. As highlighted by participants of the recent climate change seminar 'Food for Thought' event hosted by Tonkin and Taylor (2019), as New Zealand's largest city, Auckland has two important roles in leading the research and adaption to climate change. Firstly, due to the population size of Auckland, the scale of the impacts of increased extreme heat events will be much greater. Secondly, with significant capital resource, Auckland Council can lead the way in demonstrating how to protect its citizens.

The impacts Auckland could face from increased extreme heat events have the potential to be damaging and the risks are imminent. There will be some acclimatisation in the long-term, accompanied by associated adaptation of the built environment. It is noteworthy, though, that the 2040 projections represent the period 2030-2050 (Pearson et al., 2018). The 10-15 extra hot days (and 25 in the south and north) are just over a decade away. It is unlikely that society will have the opportunity to adapt and acclimatise to these changes within this period without some intervention (Taylor, 2014; Williams et al., 2013). Extreme heat events around the world have highlighted the severity of this risk, with 15,000 people dying as a direct result of the 2003 heatwave in France, 140 deaths reported in California during the 2006 heat wave (Hansen et al., 2008) and numerous deadly heat waves recorded in Australia between 1995-2006 (Knowlton, et al., 2009).

The development of the HVI enables a spatial demonstration of where vulnerable communities are in Auckland. Protecting these vulnerable individuals and communities will need a considered approach as the underlying causes of vulnerability in each CAU is not homogenous.

As demonstrated in the literature, the most vulnerable groups will be those with limited means to adapt and with underlying health conditions that increase their susceptibility to the hazard of extreme heat. Where communities show high vulnerability, for example an elderly, low income, minority ethnic population with underlying health conditions, the risk of heat impacts affecting a large proportion of the population is increased. This is not to say that on an individual or small group level the population outside of the high rated HVI will be immune to the effects of heat. Enabling the resilience of the whole population is a preferred outcome of the HVI.

The omission of social infrastructure in this work is acknowledged as a limitation. During times of disaster it is social infrastructure that often determines the outcome for individuals (Klinenberg, 2018). In the example of heat, it will be the neighbour checking on a neighbour, or the provision of a cool space within an accessible public building that will determine how vulnerable a community is. Social infrastructure is difficult to measure, but community cohesion thrives when opportunities are available to develop community bonds. As noted in the results, some areas identified as highly vulnerable in the HVI, may have significant resilience due to their social infrastructure. It is anticipated that this omission presents a future research opportunity to refine the HVI.

Occupational risk is also a factor to be considered in the wider context of heat vulnerability. The Household Labour Force Survey indicates that construction is the largest growing sector of employment in New Zealand with two thirds of the growth in Auckland and Wellington. House construction has been the third highest employment growth sector for Māori employment since the year 2000 (Infometrics, 2018). Construction and utilities have seen a 78 per cent rise in the number of Pacific people employed over three years (MBIE, 2017). The result of these trends is that Māori and Pacific people could be disproportionally affected by the impact of increasing hot days at work. The current advice from Worksafe regarding working in extreme temperatures was written in 1997, and specifically states that extreme heat from weather is not considered to be an occupational risk (Worksafe, 2017). Arguably this advice is likely to change with the climate, and the identification of specific at-risk occupations will likely be updated in New Zealand in the coming years,

Heat-related deaths are largely preventable through behavioural change and natural and built environment interventions (McGeehin & Mirabelli, 2001). To coordinate these interventions, heat management plans are becoming more commonplace throughout global cities (Bernard & McGeehin, 2004 ; Bosch, 2003; Hayhoe, et al., 2010; Kovats & Ebi, 2006; New York City Panel on Climate Change, 2013). Notably many of these management plans have been implemented following significant deaths from extreme heat events, at present Auckland does not currently have a heat management plan in place.

5.1.1 Building structure and tenure related risks

The greatest risk to individuals during a heat event occurs within the home where the most heat vulnerable individuals (the elderly, very young, chronically ill and socially isolated) spend much of their time (Klinenberg, 2003). Sensitivity to heat can be caused by physiological, environmental (natural and built) or socio-economic restrictions; the most vulnerable communities have limited capacity to adapt due to all these causes.

The socio-deprived and those in rental accommodation tend to have access to poorer quality housing (White, et al., 2017), and limited capacity to make physical changes to their property (Instone et al., 2015; Joynt, 2017), which would protect them against extreme heat. The existing building stock in New Zealand has poor levels of insulation, particularly in the private rental sector (White et al., 2017).

In New Zealand, property standards for new and existing building are governed by building and planning legislation contained in the Building Regulations 1992, Building Act 2004, Healthy Homes Guarantee Act 2017 and Resource Management Act (RMA) 1991. Neither regulation has specific reference to explicitly protect against overheating. Thermal insulation is a requirement under both the Building Regulations 1992, Building Act 2004 and Healthy Homes Guarantee Act 2017, and is one means of protecting buildings from excessive heat; however, this is only effective when combined with shading and ventilation, which are not specified in current legislation. MBIE does provide advice on building thermally efficient buildings without risk of overheating in design guidance however this is non-mandatory.

If the building legislation remains unchanged under a changing climate, properties will be increasingly susceptible to overheat. There is no legislative requirement in New Zealand for the retrofit of passive ventilation, double glazing and solar shading, which means that even where the thermal capacity of residential dwellings is improved, the ability for buildings to be passively cooled will not be guaranteed and this can cause loss of thermal comfort in a dwelling (Gupta & Greggs, 2012). Notably, reliance on mechanical ventilation is problematic as the use of air conditioning can be affected by income (Eisenman et al., 2016), and also when powered by fossil fuel energy contributes to the problem of climate change.

5.1.2 Measures to protect vulnerable individuals

Vulnerable individuals include the very young, elderly, chronically ill, socially isolated and economically deprived. Buddy systems are recommended by many jurisdictions as an effective outreach option for high-risk individuals. The outreach may be undertaken by professionals (health workers) or by volunteers, including friends or relatives (Kovats & Ebi, 2006). In Philadelphia pre-existing buddy systems are used for neighbours to check on neighbours during heatwaves. Whereas systems in the European cities of Rome, Lisbon, France, Italy, Germany and Spain use registers of vulnerable people and those that have asked persons to register themselves or their relatives voluntarily, as part of the WHO led heatwave plans established after the 2003 Heatwave (Kovats & Ebi, 2006). Auckland Council and Civil Defence currently have an Emergency Management Plan in place for natural disaster alerts. The existing plan already supports a buddy system as well as notifications of civil defence alerts through the media and social media (Auckland Civil Defence and Emergency Management, 2016).

As many of the most vulnerable members of Auckland's community will be registered through the DHB due to their heat sensitive chronic conditions, the means to alert these members of society to risks is already established.

Beyond health access points the HVI indicates that the locations of the most susceptible populations to the projected impacts of heat events are predominantly within areas already subject to community interventions, for example the Southern Initiative and the Tāmaki regeneration area. Where existing programmes are already in place the development of a plan to reduce vulnerability to extreme heat events could be directed through them.

5.2 Vulnerable populations, land use and social infrastructure

5.2.1 Green infrastructure

At a community/ neighbourhood level vulnerability can be significantly heightened or mitigated with green infrastructure (Oliveria, 2011). Neighbourhood cooling can be achieved with increased tree canopy and greenspace (Elmes et al., 2017). As Auckland continues to experience urban growth, the existing green infrastructure may experience further pressure. Mapping the existing greenspace relative to the high deprivation areas illustrates that there is already a tendency for limited green infrastructure to be in areas of high socio-economic deprivation. For residents in these areas, green infrastructure should be prioritised as the residents' ability to adapt their dwellings is constrained by low income and for some, limited property rights.

Monitoring the changes in land cover relative to urban development over time can be a good indicator for where future heat risks may occur. In a recent project undertaken by Auckland Council, tree canopy changes over a 10 years period in the Waitematā Local Board (WLB) area were evaluated (Lawrence, Ludbrook & Bishop, 2018). The research found that 61.23ha of tree canopy were lost from WLB over 10 years. The loss was made up of 12,879 different detected clearances; meaning a minimum of 12,879 trees were cleared (Lawrence, Ludbrook & Bishop, 2018). The WLB is only a very small area in the Auckland region; urban canopy loss could have implications for future protection of heat effects in these areas. The trees were predominantly removed from private land in existing 'leafy suburbs' of Arch Hill, Freemans Bay, Grey Lynn, Parnell, Ponsonby, Western Springs and Westmere, with 75 per cent of the trees removed having no statutory protection.

The Urban Forestry Strategy, currently being finalised by the Natural Environment Strategy Team, aims to both document existing urban forestry canopy in Auckland and propose extension and protection of this canopy for a variety of benefits. The heat protection services provided by the urban tree canopy are significant, and urban trees mitigate the magnitude and timing of the urban heat island effect, even in suburban areas with less impervious coverage (Elmes et al., 2017). The RMA protects against removal and trimming of trees of significance, based on the status of the tree rather than the ecosystem services it provides. Where communities have limited adaptive capacity, embedding community/ neighbourhood scale adaptation through increasing green infrastructure could significantly reduce vulnerability to extreme heat events. The findings of the HVI research could inform prioritisation work under the Urban Forestry Strategy, which helps value the multifunctional role they play in Auckland's neighbourhoods.

5.2.2 Social infrastructure

Auckland has no spatially compiled inventory of social infrastructure. Where there is a deficit of social infrastructure, particularly within areas of social deprivation the vulnerability of the community to heat exposure is considerably increased (Klinenberg, 2003).

Further development of the HVI would include identification of social infrastructure that has for example a network of community cool spaces, but also areas with and without existing community groups and community cohesion that if present would mitigate some of the vulnerability of the community considerably.

Cataloguing and spatially analysing potential community cool spaces could further offer insights into lesser and greater vulnerability to heat across the Auckland region. Community cool spaces could be located in existing facilities by extending hours and opening public places such as public swimming pools, public parks, or large cooled buildings such as shopping centres, libraries, community centres and schools (Eisenman et al., 2016; Kovats & Ebi, 2006). In Auckland, the use of marae and places of worship could also be explored as community cool spaces. Use of these areas is affected by accessibility, with community cool spaces beyond a 1km radius walking distance deemed inaccessible (Eisenman et al., 2016).

Identifying the distribution of social infrastructure that is in place or required could help mitigate the vulnerability to increased extreme heat events at the community/neighbourhood scale. Access to cool space varies across the city making some more vulnerable to increasing extreme heat events due to their house, job and neighbourhood overheating.

Heat management plans have been implemented around the globe, particularly in regions that have experienced significant heat-related mortality rates. Heat management plans often include a cool space network. Due to Auckland's vulnerability to natural disasters it has a well-established civil defence plan and network of civil defence centres that could be utilised during an extreme heat event. The Civil Defence Emergency Act 2002 requires under section 12 that all regional and territorial authorities have a civil defence management plan in place. At present the plan created by the Auckland Civil Defence and Emergency Management (2016) highlights a range of environmental, biological and terrorist threats, but heat waves are not included.

Extreme heat events pose an insidious risk, as the impacts on the community are difficult to identify during a hazard event. For example, identifying an isolated elderly resident in a heat wave is more complex than identifying an area affected by flood. Heat management plans underpinned by HVI have been used with great effect globally to reduce the risk to vulnerable populations.

6.0 Conclusion

The Auckland region will experience the effects of increased extreme heat events in just over a decade based on the RCP 8.5 business as usual scenario. By the beginning of the 2100s, Auckland is projected to experience more than 70 - 80 extra hot days, with the south and north of the region experiencing over 90 more hot days than baseline conditions[15]. Essentially, Aucklanders will be exposed to three months of extra hot days.

Extreme heat events pose a significant threat to the health and well-being of Auckland's population. Evidenced by extreme heat events reported in cities around the world, extreme heat events can have a catastrophic effect on the population, particularly those that are chronically ill, socially marginalised or with reduced capacity to adapt and mitigate the effects of heat. Therefore, extreme heat events will disproportionately affect those that are unable to adapt to extreme heat. The most vulnerable groups to heat-related stress will be the elderly, the very young, the chronically ill, the socially isolated, low skilled labourers, those in poor quality housing and neighbourhoods and those with limited income and ability to adapt.

The HVI was developed using 10 indicator variables collated at CAU level from the Census 2013, New Zealand Land Cover Database (LCDB) and the New Zealand Indices of Multiple Deprivation (IMD). The most vulnerable areas were highlighted as within the south Auckland areas of Māngere-Ōtāhuhu, Ōtara-Papatoetoe, Manurewa and Papakura; eastern local board areas of Maungakiekie-Tāmaki; western areas of Henderson-Massey Local Board area. Within the areas highlighted as vulnerable, there will be certain subgroups whose risks are further elevated.

Māori and Pacific people have a heightened vulnerability to extreme heat events due to increased cardiovascular disease, diabetes, renal disease, depression, anxiety, and respiratory illness (Ministry of Health/ Manatū Hauora, 2018). The following factors also increase the vulnerability of Māori and Pacific people: high socio-economic deprivation, low educational attainment, high private rental occupation, and employment in manual labour jobs. It is also acknowledged that manaakitanga[16] and social infrastructure inherent within these communities offers significant mitigation during times of crisis, however quantification of this is outside the scope of this project.

[15] Changes relative to the baseline climate of 1986-2005 (termed '1995').

[16] Manaakitanga hospitality, kindness, generosity, support - the process of showing respect, generosity and care for others.

The elderly and very young are also more susceptible to hot days due to physiological weaknesses that limit the body's ability to thermo-regulate. Elderly people are also more likely to live alone, heightening their risk as social isolation which is found to be a causal factor in heat-related mortality. Many elderly people also have constrained mobility; which has been found to be a causal factor in heat-related morbidity/ mortality numbers even when controlling for other social vulnerability factors (Eisenman et al., 2016). Future population projection trends indicate increasing numbers and proportions of the population at the older ages (Statistics New Zealand, 2018). While life expectancy is increasing, the improvements in health expectancy is growing at a slower rate, meaning New Zealanders are experiencing more of their lives in poor health (Ministry of Health/ Manatū Hauora, 2018).

Without significant changes to socio-economic profiles and health outcomes, the trajectory is that the current vulnerable populations will continue to be vulnerable to extreme heat events under the changing climatic conditions over the next 100 years. This work presents an opportunity to look beyond the immediately apparent protection of life and property which dominates climate change responses, and offer an opportunity to address other social goals such as poverty alleviation, social isolation, and empowerment (Heltberg, 2009), which will increase the Auckland population's resilience to extreme heat.

Vulnerability to extreme heat events will be compounded or mitigated by the extent and proximity of social and green infrastructure. Identifying, preserving and where necessary, implementing greater social and green infrastructure, is a proactive measure for territorial authorities to take to protect against the impacts of extreme heat events.

The HVI could contribute to the urban forest strategy (Natural Environment Strategy Team, Auckland Council) which aims to prioritise retention of green infrastructure. The HVI has the potential to inform planting tools using a GIS platform to highlight benefits and opportunities achievable by planting in different areas around the region (Beacon Environmental, 2015).

Heat management plans have been implemented around the world, where extreme heat is recognised as a civil hazard particularly in regions that have suffered significant mortality during extreme heat events. The current Auckland Civil Defence and Emergency Management Group plan for Auckland identifies extreme heat events as a factor 'influencing hazards' but not as specific hazard itself (Auckland Civil Defence and Emergency Management, 2016).

Heat management plans often include heat wave warning systems (HWWS), using social media, media and community facilities. Heat management plans also collate and promote an inventory of social infrastructure (community cool spaces) and green infrastructure available to communities during extreme heat events, including existing civil defence centres. Heat management plans support the provision of information and education, providing practical advice and outreach to residents on how to prepare and protect themselves (and their neighbours) before and during an extreme heat event. For example, by using buddy system and by utilising existing services such as health and social network and community groups.

Occupation is also a determinant of vulnerability to heat. Labourers in the construction industry, farming and mining are more vulnerable to extreme heat impacts (Schulte & Chun, 2009). Auckland has several primary industries where workers will be vulnerable to increased extreme heat events, in particular farm labourers and those in the construction sector. Currently the advice on extreme heat in the workplace provided by Worksafe and written in 1997 does not recognise climate related heat as a risk (Worksafe, 2017). As Auckland's climate changes, heat induced occupational health risk will also grow, preparing employees and employers for these changes and modifying work environments and/or working hours may be required going forward.

In summary, projected increased extreme heat events will have varying impacts on Aucklanders in the coming decades. The HVI enables a spatial demonstration of the CAUs where extreme heat events will have the worst impact. The development of the HVI is the first step in increasing Auckland's resilience to extreme heat events by identifying areas to focus resources and interventions to improve the adaptive capacity and decrease the risk.

This report is the first iteration of the HVI using the best available data at the time. It is envisaged that as new data is generated, i.e. 2018 census, new vegetation cover data and more in-depth social infrastructure analysis, legislative and regulatory reform, the HVI will be refined and improved and could potentially yield new data on the location of vulnerable sectors of the population. This tool is intended to illustrate the heterogeneity of impacts of the anticipated rise in hot days and stimulate policy discussion on potential adaptation strategies.

7.0 References

Alana, L., Peng, B., Philip, R., Monika, N., Dino, P., & Graeme, T. (2008). The effect of heat waves on hospital admissions for renal disease in a temperate city of Australia. *International Journal of Epidemiology, 37*(6), 1359

Anderson, C. (2017, 31 October). New Zealand considers creating climate change refugee visas. Guardian retrieved from https://www.theguardian.com/world/2017/oct/31/new-zealand-considers-creating-climate-change-refugee-visas

Åström, C., Orru, H., Rocklöv, J., Strandberg, G., Ebi, K. L., and Forsberg, B. (2013). Heat-related respiratory hospital admissions in Europe in a changing climate: A health impact assessment. *BMJ open, 3*(1) e001842.doi:10.1136/bmjopen-2012001842

Åström, D., Forsberg, B., and Rocklöv, J. (2011). Heat wave impact on morbidity and mortality in the elderly population: A review of recent studies. Maturitas, 69, 99-105.

Atkinson, J., Salmond, C., and Crampton, P. (May 2014). *NZDep 2013 Index of Deprivation*. Department of Public Health, University of Otago, Wellington and Division of Health Sciences, University of Otago.

Auckland Civil Defence and Emergency Management. (2016). Auckland Civil Defence and Emergency Management Group Plan 2016 - 2021. In Auckland Council (Ed.), He tapui tangata hei ahuru mowai mo Tāmaki Makaurau. Auckland: Auckland Civil Defence.

Auckland Council (2017). National Policy Statement on Urban Development Capacity 2016: Housing and business development capacity assessment for Auckland. Auckland, New Zealand: Auckland Council.

Auckland Council. (2018). Auckland Council One Million Trees. Retrieved from https://www.aucklandcouncil.govt.nz/mayor-of-auckland/mayor-priorities/protecting-our-environment/Pages/million-trees.aspx

Auckland Council (2019). Summary of the 2019 Climate Change Risk Assessment. Prepared by Arup for Auckland Council. Auckland Council technical report, TR2019/019

Barreca, A. I. (2012). Climate change, humidity, and mortality in the United States. *Journal of Environmental Economics and Management, 63*, 19-34.

Beacon Environmental. (2015). Priority tree planting areas to grow Peel's urban forest. Ontario Canada. Retrieved from https://www.peelregion.ca/planning/climatechange/reports/pdf/FinalRpt-TPPT-2015-Aug07.pdf

Bernard, S. M., and McGeehin, M. A. (2004). Municipal Heat Wave Response Plans. American *Journal of Public Health, 94*(9), 1520-1522.

Berry, P., Campbell-Lendrum, D., Corvalan, C., and Guillemot, J. (2013). Protecting Health from Climate Change: Vulnerability and Adaptation Assessment. World Health Organisation, Switzerland.

Bhaskaran, K., Hajat, S., Haines, A., Herret, E., Wilkinson, P., and Smeeth, L. (2010). Short term effects of temperature on risk of myocardial infarction in England and Wales: Time series regression analysis of the myocardial ischaemia national audit project (MINAP) registry. *BMJ, 341*, 3823. doi:10.1136/bmj.c3823

Bolton, A. (2018). Climate Change and Environmental Health. Report prepared for the Ministry of Health, report no: FW17059. Retrieved from https://www.esr.cri.nz/assets/Uploads/Climate-Change-and-Env-Health-FINAL-20180503.pdf

Bosch, X. (2003). France sets up action plan to tackle heat-related deaths. *The Lancet, 262*(9384), 624. doi:10.1016/s0140-6736(03)14196-7

Borrell, C., Marı´-Dell'Olmo, M., Rodriguez-Sanz, M., Garcia-Olalla, P., Cayla, J. A., Benach, J. (2006). Socioeconomic position and excess mortality during the heat wave of 2003 in Barcelona. *European Journal of Epidemiology,21,* 633-640

Bowler, D. E., Buyung-Ali, L., Knight, T. M., and Pullin, A. S. (2010). Urban greening to cool towns and cities: A systematic review of the empirical evidence. *Landscape and Urban Planning, 97*(3), 147-155. doi:10.1016/j.landurbplan.2010.05.006

BRANZ. (2015). Controlling temperature with passive design: an introduction. Retrieved from http://www.level.org.nz/passive-design/controlling-temperature-withpassive-design-an-introduction/

Cheng, J., & Berry, P. (2013). Health co-benefits and risks of public health adaptation strategies to climate change: a review of current literature. *International Journal of Public Health, 58*(2), 305-311.

Chuang, W. G. P. (2015). Predicting Hospitalization for Heat-Related Illness at the Census-Tract Level: Accuracy of a Generic Heat Vulnerability Index in Phoenix, Arizona (USA). *Environmental Health Perspectives, 123* (6), 606-612. doi:10.1289/ehp.1307868

Civil Defence Emergency Act (2002). Retrieved from http://www.legislation.govt.nz/act/public/2002/0033/51.0/DLM149789.html

Counties Manukau District Health Board. (2015). Population profile. Retrieved from https://countiesmanukau.health.nz/about-us/our-region/population-profile/

Cutter, S. L., Boruff, B. J., & Shirley, W. L. (2003). Social vulnerability to environmental hazards. . *Social Science Quarterly, 84*, 242-261.

de Smith, M., Goodchild, M., and Longley, P. (2018). Univariate classification schemes in Geospatial Analysis – A Comprehensive Guide, 3rd edition 2006-2009 (6th ed.).

Diabetes Auckland. (2018). Living life well. Retrieved from https://diabetesauckland.org.nz/

Dong, Z., Pan, Z., An, P., Zhang, J., Zhang, J., Pan, Y., . . . Pan, X. (2018). A quantitative method for risk assessment of agriculture due to climate change. *Theoretical and Applied Climatology, 131*(1-2), 653-659. doi:10.1007/s00704-016-1988-2

Ebi, K., Ogden, N., Semenza, J., and Woodward, A. (2017). Detecting and attributing health burdens to climate change. *Environmental Health Perspectives, 125*(8). doi:10.1289/EHP1509

Eisenman, D., Wilhalme, H., Tseng, C., Chester, M., English, P., Pincetl, S., . . . Dhaliwal, S. (2016). Heat death association with the built environment, social vulnerability and their interactions with rising temperature. *Health & Place, 41*, 89-99. doi:10.1016/j.healthplace.2016.08.007

Elmes, A., Rogan, J., Williams, C., Samuel, R., Nowak, D., and Martin, D. (2017). Effects of urban tree canopy loss on land surface temperature magnitude and timing. *ISPRS Journal of Photogrammetry and Remote Sensing, 128*, 338-353. doi:10.1016/j.isprsjprs.2017.04.011

Exeter, D., Zhai, J., Crengle, S., Lee, A., and Browne, M. (2017). The New Zealand indices of multiple deprivation (IMD): A new suite of indicators for social and health research in Aotearoa, New Zealand. *PLoS ONE 12*(8). doi:10.1371/journal.pone.0181260

Exeter, D., Zhao, J., Crengle, S., Lee, A. C. L., & Browne, M. (2013). New Zealand Index of Multiple Deprivation (IMD) [IMD 2013 (61 MB, ArcGIS shapefile)].

Fernandez, M., and Golubiewski, N. E. (2019). An assessment of vulnerability to climate change in Auckland. Auckland Council technical report, TR 2019/011

Flanagan, B. E., Gregory, E. W., Hallisey, E. J., Heitgerd, J. L., & Lewis, B. (2011). A Social Vulnerability Index for Disaster Management. *Journal of Homeland Security and Emergency Management, 8* (1), 3. doi:10.2202/1547-7355.1792

Fouillet, A., Rey, G., Laurent, F., Pavillon, G., Bellec, S., Guihenneuc-Jouyaux, C., . . . Hémon, D. (2006). Excess mortality related to the August 2003 heat wave in France. *International Archives of Occupational and Environmental Health, 80* (1), 16-24 doi:10.1007/s00420-006-0089-4

Graham, D.A., Vanos, J.K., Kenny, NA., Brown, R.D. (2016). The relationship between neighbourhood tree canopy cover and heat-related ambulance calls during extreme heat events in Toronto, Canada. *Urban Forestry and Urban Greening, 20*, 180-186. doi:10.1016/j.ufug.2016.08.005

Gronlund, C., P. Sullivan, K., Kefelegn, Y., Cameron, L., & O'Neill, M. (2018). Climate change and temperature extremes: A review of heat- and cold-related morbidity and mortality concerns of municipalities. *Maturitas 114.* 54-59

Gupta, R., & Greggs, M. (2012). Using UK climate change projections to adapt existing English homes for a warming climate. *Building and Environment, 55* (2) 20-42.

Hajat, S., and Kosatky, T. (2010). Heat-related mortality: a review and exploration of heterogeneity. *Journal of Epidemiology & Community Health, 64*, 753-760. doi:10.1136/jech.2009.087999

Hansen, A., Bi, P., Nitschke, M., Ryan, P., Pisaniello, D., and Tucker, G. (2008). The effect of heat waves on hospital admissions for renal disease in a temperate city of Australia. *Environmental Health Perspectives, 116* (10), 1369-1375. doi: 10.1289/ehp.11339

Hansen, A., Bi, P., Saniotus, A., and Nitschke, M. (2013). Vulnerability to extreme heat and climate change: is ethnicity a factor? *Global Health Action, 6*. doi:10.3402/gha.v6i0.21364

Hardy, R., and Hauer, M.E. (2018). Social vulnerability projections improve sea-level rise risk assessments. *Applied Geography, 91*, 10-20. doi:10.1016/j.apgeog.2017.12.019

Harlan, S. L., Brazel, A. J., Prashad, L., Stefanov, W. L., & Larsen, L. (2006). Neighborhood microclimates and vulnerability to heat stress. *Social Science & Medicine, 63*(11), 2847-2863.doi:10.1016/j.socscimed.2006.07.030

Hayhoe, K., Sheridan, S., Kalkstein, L., & Greene, S. (2010). Climate change, heat waves, and mortality projections for Chicago. *Journal of Great Lakes Research, 36*, 65-73. doi:10.1016/j.jglr.2009.12.009

Healthy Homes Guarantee Act 2017. Retrieved from www.legislation.govt.nz/act/public/2017/0046/25.0/DLM6627702.html

Heart Foundation. (2018). Retrieved from https://www.heartfoundation.org.nz/statistics

Heart Research Institute. (2018). Facts about heart disease. Retrieved from http://www.hri.org.nz/about-heart-disease/facts-about-heart-disease

Heltberg, R. Siegel, P.B., Jorgensen, S.L. (2009). Addressing human vulnerability to climate change: Toward a 'no-regrets' approach. *Global Environmental Change, 19,* 89-99. doi: 10.1016/j.gloenvcha.2008.11.003

Hiemstra J.A., Saaroni H., Amorim J.H. (2017). *The Urban Heat Island: Thermal Comfort and the Role of Urban Greening*. Pearlmutter D. et al., (eds). The Urban Forest. Future City, Springer, Chamberlain vol 7, 7-19. doi.org/10.1007/978-3-319-50280-9_2

Hondula, D. M., Davis, R.E., Saha, M.V., Wegner, C.R., Veazey, L.M. (2015). Geographic dimensions of heat-related mortality in seven U.S. cities. *Environmental Research, 138*, 439-452. doi:10.1016/j.envres.2015.02.033.

Infometrics. (2018). Occupational employment. Retrieved on May 7th, 2018 from https://ecoprofile.infometrics.co.nz/Auckland/Skills/BroadOccupation

Instone, L., Mee, K. J., Palmer, J., Williams, M., & Vaughan, N. (2015). *Climate change adaptation in the rental sector* In J. P. Palutikof, S. L. Boulter, J. Barnett, & D. Rissik (Eds.), Applied Studies in Climate Adaptation (pp. Pages: 372-379). Online: John Wiley & Sons, Ltd. doi:10.1002/9781118845028

Johnson, D., Stanford, A., Lulla, V., and Luber, G. (2012). Developing an applied extreme heat vulnerability index utilizing socioeconomic and environmental data. *Applied Geography, 35*(1-2), 23-31. doi:10.1016/j.apgeog.2012.04.006

Joynt, J. (2017). Renting in Auckland: tenant, landlord and property manager perspectives. Auckland Council, New Zealand. Auckland Council technical report, TR2017/032

Joynt, J., Tuatagaloa, P., and Lysnar, P (2016). Pacific people and housing in Auckland: a stocktake of issues, experiences and initiatives. Auckland Council, New Zealand. Auckland Council technical report, TR2016/027

Kjellstrom, T., Butler, A.J., Lucas, R.M., Bonita, R. (2010). Public health impact of global heating due to climate change: potential effects on chronic non-communicable diseases. *International Journal Public Health, 55*(97). doi:10.1007/s00038-009-0090-2

Klinenberg, E. (2003). *Heat Wave: A Social Autopsy of Disaster in Chicago (Illinois).* Chicago, Illinois, USA: University of Chicago Press.

Klinenberg, E. (2018). *Palaces for the people: How to build a more equal united society*. London: The Bodley Head.

Knowlton, K., Rotkin-Ellman, M., King, G., Margolis, H. G., Smith, D., Solomon, G., and English, P. (2009). The 2006 California heat wave: impacts on hospitalizations and emergency department visits. *Environmental Health Perspectives, 117*(1), 61.

Kovats, R., and Ebi, K. L. (2006). Heatwaves and public health in Europe. *European Journal of Public Health, 16*(6), 592-599.

Krafft, J., and Fryd, O. (2016). Spatiotemporal patterns of tree canopy cover and socioeconomics in Melbourne. *Urban Forestry & Urban Greening, 15*, 45-52. doi:10.1016/j.ufug.2015.10.011

Lawrence, G., Ludbrook., M and Bishop, C. (2018). Tree loss in the Waitematā Local Board over 10 years (2006-2016) Auckland Council technical report TR2018/021

Lee, Y. Y., Din, M. F. M., Ponraj, M., Noor, Z. Z., Iwao, K., & Chelliapan, S. (2017). Overview of Urban Heat Island (UHI) Phenomenon Towards Human Thermal Comfort. *Environmental Engineering and Management Journal*, *16*(9), 2097-2111

Lin, S., Hsu, W. H., Van Zutphen, A. R., Saha, S., Luber, G., and Hwang, S. A. (2012). Excessive heat and respiratory hospitalizations in New York State: Estimating current and future public health burden related to climate change. *Environmental Health Perspectives, 120* (11), 1571-1577. doi: http://doi.org/10.1289/ehp.1104728

Lindley, S. J., Handley, J. F., Theuray, N., Peet, E., & Mcevoy, D. (2006). Adaptation Strategies for Climate Change in the Urban Environment: Assessing Climate Change Related Risk in UK Urban Areas. *Journal of Risk Research, 9* (5), 543-568. doi:10.1080/13669870600798020

Lorrey, A. M., Pearce, P. R., Barkus, C., Anderson, S. J., and Clement-Jones, A. (2018). Auckland Region climate change projections and impacts: Summary report. Retrieved from Auckland Council. TR2017/031-2.

Ma, J. (2016). PhD thesis. Green infrastructure and urban liveability: measuring accessibility and equity. (PhD), University of Auckland, Auckland.

Maller, C. J., and Strengers, Y. (2011). Housing, heat stress and health in a changing climate: promoting the adaptive capacity of vulnerable households, a suggested way forward. *Health Promotion International, 26*(4). doi:10.1093/heapro/dar003

Managan, A., Uejio, C., Sahal, S., Schramm, P., Marinucci, G.D., Langford Brown, C., Hess, J.J., Luber, G. (2014). Assessing Health Vulnerability to Climate Change: A Guide for Health Departments Retrieved from Atlanta, USA

MBIE. (2017). Pacific people in the labour market. Retrieved from http://www.mbie.govt.nz/info-services/employment-skills/labour-market-reports/pacific-peoples-labour-market-trends/june-2017/employment-industry

MBIE. (2018). Housing affordability perspective: Housing percentage measure. Retrieved from http://www.mbie.govt.nz/info-services/housing-property/sector-information-and-statistics/housing-affordability-measure/latest-results/housing-affordability-perspective-housing-percentage-measure

McGeehin, M.A, and Mirabelli, M. (2001). The potential impacts of climate variability and change on temperature-related morbidity and mortality in the United States. *Environmental Health Perspectives, 109*(2), 185-189.

McMichael, A., Woodruff, R.E., and Hales, S. (2006). Climate change and human health: present and future risks. *The Lancet, 367*, 859-869. doi:10.1016/S0140-6736(06)68079-3

McNeil, S., Plagmann, M., McDowall, P., & Basset, M. (2015). The role of ventilation in managing moisture inside New Zealand homes. BRANZ

McPherson, E., Simpson, J., Xiao, A., and Wu, C. (2011). Million trees Los Angeles canopy cover and benefit assessment. *Landscape and Urban Planning, 99*, 40-50.

MedicineNet.com. (2003, 6/11/2003). Hyperthermia: A hot weather hazard for older people. Retrieved from https://www.medicinenet.com/script/main/art.asp?articlekey=23619

Michelozzi, P., Accetta, G., De Sario, M., D'Ippoliti, D., Marino, C., Baccini, M., . . . Perucci, C. A. (2009). High Temperature and Hospitalizations for Cardiovascular and Respiratory Causes in 12 European Cities. *The American Journal of Respiratory and Critical Care Medicine, 179,* 383-389. doi:10.1164/rccm.200802-217OC.

Ministry for the Environment. (2018). The New Zealand Land Cover Database (LCDB). Retrieved from https://lris.scinfo.org.nz/layer/48423-lcdb-v41-land-cover-database-version-41-mainland-new-zealand/

Ministry of Health/ Manatū Hauora. (2018). Health and Independence Report 2017. Retrieved from https://www.health.govt.nz/system/files/documents/publications/health-and-independence-report-2017-v2.pdf

Ministry of Health/ Manatū Hauora. (2015). Regional results from the 2011-2014 New Zealand Health Survey. Retrieved from https://www.health.govt.nz/publication/regional-results-2011-2014-new-zealand-health-survey

Ministry of Health/ Manatū Hauora. (2016). Office of the Director of Mental Health Annual Report. Retrieved from https://www.health.govt.nz/system/files/documents/publications/office-of-the-director-of-mental-health-annual-report-2016-dec17-v2.pdf

Ministry of Health/ Manatū Hauora. (2017). Annual update of key results 2016/17: New Zealand health survey. Retrieved from https://www.health.govt.nz/publication/annual-update-key-results-2016-17-new-zealand-health-survey

Mitchell, I. (2015). Can work, cannot afford to buy the intermediate housing market (ER5). Livingston and Associates Ltd for BRANZ, New Zealand.

New York City Panel on Climate Change. (2013). Climate Risk Information 013: Observations, Climate Change Projections, and Maps. Retrieved from http://www.nyc.gov/html/planyc2030/downloads/pdf/npcc_climate_risk_information_2013_report.pdf

New Zealand Nephrology. (2015). 2015 New Zealand nephrology annual data report: About care for end-stage kidney disease treated with dialysis or kidney transplantation. Retrieved from https://www.kidneys.co.nz/resources/file/nz_care_processes_and_treatment_targets_report_2015-1.pdf

Nitschke, M., Tucker, G. R., Hansen, A. L., Williams, S., Zhang, Y., & Bi, P. (2011). Impact of two recent extreme heat episodes on morbidity and mortality in Adelaide, South Australia: a case-series analysis. *Journal of Environmental Health, 10*(1), 42. doi:10.1186/1476-069x-10-42

Oke, T. (1973). City size and the urban heat island. *Atmos Environ,7*, 769-779.

Oliveria, S., Andrade, G., Vaz, T. (2011). The cooling effect of greenspaces as a contribution to the mitigation of urban heat: A case study in Lisbon. *Building and Environment, 46*(11), 2186-2194. doi:10.1016/j.buildenv.2011.04.034

Page, L., Hajat, S., Kovats, S., & Howard, L. M. (2012). Temperature-related deaths in people with psychosis, dementia and substance misuse. *The British Journal of Psychiatry, 200*, 485-490. doi:10.1192/bjp.bp.111.100404

Pearce, P., Bell, R. G., Bostock, H., Carey-Smith, T., Collins, D., Fedaeff, N. (2018). Auckland Region climate change projections and impacts. National Institute of Water and Atmospheric Research (NIWA) on behalf of Auckland Council.

Pierse, N., Carter, K., Bierre, S., Law, D., and Howden-Chapman, P. (2016). Examining the role of tenure, household crowding and housing affordability on psychological distress, using longitudinal data. *Journal of Epidemiology and Community Health, 70*(10), 961-966. doi:10.1136/jech-2015-206716

Reid, C. E., O'Neill, M. S., Gronlund, C. J., Brines, S. J., Brown, D. G., Diez-Roux, A. V., & Schwartz, J. (2009). Mapping Community Determinants of Heat Vulnerability. *Environmental Health Perspectives, 117*(11). doi:10.1289/ehp.0900683

Royal Society/Te Apārangi. (2017). Human health impacts of climate change for New Zealand: Evidence Summary. Retrieved from https://royalsociety.org.nz/assets/documents/Report-Human-Health-Impacts-of-Climate-Change-for-New-Zealand-Oct-2017.pdf

Rygel, L., O'Sullivan, D., & Yarnal, B. (2006). A Method for Constructing a Social Vulnerability Index: An Application to Hurricane Storm Surges in a Developed Country. *Mitigation and Adaptation Strategies for Global Change, 11*(3), 741-764. doi:10.1007/s11027-006-0265-6

Salmond, C., and Crampton, P. (2012). Development of New Zealand's Deprivation Index (NZDep) and its Uptake as a National Policy Tool. *Canadian Journal of Public Health / Revue Canadienne de Santé Publique, 103*, 7-11.

Schulte, P., and Chun, H. (2009). Climate change and occupational safety and health: Establishing a prelimnary framework. *Journal of Occupational and Environmental Hygiene, 6*, 542-554. doi:10.1080/15459620903066008

Statistics New Zealand. (2013). New Zealand Census of Population and Dwellings.

Statistics New Zealand. (2018). Population projections overview. Retrieved from http://archive.stats.govt.nz/browse_for_stats/population/estimates_and_projections/projections-overview/nat-ethnic-pop-proj.aspx.

Statistics New Zealand. (2017). Labour Market Statistics: September 2017 quarter. Retrieved from http://archive.stats.govt.nz/browse_for_stats/income-and-work/employment_and_unemployment/LabourMarketStatistics_HOTPSep17qtr.aspx

Talbot, N. (2019). Climate change, Air Pollution and Potential Public Health Impacts for Auckland. Auckland Council technical report, TR2019/013

Taylor, N. A. S. (2014). Human heat adaptation. *Comprehensive Physiology, 4*(1), 325-365. doi:10.1002/cphy.c130022

Telfar-Barnard, L., and Zhang, J. (2016). The impact of respiratory disease in New Zealand:2016 update. Retrieved from https://s3-ap-southeast-2.amazonaws.com/assets.asthmafoundation.org.nz/documents/REPORT-The-impact-on-respiratory-disease-in-New-Zealand-2016-update.pdf

Tonkin and Taylor, (2019). Food for Thought Climate change- manging risk and fostering resilience. Seminar February 28th, 2019. Eden Park, Auckland

Wang, X., Lavigne, E., Ouellette-kuntz, H., & Chen, B. (2014). Acute impacts of extreme temperature exposure on emergency room admissions related to mental and behaviour disorders in Toronto, Canada. *Journal of Affective Disorders.155,* 154-161 doi:10.1016/j.jad.2013.10.042

Warin, B., Exeter, D. J., Zhao, J., Kenealy, T., and Wells, S. (2016). Geography matters: the prevalence of diabetes in the Auckland Region by age, gender and ethnicity. *NZMA, 129*(1436), 1-14.

White, V. W., Jones, M., Cowan V. & Chun, S. (2017). BRANZ 2015 House Condition. Survey: Comparison of house condition by tenure (SR37 [2017]). Retrieved from Judgeford, New Zealand

Williams, K., Gupta, R., Hopkins, D., Gregg, M., Payne, C., Joynt, J., and Bates-Brkljac, N. (2013). Retrofitting England's suburbs to climate change. *Building Research and Information, 41*(5), 517-531. doi:10.1080/09613218.2013.808893

Witten, K., Wall, M., Carroll, P., Telfar Barnard, L., Asiasiga, L., Graydon-Guy, T., Huckle, T., Scott, K. (2017). The New Zealand Rental Sector, 2017. Retrieved from https://www.branz.co.nz/cms_show_download.php?id=d6ecd1fccf14b21e12ab304375fb5bc9e0fe44f1

Wolf, T., & McGregor, G. (2013). The development of a heat wave vulnerability index for London, United Kingdom. *Weather and Climate Extremes, 1*, 59-68.

Worksafe. (2017). Guidelines for the management of work in extremes of temperatures. Wellington: Occupational Safety & Health Service. Retrieved from https://worksafe.govt.nz/dmsdocument/773-working-in-extremes-of-temperature

World Weather Online. (2018). Retrieved from https://www.worldweatheronline.com/dubai-weather-averages/dubai/ae.aspx

Xu, Z., Sheffield, P. E., Su, H., Wang X., Bi, Y., and Tong, S. (2014). The impact if heat waves on children's health: a systematic review. *Int J Biometeorol, 58*(239). doi:10.1007/s00484-013-0655-x

Appendix: HVI data set all CAUs

HVI data set all CAUs

CAU	Ranked from least to most vulnerable 0-10 (10 variables that inform the HVI)										Overall HVI Score out of 100 HVI rank
CAUDESCRIP	One Person House hold	Rental tenure	Rent Burden	Māori - pop	Pacific -pop	Non-Green space	No English	Pop'n over 65	Pop'n under 5s	Weighted by pop'n IMD/ CAU	
Fairburn	7	9	9	6	9	10	9	5	6	10	80
Manurewa Central	7	9	8	9	6	10	9	6	5	9	78
Manurewa East	6	9	9	9	7	8	8	5	6	10	77
Ranui Domain	7	8	10	8	7	8	8	5	6	10	77
Tāmaki	7	9	7	9	8	7	8	6	5	10	76
Point England	8	10	6	8	8	5	10	6	5	10	76
Ōtāhuhu North	7	9	8	5	8	10	10	4	5	10	76
Beaumont	6	9	8	9	7	9	8	4	6	10	76
Burbank	2	9	9	9	9	10	8	3	6	10	75
Homai West	3	9	8	10	8	9	8	4	6	10	75
Ōtāhuhu West	6	9	8	7	8	8	10	4	5	10	75
Ōtara South	3	9	7	8	10	9	8	5	6	10	75
Wymondley	2	10	10	7	10	8	8	4	6	10	75
Urlich	6	7	10	9	7	9	6	5	6	10	75
Papakura North	10	8	8	9	4	9	4	10	4	8	74
Clendon South	2	9	9	9	9	8	9	3	6	10	74
Ferguson	2	9	8	8	10	8	9	4	6	10	74
Harania East	2	9	8	7	10	9	9	4	6	10	74
Papakura East	4	9	9	10	6	10	6	4	6	10	74
Harania West	3	9	7	7	10	9	9	5	5	9	73
Papakura South	7	9	8	10	7	7	6	3	6	10	73
Mascot	4	9	6	7	10	7	9	5	6	10	73
Wiri	3	10	8	9	9	5	8	5	6	10	73
Arahanga	3	9	7	8	10	7	8	4	6	10	72
Ōtara East	3	9	7	8	10	6	9	4	6	10	72
Ōtara North	3	9	9	8	10	5	8	4	6	10	72
Ōtara West	3	10	8	9	10	4	9	3	6	10	72
Rowandale	3	9	7	9	9	9	8	2	6	10	72
Papakura Central	10	9	7	9	4	7	4	9	4	9	72
Puhinui South	7	9	9	6	6	9	8	5	4	9	72
Henderson North	9	6	8	5	5	9	7	10	4	8	71
Favona North	4	9	6	7	10	7	8	6	5	9	71
Leabank	4	8	9	10	7	5	7	5	6	10	71
Henderson South	6	8	9	8	6	7	7	6	5	9	71
Homai East	4	8	8	9	8	8	7	4	5	10	71
Māngere Central	2	9	5	7	10	8	9	5	6	10	71
New Lynn North	7	8	7	6	5	9	9	6	5	8	70

Glen Innes West	5	9	8	8	8	7	7	4	5	9	70
Rongomai	2	9	8	8	10	5	9	3	6	10	70
Mt Wellington South	4	9	6	8	8	7	8	5	6	9	70
Viscount	2	9	7	7	10	8	8	4	5	10	70
Hyperion	3	9	6	9	8	9	7	3	6	10	70
Massey Park	8	7	8	9	5	7	5	6	5	10	70
New Lynn South	7	7	8	5	5	10	9	6	5	8	70
Glenavon	6	9	8	5	6	8	9	5	5	8	69
Papatoetoe North	6	8	7	6	6	9	8	6	5	8	69
Clendon North	3	9	7	9	9	7	7	2	6	10	69
Ōtāhuhu East	6	9	6	7	9	6	8	4	5	9	69
Roberton	8	8	7	5	5	9	9	5	5	8	69
Fruitvale	8	7	8	4	5	9	8	7	5	8	69
Oranga	6	9	5	6	8	9	7	5	5	9	69
Edgewater	8	7	8	6	5	7	8	9	4	6	68
Weymouth West	4	7	8	9	8	6	7	4	6	9	68
Papatoetoe Central	8	7	5	5	5	9	9	8	4	8	68
Onehunga North West	9	9	6	3	5	10	7	9	4	6	68
Randwick Park	3	7	9	9	7	7	8	3	6	9	68
Lynnmall	8	9	8	3	5	8	10	5	4	8	68
Glen Eden East	8	7	8	5	5	9	7	6	5	8	68
Favona West	2	10	5	6	10	7	9	3	6	10	68
Māngere Station	1	10	7	7	10	6	10	2	5	10	68
Waimumu North	4	7	9	8	7	8	7	3	6	9	68
Mt Wellington North	5	9	5	5	6	10	9	6	5	8	68
Papatoetoe East	4	8	7	6	6	9	10	5	4	9	68
Panmure Basin	8	7	8	5	4	10	8	7	4	7	68
Papatoetoe West	4	8	7	7	7	9	8	4	5	9	68
Mcleod	6	7	8	7	5	8	8	6	5	8	68
Walmsley	3	10	8	3	8	7	10	3	6	9	67
Weymouth East	4	8	7	9	7	7	7	4	5	9	67
Westgate	7	6	10	5	5	7	6	10	4	7	67
McLaren Park	4	7	8	7	7	9	6	5	5	9	67
Onehunga South East	8	9	5	5	5	9	8	6	4	8	67
Clover Park	2	7	4	7	10	9	9	4	5	10	67
Starling Park	4	6	8	8	7	7	8	3	6	9	66
Aorere	2	7	6	7	9	8	8	4	6	9	66
Kingdale	4	8	7	8	6	6	8	5	5	9	66
Papakura North East	6	7	7	9	5	8	4	5	6	9	66
Fairdene	5	7	6	7	5	8	8	6	5	9	66
Avondale West	6	8	7	5	7	5	9	6	4	9	66
Harania North	1	9	5	6	10	6	9	4	6	10	66

Dingwall	4	6	7	6	5	10	10	6	4	8	66
Parrs Park West	4	8	9	7	7	6	6	3	6	9	65
Glen Innes East	4	9	5	8	8	7	6	4	5	9	65
Kelston Central	4	6	8	7	7	6	8	5	5	9	65
Tuff Crater	8	7	7	5	5	5	8	10	4	6	65
Wesley	6	9	5	4	7	6	10	5	4	9	65
Parakai Urban	8	6	10	9	3	2	2	10	5	10	65
Rosebank	4	7	8	6	7	7	7	5	5	8	64
Puhinui North	5	6	6	5	5	10	9	6	4	8	64
Kohuora	3	8	7	8	8	5	8	3	5	9	64
Māngere Bridge	7	6	4	8	7	6	6	7	5	8	64
Mt Wellington West	8	7	4	4	4	10	6	10	4	7	64
Edmonton	6	6	7	6	5	9	7	6	4	8	64
Takanini North	4	9	7	9	5	2	8	4	6	10	64
Takanini South	7	8	7	9	5	3	5	6	5	8	63
Three Kings	7	9	6	4	5	8	8	5	4	7	63
Redoubt North	3	6	7	6	7	7	9	5	5	8	63
Middlemore	1	1	7	9	7	2	10	6	10	10	63
Māngere East	3	7	5	6	8	7	8	5	5	9	63
Owairaka West	6	9	5	5	5	6	9	4	5	9	63
Favona South	2	9	3	7	9	7	8	3	5	10	63
Rewarewa	7	6	7	5	5	7	7	8	4	7	63
West Harbour	3	7	8	8	5	8	6	3	6	9	63
Akarana	4	9	7	3	7	5	10	5	4	9	63
Rosehill	5	7	6	9	5	6	5	6	5	9	63
Te Papapa	8	8	5	5	7	7	6	4	5	8	63
Tangutu	6	6	8	7	5	7	6	4	5	8	62
Sandringham East	7	8	7	3	4	10	8	4	5	6	62
Oratia	5	5	8	7	7	6	5	6	5	8	62
Glendene North	5	6	8	7	5	7	6	6	4	8	62
Mt Wellington Domain	8	9	6	5	5	5	8	5	5	6	62
Ferndale	7	9	4	5	5	9	7	4	5	7	62
Pakuranga Central	4	6	8	5	4	8	9	7	5	6	62
Royal Road West	4	6	8	7	5	10	5	4	5	8	62
Wellsford	8	6	8	9	2	2	3	10	5	9	62
Matipo	8	5	5	8	5	8	4	7	5	7	62
Ranui South	4	6	8	8	5	7	5	4	6	9	62
Waterview	8	9	5	5	5	7	6	5	4	8	62
Hamlin	4	8	5	6	5	9	8	4	5	8	62
Sandringham West	6	8	6	3	5	9	8	5	5	6	61
Woodglen	6	6	7	7	5	9	4	4	5	8	61
Durham Green	5	5	6	8	5	9	5	6	5	7	61
Birkdale North	4	6	8	6	5	8	6	6	5	7	61
Ocean View	7	6	7	4	3	8	9	8	4	5	61

Glendene South	5	6	6	6	6	9	5	5	4	8	60
St Johns	8	9	7	3	4	7	7	5	4	6	60
Waiuku East	8	5	8	8	3	5	3	8	5	7	60
Māngere South	2	8	6	7	9	3	8	3	5	9	60
New Windsor	4	6	7	3	5	9	9	6	4	7	60
Royal Heights	5	6	7	8	5	6	5	6	4	8	60
Avondale South	6	5	7	3	5	9	8	7	4	6	60
Parrs Park	4	9	4	7	7	5	7	3	5	9	60
Waikowhai East	4	8	5	3	7	6	9	5	5	8	60
Waimumu South	4	6	7	8	5	7	5	4	5	8	59
Owairaka East	6	7	8	3	5	8	7	6	4	5	59
Manukau Central	10	10	4	9	5	3	4	3	2	9	59
Point Chevalier South	7	8	8	5	5	4	6	4	5	7	59
Pukekohe North	6	6	7	9	5	5	4	5	5	7	59
Beachhaven North	7	6	6	7	5	7	4	5	5	7	59
Glenfield North	5	6	7	4	3	10	8	5	4	7	59
Onehunga South West	8	6	6	5	5	7	5	7	4	5	58
Auckland Central West	9	10	10	2	2	9	7	2	2	5	58
Helensville	8	4	9	8	4	2	3	8	4	8	58
Springleigh	5	8	8	4	4	6	8	5	5	5	58
Waiuku West	8	5	8	8	2	5	2	9	4	7	58
Point Chevalier West	8	5	9	5	4	7	3	10	4	3	58
Pakuranga East	4	6	6	5	4	9	9	6	4	5	58
Onehunga North East	8	7	4	4	4	10	5	6	5	5	58
Wakeling	6	5	5	5	5	9	6	7	4	6	58
Target Road	5	7	7	3	3	10	8	5	4	6	58
Highland Park	8	5	6	2	2	9	9	10	3	4	58
Stanmore Bay East	8	5	8	6	2	6	3	9	4	7	58
Te Atatu Central	6	5	6	8	5	4	6	6	5	6	57
Howick Central	8	6	7	3	2	10	5	8	4	4	57
Red Hill	4	6	7	10	5	4	3	5	5	8	57
Grafton East	8	10	4	5	4	10	5	3	3	5	57
Blockhouse Bay	7	4	9	3	3	6	7	10	3	5	57
Surrey Crescent	8	9	6	5	5	5	4	4	4	6	56
Sandringham North	7	8	6	3	4	9	5	4	5	5	56
Takanini West	6	5	7	8	5	6	4	7	4	4	56
Hillpark	5	4	5	7	5	8	6	6	4	6	56
St Lukes	7	9	6	4	4	8	6	4	3	5	56
Sunnyvale	5	5	7	8	5	3	5	6	4	8	56
Point Chevalier East	8	5	6	5	4	8	4	6	5	5	56

Penrose	4	9	1	4	5	9	8	3	5	8	56
Auckland Harbourside	9	10	10	2	1	10	5	3	2	4	56
Elsmore Park	3	6	9	4	4	5	9	5	5	6	56
Birkdale South	6	6	8	5	4	6	5	5	5	6	56
Sunnybrae	7	6	5	3	2	8	8	8	3	5	55
Ellerslie South	7	8	3	3	4	10	6	4	5	5	55
Arch Hill	8	9	8	4	4	8	3	2	3	6	55
Highbrook	1	9	4	8	4	6	8	5	5	5	55
Lynfield North	5	6	7	2	4	5	9	7	4	6	55
Auckland Central East	10	10	10	2	1	8	6	2	1	5	55
Eden Terrace	8	9	6	4	4	10	4	2	2	6	55
Mt Eden North	8	9	6	5	3	7	5	4	3	5	55
Grange	6	6	1	6	7	3	7	6	4	8	54
Manly	7	4	9	4	2	8	2	10	3	5	54
Donegal Park	3	8	4	5	5	3	9	5	5	7	54
Pukekohe West	8	5	6	6	2	4	4	10	4	5	54
Warkworth	8	5	8	5	3	3	3	10	3	6	54
Glenfield Central	6	6	7	2	2	9	7	7	3	5	54
Windsor Park	9	4	8	1	2	6	8	10	2	3	53
Grafton West	8	10	10	3	2	8	5	2	1	4	53
Stanmore Bay West	5	5	9	5	1	9	3	6	4	6	53
Waiheke Island	9	5	9	5	2	1	2	10	4	6	53
One Tree Hill East	6	6	5	3	4	10	6	5	4	4	53
Ellerslie North	8	7	4	3	3	9	5	6	4	4	53
Pigeon Mountain South	9	4	6	1	1	10	7	10	2	3	53
Opaheke	5	3	8	9	4	6	2	6	4	6	53
Wattle Farm	4	3	4	9	5	6	4	7	5	6	53
Mt Albert Central	6	7	7	3	3	8	5	5	4	5	53
Lake Pupuke	8	5	8	2	1	9	4	10	3	3	53
Westlake	8	7	5	2	1	5	7	10	3	5	53
Freemans Bay	9	8	6	3	3	9	2	6	2	5	53
Seacliffe	8	6	5	5	2	8	4	7	4	4	53
Green Bay	9	2	7	4	4	5	3	10	3	5	52
Newmarket	7	9	5	2	2	9	8	3	2	5	52
Hillsborough West	4	6	5	2	4	9	8	6	3	5	52
Ōrākei North	8	6	3	7	3	4	5	8	3	5	52
Mt Eden South	6	6	7	3	2	10	5	5	4	4	52
Kingsland	6	9	5	5	5	8	3	2	3	6	52
Ambury	6	4	4	8	5	3	4	8	4	6	52
Sunnynook	4	5	7	3	2	9	8	5	4	4	51
Oratia West	6	2	7	5	3	1	6	10	5	6	51
Waikowhai West	6	4	7	2	4	4	7	9	3	5	51
Bayswater	6	6	4	6	3	8	3	6	5	4	51
Hillsborough	7	5	5	3	4	5	5	9	3	5	51

East											
Orewa	9	4	9	3	2	6	1	10	2	5	51
Browns Bay	8	5	6	2	1	7	4	10	3	5	51
Witheford	4	5	9	4	3	5	7	4	4	6	51
Burswood	3	6	3	3	3	8	9	6	4	6	51
Forrest Hill	5	5	7	2	1	9	8	7	3	3	50
Greenmount	5	7	4	2	2	6	9	7	4	4	50
Grey Lynn East	8	8	4	3	4	10	3	3	3	4	50
Pigeon Mountain North	3	6	7	3	2	7	9	5	4	4	50
Glendhu	4	5	7	4	3	5	6	5	5	6	50
Balmoral	6	7	5	3	3	10	4	4	4	4	50
Grey Lynn West	6	7	4	5	5	8	3	3	4	5	50
Bledisloe Park	8	5	5	5	3	2	4	8	4	6	50
Dannemora	4	6	8	2	1	9	8	6	3	3	50
Red Beach East	8	3	6	4	1	9	2	10	3	3	49
Henderson West	3	2	8	5	4	7	5	6	4	5	49
Pakuranga North	4	2	9	3	1	10	7	8	3	2	49
Kaipatiki	4	5	4	3	3	7	8	5	5	5	49
Vipond	8	2	7	5	1	5	2	10	4	5	49
Massey West	7	6	1	8	5	1	3	7	4	7	49
Royal Oak	6	5	4	2	3	10	6	7	3	3	49
Howick West	6	4	4	3	2	10	7	6	4	3	49
Sturges North	3	3	8	4	4	4	7	6	4	6	49
Sunnyhills	5	2	9	3	2	7	7	8	3	3	49
Epsom Central	5	6	7	1	2	8	8	6	2	4	49
Mt St John	4	6	5	3	3	8	7	7	2	4	49
Monarch Park	6	3	7	3	2	7	7	6	4	4	49
Pahurehure	5	2	5	6	3	8	4	8	3	5	49
Remuera South	6	6	7	1	2	10	6	6	2	2	48
Ponsonby East	8	7	3	3	4	10	3	4	3	3	48
Beachhaven South	4	5	5	6	4	5	4	6	4	5	48
Mt Eden East	6	7	4	2	2	10	5	5	3	4	48
Newton	8	10	4	3	2	10	3	1	1	6	48
Northcote South	7	5	5	3	2	7	5	7	4	3	48
Windy Ridge	4	6	6	5	3	3	5	5	5	6	48
Sherbourne	8	9	5	3	2	6	3	4	2	6	48
Snells Beach	8	4	9	3	2	2	2	10	3	5	48
Palm Heights	3	4	5	6	5	3	7	4	4	7	48
Lynfield South	4	5	6	2	4	5	7	7	3	5	48
Ponsonby West	6	6	5	4	4	7	3	4	5	3	47
Hauraki	6	5	5	3	1	10	4	7	4	2	47
Northcross	6	7	4	1	1	7	9	5	4	3	47
Half Moon Bay	4	3	8	2	2	9	6	8	3	2	47
Birdwood East	2	4	1	6	5	3	8	4	6	8	47

Hobsonville East	3	9	4	6	3	2	5	3	6	6	47
TŌtara Heights	3	2	7	5	4	4	6	7	4	5	47
Mission Bay	8	6	6	2	1	7	3	8	3	3	47
St Marys	8	9	4	3	2	8	2	6	2	3	47
Murvale	3	5	8	1	1	8	9	5	3	3	46
Abbotts Park	7	5	6	2	2	6	5	7	4	2	46
Epsom North	4	6	5	2	2	8	7	6	2	4	46
Great Barrier Island	10	2	1	7	2	1	2	10	3	8	46
Huapai	7	3	8	4	2	2	2	9	4	5	46
Mt Hobson	6	7	5	2	3	7	6	5	2	3	46
St Lukes North	4	7	1	5	5	9	4	3	3	5	46
Waiwera	10	8	1	5	1	2	1	10	2	6	46
Crown Hill	6	4	5	2	1	10	5	7	4	2	46
Maungawhau	5	6	5	2	2	10	5	4	4	3	46
Remuera West	8	5	4	2	1	10	3	9	2	2	46
Crum Park	6	2	6	4	4	5	4	6	4	5	46
Mairangi Bay	4	2	9	2	1	10	5	8	3	2	46
Meadowbank North	8	5	5	2	2	6	4	7	4	3	46
North Harbour East	6	6	4	2	1	5	8	7	3	3	45
Albany	6	8	9	2	1	2	5	5	3	4	45
Narrow Neck	8	5	6	3	1	5	3	8	4	2	45
Leigh	6	2	2	7	2	4	2	10	3	7	45
Matheson Bay	8	4	2	3	2	3	3	10	3	7	45
Red Beach West	8	4	6	3	1	4	2	10	3	4	45
Swanson	6	5	2	7	4	2	3	4	4	8	45
Takapuna Central	8	6	5	2	1	4	4	10	2	3	45
Bucklands Beach South	3	4	8	1	1	9	8	7	2	2	45
Westmere	6	5	5	5	4	5	3	4	5	3	45
Unsworth Heights	3	5	6	2	2	7	6	6	4	4	45
St Heliers	7	3	6	2	1	8	3	10	3	2	45
Kohimarama West	8	4	4	1	1	8	3	10	4	2	45
Glen Innes North	8	3	4	2	2	6	4	10	3	3	45
Castor Bay	4	2	10	2	1	8	4	9	3	1	44
Waiake	4	2	8	2	1	9	4	8	4	2	44
Kauri Park	6	5	5	4	2	4	5	6	4	3	44
Howick South	4	3	5	2	1	9	6	8	4	2	44
Kawakawa-Orere	8	3	1	8	2	1	1	10	3	7	44
Point Wells	8	2	5	3	1	9	1	10	2	3	44
Wade Heads	6	3	9	3	1	3	2	8	4	5	44
Awhitu	7	2	8	6	1	1	1	9	3	6	44
Epsom South	3	4	7	2	2	10	7	5	2	2	44
Cape Rodney	6	2	6	7	2	1	2	8	4	6	44
Karekare	8	3	8	5	2	1	2	5	4	6	44
Torbay	6	3	5	2	1	9	3	9	3	3	44

Redoubt South	2	2	4	5	5	3	8	5	4	6	44
Millhouse	3	2	5	1	1	9	9	8	3	2	43
Baverstock Oaks	2	4	3	2	3	7	10	4	4	4	43
Weiti River	8	6	1	4	2	4	2	7	3	6	43
Kaurilands	6	2	5	5	3	5	3	5	4	5	43
Herne Bay	8	6	4	2	1	10	1	6	3	1	42
Mt Victoria	8	4	4	2	1	8	2	8	3	2	42
Parnell West	9	8	4	2	1	4	3	6	2	3	42
Whenuapai West	4	9	4	5	2	1	4	4	4	5	42
Matakana	7	3	5	5	1	3	2	8	4	4	42
Runciman	8	4	3	5	3	1	3	8	3	4	42
Birkenhead East	6	5	5	2	1	6	4	7	3	3	42
Ormiston	2	3	9	2	3	1	10	3	5	4	42
Fairview	5	2	4	2	1	5	8	8	4	2	41
Waitaramoa	6	2	8	1	1	9	3	8	2	1	41
Kawau	10	2	1	2	1	1	5	10	4	5	41
South Head	7	2	1	7	2	1	2	9	3	7	41
Army Bay	4	4	6	3	2	2	2	9	4	5	41
Mellons Bay	7	2	5	2	1	7	3	10	2	1	40
One Tree Hill Central	7	6	3	2	2	2	5	8	2	3	40
Glamorgan	4	3	5	3	1	9	3	5	4	3	40
Konini	5	2	6	5	3	3	3	5	4	4	40
Eden Road-Hill Top	4	5	3	4	4	1	5	6	3	5	40
Kohimarama East	6	2	4	2	1	9	3	8	4	1	40
Gulf Harbour	4	6	5	2	2	2	3	8	4	4	40
North Harbour West	2	5	6	2	1	4	9	5	4	2	40
Hatfields Beach	5	4	1	5	2	4	3	6	4	5	39
Oaktree	4	3	3	2	1	9	6	6	3	2	39
Glenbrook	6	2	7	5	2	1	2	7	3	4	39
Ōrākei South	5	3	8	1	1	7	3	7	3	1	39
Islands-Motutapu Rangitoto Rakino	10	1	1	5	3	1	5	5	3	5	39
Kaukapakapa	4	2	9	6	2	1	2	4	3	6	39
Rothesay Bay	4	3	5	2	1	8	5	6	3	2	39
Mahurangi	7	3	3	2	2	1	3	10	3	5	39
Golfland	4	2	5	2	2	4	6	8	3	3	39
Parnell East	8	6	3	2	1	5	2	8	2	1	38
Armour Bay	7	1	8	3	1	1	2	4	5	6	38
Orewa West	1	7	2	3	1	1	4	9	4	6	38
Parakai Rural	5	2	2	7	2	1	3	6	4	6	38
Lucken Point	3	1	3	3	2	8	6	6	3	3	38
Awaruku	3	2	7	2	1	7	3	7	3	3	38
Waiata	6	2	3	1	1	9	2	10	2	2	38
Laingholm	5	1	9	5	1	2	2	4	5	4	38
Bucklands and	4	4	5	1	1	5	5	9	2	2	38

Eastern Beaches										
Muriwai Beach	8	3	1	5	2	2	3	5	5	3	37
Pinehill	3	4	3	1	1	5	10	4	4	2	37
Hobsonville South	4	1	1	3	2	7	4	10	3	2	37
Meadowland	3	1	4	2	1	6	9	7	3	1	37
Cockle Bay	4	2	6	2	1	8	2	8	3	1	37
Kaukapakapa Rural	5	2	9	3	1	1	2	6	4	4	37
Paerata-Cape Hill	4	4	1	7	3	1	3	5	5	4	37
Tauhoa-Puhoi	5	2	7	5	1	1	1	7	3	5	37
Rewiti	6	3	6	5	2	1	1	6	3	3	36
Cape Rodney South	6	2	5	3	1	1	1	10	3	4	36
Meadowbank South	5	2	5	1	1	4	6	7	3	2	36
Drury	4	2	4	6	2	1	3	7	3	4	36
Murrays Bay	3	2	4	2	1	8	4	7	3	1	35
Chelsea	3	2	6	2	1	3	6	7	3	2	35
Algies Bay	8	4	1	2	1	2	1	10	3	3	35
Kumeu West	5	5	4	2	2	1	1	8	3	4	35
Stanley Bay	4	2	4	4	2	8	2	5	3	1	35
Kingseat	4	3	4	5	2	1	2	7	3	4	35
Kumeu East	4	3	1	5	2	1	4	7	3	5	35
Ardmore	4	3	1	5	2	1	4	7	3	5	35
Otimai	4	1	8	4	2	1	2	6	3	3	34
Kaikoura and Rangiahua Islands	1	1	1	9	1	1	1	10	9	-	34
Stillwater	5	2	1	3	1	8	2	4	4	4	34
Taupaki	6	3	1	3	2	1	2	8	3	5	34
Point View	2	2	5	2	2	3	8	5	3	2	34
Opanuku	4	2	4	6	2	1	2	5	3	5	34
South Waiuku	4	1	1	6	1	4	2	6	4	5	34
Herald	4	2	1	4	2	4	3	7	3	3	33
Bombay	4	4	1	5	1	1	2	7	3	5	33
Omaha	6	2	1	2	1	3	2	10	4	2	33
Waipareira West	7	3	1	2	2	1	2	10	3	2	33
Patumahoe	3	2	3	5	2	1	3	7	4	3	33
Mission Heights	1	1	1	2	2	5	10	3	5	3	33
Riverhead Urban	4	2	1	5	2	2	2	4	5	5	32
Beachlands-Maraetai	4	2	5	4	1	2	2	6	4	2	32
Birdwood West	3	2	1	5	3	1	3	6	2	6	32
Kilkenny	2	1	1	1	2	9	8	5	2	1	32
Waitākere	4	1	2	5	2	1	3	5	4	5	32
Titirangi South	5	1	5	2	2	2	2	7	4	2	32
Paremoremo East	3	5	3	5	2	1	3	4	3	2	31
Glendowie	4	1	4	2	1	6	2	6	4	1	31
Clevedon	6	3	4	3	1	1	1	7	3	2	31

Bremner	4	2	2	4	1	1	3	10	2	2	31
Hingaia	3	1	1	4	2	2	5	6	5	2	31
Mill Road	1	1	1	5	3	6	3	4	3	4	31
Paparata	6	2	3	5	1	1	3	3	5	2	31
Redoubt East	3	1	1	4	3	2	5	6	2	4	31
Tahekeroa	4	2	6	3	1	1	1	6	3	3	30
Muriwai Valley	3	5	1	4	1	1	2	5	5	3	30
Silverdale North	4	5	1	2	1	1	2	6	3	5	30
Turanga	3	2	8	3	1	1	3	6	2	1	30
Waimauku	4	1	1	5	1	2	1	6	5	4	30
Stonefields	3	1	1	2	1	4	6	5	5	2	30
Dairy Flat-Redvale	3	2	8	2	1	1	3	5	2	2	29
Greenhithe	3	2	5	2	1	3	4	4	4	1	29
Bleakhouse	3	1	1	1	1	7	4	8	2	1	29
Campbells Bay	4	2	2	2	1	3	2	9	2	1	28
Buckland	3	2	1	5	1	3	1	5	4	3	28
Shelly Park	3	1	1	2	1	5	4	7	3	1	28
Silverdale South	4	3	1	2	1	1	2	6	3	5	28
Hunua	3	1	3	5	1	1	1	7	3	2	27
Helensville South	4	1	3	3	1	1	2	7	3	2	27
Riverhead	4	2	5	2	1	1	2	5	3	2	27
Swanson South	3	1	1	5	1	1	2	6	3	4	27
Paremoremo West	4	2	1	2	2	1	2	6	3	3	26
Waima	4	1	1	3	1	2	3	4	5	2	26
Whangapouri Creek	3	1	2	2	1	1	2	9	3	2	26
Silverdale Central	2	1	1	2	1	2	5	5	5	2	26
Long Bay	4	3	1	2	1	1	3	6	2	2	25
Waitākere West	5	1	2	3	1	1	1	5	3	3	25

Find out more: phone 09 301 0101, email
rimu@aucklandcouncil.govt.nz or visit
aucklandcouncil.govt.nz and knowledgeauckland.org.nz

Auckland Council
Te Kaunihera o Tāmaki Makaurau