Adapting and mitigating wildfire risk due to climate change: extending knowledge and best practice

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Report information sheet

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Executive Summary

Extreme wildfires are increasingly making headlines in the media, with damaging fire seasons over the past few years in Portugal, Greece, California, British Columbia and most recently in Australia during the devastating 2019-2020 fire season. Climate change has been cited as playing a significant role in the increasing severity and length of fire seasons, and Aotearoa New Zealand has not been immune with larger wildfires occurring earlier in recent years. This risk is higher in some areas than others dependent on climate patterns and the distribution of human development, particularly in the rural-urban interface (RUI) where houses and other urban development are adjacent to or intermixed with rural vegetation. There is a need to communicate where the risk of wildfire is highest and provide agencies with recommendations for homeowners and communities in these areas to manage their risk.

This project

The aim of this study *'Adapting and mitigating wildfire risk due to climate change: extending knowledge and best practice'* has been to support agencies in planning for and reducing the risk of extreme wildfires in Aotearoa New Zealand's vulnerable RUI. In meeting this aim we have applied the latest high-resolution climate models and a new mapping of the growing RUI to enable wildfire threat assessment and prioritisation of engagement and risk reduction efforts. We then have recommended best practice wildfire risk reduction, mitigation and preparedness actions agencies can communicate when engaging with at-risk RUI communities.

The project has built upon and extended recent research to understand where climate change is increasing the risk of wildfire, where communities are most exposed at the interface between urban development and rural vegetation, and what risk reduction and mitigation actions households and communities can implement to reduce their wildfire risk and increase their preparedness.

This study has been funded by the Ministry for Primary Industries (MPI) under the Sustainable Land Management and Climate Change (SLMACC) Fund.

Key results

Changing Wildfire Risk with Climate Change

Recent research has updated our knowledge on wildfires in Aotearoa New Zealand and the effect of climate change. Observations of weather and fire conditions that uses the latest dynamically downscaled climate scenarios (IPCC's 5th Assessment Report (AR5)) and application of a fire weather risk algorithm explicitly run with these regional climate projections at a high (5x5 kilometre) spatial resolution have been used to develop updated estimates of projected changes in fire risk. The results of this study have found that on average fire risk will increase, both in season length of fire weather conditions and the intensity of fires that may take hold, until at least mid-century, regardless of climate mitigation efforts.

The highest fire dangers have been found in the seasonally drought-prone and arid locations of Aotearoa New Zealand. For many regions, it was found that compared to the last two decades the fire risk is expected to become appreciably worse through the rest of the century. For the first time, it has been predicted that conditions that led to the devastating 'Black-Summer' fires in Australia will occur every 3-20 years in areas of the Mackenzie Country, Central Otago and Marlborough. This has implications for Aotearoa New Zealand's carbon sequestration ambitions and financial capital in planted forests.

Mapping of the Rural-Urban Interface at-risk Communities

A simple methodology has been identified that defines the extent of the RUI where people and property are at greatest risk from wildfire. This utilises the new national building footprint dataset and Land Cover Database (LCDB) vegetation types, together with internationally recognised definitions for 'interface' and 'intermix' areas based on building density and proximity to flammable vegetation.

Nearly 17% of Aotearoa New Zealand (over 4.6 million ha) has been mapped as RUI and, therefore, potentially at high risk from wildfires. This is made up of around 0.8% (almost 221,000 ha) of higher density interface and 16.1% (nearly 4.4 million ha) in the less densely populated, more rural intermix. With its higher population, the area of RUI (both interface and intermix) is higher in the North Island compared to the South Island. Regionally, the proportion of both interface and intermix is highest in the north of the North Island (Te Hiku), and lowest in the south of the South Island (Te Kei).

These results should be treated with some caution, and considered interim, as validation of the methodology and its outputs is still required. This is especially important given the known issues associated with the accuracy and currency of the underpinning landcover and building datasets on which the mapping is based. Regular updates of the mapping will also be required, as it is important that RUI growth is regularly monitored so that fire managers become aware of new changes to the high-risk environment, enabling them to interact appropriately to audiences of different experience.

Northern Wānaka/Albert Town Community Case Study

A study of the northern Wānaka and Albert Town community targeted suburban residents on the urban side of the RUI to understand elements of social wildfire risk and preparedness. Many permanent Mt Iron residents exhibited high wildfire awareness and anxiety, and voiced their concern of the potential threat to lives and property to local agencies. These concerns included restrictions to remove protected native kānuka vegetation around their properties, flammability of cedar cladding of their houses, and access for fire trucks on the same one-way evacuation routes for residents and daily recreational walkers. Most aware and well-resourced permanent residents have commenced individual household and collective community preparedness actions and are planning additional measures for their properties. Conversely, the wider community appears to have a lower fire risk awareness and use fireworks and braziers, and inappropriately dispose of cigarette butts, despite a year-round fire ban in the Mt Iron 'red zone'.

Wildfire Mitigations for Homeowners and Communities

A series of approximately 170 wildfire risk reduction and mitigation recommendations has been developed to be implemented when constructing or remodelling a home, landscaping or designing defensible spaces, preparing for the start of each wildfire season, planning for wildfire evacuation and during a wildfire event to provide advice for homeowners and the community to prepare themselves and their homes to reduce their risk from wildfire.

Implications of results for the client

These findings show which areas are prone to high fire danger and have significant implications for some Fire Districts, forest managers and investors, as well as climate mitigation and afforestation programmes. This includes implications for Aotearoa New Zealand's carbon sequestration ambitions and financial capital in planted forests.

Further work

Work is required with Fire and Emergency New Zealand to validate the results from the mapping of RUI extent to ensure accuracy before this information is release publicly, and to ensure currency with the latest datasets on landcover and building locations. Similarly, work is still required to overlay this RUI extent against the latest projected changes in fire danger and also spatial datasets of community vulnerability and resilience.

Further research is needed to focus on short-term domestic and international visitors who may lack wildfire risk awareness and preparedness, including those in holiday homes with intermittent use, short and long-term rentals, and short term and semi-permanent holiday park residents.

Research focusing on the limitations that have resulted from development planning and roading decisions is required, as well as the ability to insure. Local government planning and the Resource Management consenting process need to be evaluated to determine the factors and priorities which can cause challenges for ensuring wildfire preparedness (for example, biodiversity, soil and water protection and landscape amenity).

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Introduction

The Problem: Rationale and Context

Extreme wildfires are increasingly making headlines in the media, with damaging fire seasons over the past few years in Portugal, Greece, California, British Columbia and most recently in Australia during the devastating 2019-2020 fire season. Aotearoa New Zealand experiences between 4000-5000 vegetation fires per annum (Fire and Emergency New Zealand, 2019), which is a relatively small number when compared internationally. However, with six of the eight warmest years on record all occurring since 2013 (NIWA, 2021), Aotearoa New Zealand is not immune to extreme fire weather and fire behaviour and increases are already apparent. Recent fires near Nelson, Marlborough, Hanmer, Hawke's Bay, Mackenzie Basin and the Port Hills of Christchurch serve as graphic warnings. More homes were destroyed during the 2016-2017 fire season than have been in any of the previous 100 years (since the 1918 Raetihi Fire), and this was well surpassed in 2020-2021 (Figure 1). The Pigeon Valley fire in 2018 was, at the time, the largest individual forest fire event (2300 ha) (Table 1), and three major Marlborough forest fires of 2015 had contributed to the greatest forest loss (over 3000 ha) since the 1955 Balmoral Forest fire (3155 ha). However, notable wildfires during 2020 include the Pukaki and Ōhau fires which burned over 3100 ha and 5000 ha of land respectively and, in the second instance destroyed 48 houses in the rural-urban interface (RUI)[1]. These wildfires bring the reminder that Aotearoa New Zealand landowners are vulnerable to the damaging effects of wildfire events. It also draws attention to the need for effective fire management planning and tools for RUI areas which are most susceptible to such events. Mapping of areas where people and property are at increasing risk[2] of being impacted by wildfires, particularly within the RUI, therefore aids in identifying where risk mitigation efforts should be focused.

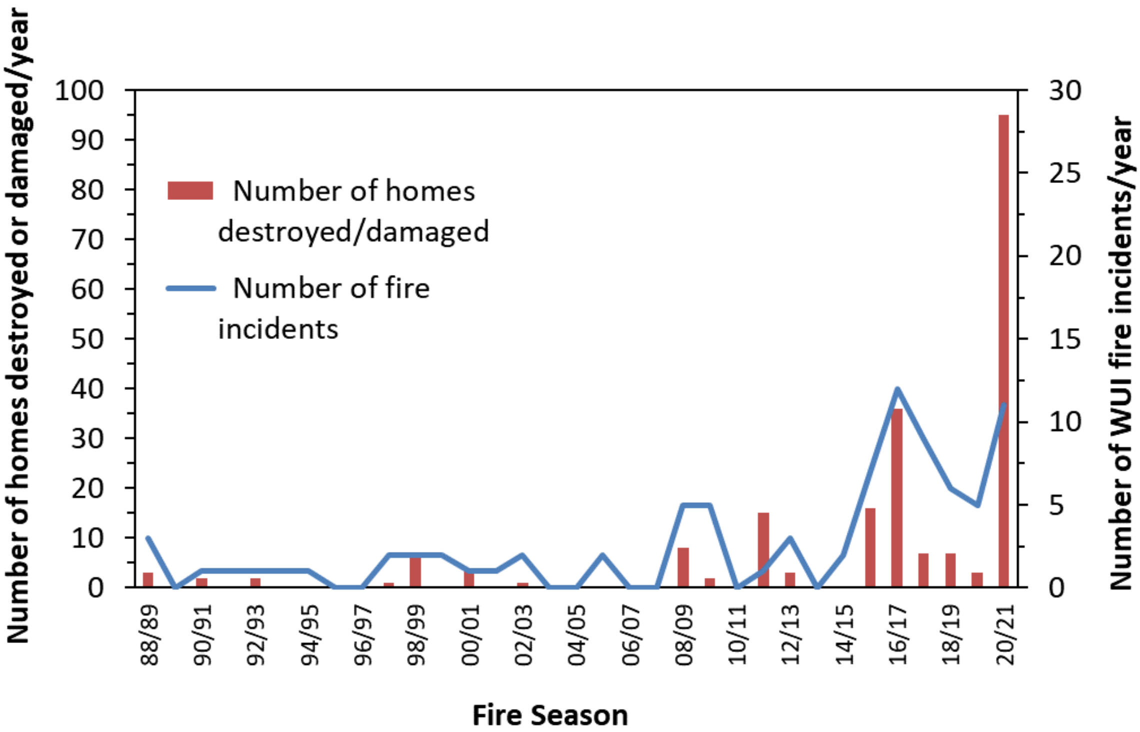

Figure 1: Home losses in RUI wildfires in Aotearoa New Zealand (1988-2021)

[1] The RUI is defined as having two components. The *intermix* is where small residential properties and other urban-associated buildings are interspersed with predominantly rural land uses. The true *interface or urban fringe* is where dense blocks of suburban housing or industrial development adjoin—but are sharply delineated from—large areas of vegetation.

[2] Wildfire risk is defined as the combination of likelihood and consequence of an event impacting a community.

Table 1: Major catastrophic wildfires in Aotearoa New Zealand since 2017.

Fire (date)	Area Burned (ha)	Costs	House losses	Other Impacts
Port Hills, Christchurch Feb 2017	1661	$7.9M firefighting, $18.3M insurance claims	9 homes destroyed & several outbuildings, 450 homes & 2800+ people evacuated	1 fatality (helicopter pilot), 400+ ha commercial forest, Adventure Park impacted incl. gondola
Pigeon Valley, Nelson/Tasman Feb 2019	2316	$12.5M firefighting, $3.98 insurance claims	1 home destroyed, 3000+ people evacuated	1949 ha commercial forest burnt, forestry sector $2M/day in lost earnings
Deep Stream, Dunedin Nov 2019	4664		1 shed destroyed, 1 threatened house evacuated	1100 ha Conservation Park burned, 60% of city water catchment area
Pukaki Downs, Twizel Aug 2020	3100	$1.2M firefighting	1 home destroyed & several outbuildings, 8 properties + 200 day visitors & campers evacuated	Wilding carbon forest burnt, 80% of scientific reserve & part of wetland Conservation Area
Lake Ōhau, Twizel Oct 2020	5032	$1.6M firefighting, $35.8M insurance claims	45 homes destroyed + 3 sheds/garages (~half of homes in village lost), whole village self-evacuated	1900 ha Department of Conservation estate & small plantation burnt

Research Rationale

Climate change predominantly increases the risk of wildfires by increasing temperatures and reducing moisture (Williams et al., 2019). Higher temperatures reduce relative humidity and prolong droughts, making fire fuels more available (Dai et al., 2018). Changing rainfall patterns also result in increased rainfall in some areas, but drier conditions in others (Shukla et al., 2019).

Climate change modelling predicts that Aotearoa New Zealand will become hotter and drier overall, creating conditions that increase both the frequency and severity of wildfire events (Pearce et al., 2005; Pearce & Clifford, 2008; Pearce et al., 2011; Scion, 2011; Watt et al., 2019). However, even the most recent of these studies relied on climate simulations that are now obsolete and used sparse spatial resolution and outdated statistical techniques. Although they used a range of global climate models and emissions scenarios, the uncertainty associated with projected changes in fire risk is also poorly understood. Therefore, the exact spatial footprint and details around potential changes in wildfire risk are not known with robust confidence due to the use of out-of-date data and basic methodology.

The increased hazard associated with changing climate is further compounded by changing human landscapes. The number of New Zealanders living and recreating within the RUI is rapidly growing (Andrew & Dymond, 2012). Not only are more people exposed to wildfire risk, but the growing number of people and homes also introduces more opportunities for human-caused wildfires to occur (Radeloff et al., 2018) through ignition sources such as mower blade strikes, recreational fires and fireworks, escaped rubbish burns, electrical faults and arson. Additionally, many new RUI residents and visitors may have little knowledge about fire risks or lack experience with fire use, so will pose greater individual risk of starting accidental wildfires than experienced rural residents (Jakes et al., 2010; Langer and Hart, 2014). Evidence suggests the general Aotearoa New Zealand public does not fully appreciate the increasing risk from wildfire or understand their mitigation options (Langer & Wegner, 2018).

Particularly in Aotearoa New Zealand, previous social research into wildfire risk has focussed on rural areas, small towns and lifestyle properties after wildfire events and other natural disasters. Little is known about the wildfire vulnerabilities, perceptions and behaviours of suburban residents in the RUI and in particular those that have not experienced a significant wildfire. The relatively recent devastating Port Hills and Nelson-Tasman wildfires within the RUI highlight the need to consider residents in the urban fringe of the RUI, who have been identified as a new audience that face growing threat from wildfires (Langer & Wegner, 2018). In addition, little is known about the effectiveness of community engagement initiatives of agencies to date – do people turn evidence of wildfire risk and guidance on preparedness activities into actions? Allied to this there is a continual influx of new land/sections and homeowners that have not been exposed to community engagement and do not have established networks to access local information. This sector of the community deserves particular emphasis. In addition, where RUI residents are aware of risk, there may be practical barriers to mitigation action. Similarly, advice developed for rural contexts may not be feasible in the RUI.

Aim of this Study

The primary aim of this study has been to support agencies in planning for and reducing the risk of extreme wildfires in Aotearoa New Zealand's vulnerable RUI. In meeting this aim we have applied the latest high-resolution climate models and a new mapping of the growing RUI to enable wildfire threat assessment and prioritisation of engagement and risk reduction efforts. Following this we have recommended best practice wildfire risk reduction, mitigation and preparedness actions agencies can communicate when engaging with at-risk RUI communities.

The project was designed and has built on Scion Rural Fire Research team's latest wildfire risk climate change simulations and research into landowners' risk perception and preparedness to understand where climate change is increasing the risk of wildfire, where communities are most exposed at the interface between urban development and rural vegetation, and what risk reduction and mitigation actions households and communities can implement to reduce their wildfire risk and increase their preparedness. This study has been funded by the Ministry for Primary Industries (MPI) under the Sustainable Land Management and Climate Change (SLMACC) Fund.

Research Alignment

This SLMACC study has utilised findings from previous rural fire research together with the latest quantitative fire climate projections currently being produced by the Scion Rural Fire Research team to assist in assessing this wildfire extension research priority. Given the urgent requirement for this improved understanding, the Ministry of Business, Innovation and Employment (MBIE) Extreme Fire programme has aligned support for this work in the form of an in-kind contribution. This support has included computing time to calculate the physical risks of climate change to fire danger needed to analyse a terabyte of NIWA climate projections (Ministry for the Environment (MfE), 2018).

The study complements Scion's research on understanding wildfire risk perception and mitigation actions in the urban fringe, as well as identifying strategies to encourage residents in complex, diverse urban fringe neighbourhoods towards better preparation for wildfire and other hazards. The allied research includes a qualitative case study on wildfire risk perception and mitigation for the Mt Iron community funded by the Resilience to Nature's Challenges Tranche 2 High Impact Weather theme and a quantitative survey in the case study area funded by Fire and Emergency New Zealand (FENZ).

The principal research objectives have been developed to align with:

- Resilience to Nature's Challenges Tranche 2 High Impact Weather theme https://resiliencechallenge.nz/scienceprogrammes/weather-theme/;
- Fire and Emergency New Zealand's 2017-2021 Statement of Intent (Fire and Emergency New Zealand, 2017);
- National Emergency Management Agency (NEMA) (formerly the Ministry of Civil Defence and Emergency Management) National Disaster Resilience Strategy (MCDEM, 2019);
- Sendai Framework for Disaster Risk Reduction (UNDRR, 2015);
- World Weather Research Programme High Impact Weather Implementation Plan (WWRP, 2014);
- Strategic priorities for Te Uru Rākau, Protecting forests from summer wildfires (MPI, 2020a);
- The One Billion Trees Programme (MPI, 2020b);
- He Pou a Rangi (Climate Change Commission), in minimising risks to forests as carbon sinks (He Pou a Rangi, Climate Change Commission 2021);

- National Climate Change Risk Assessment and the Conservation and Environment Science Roadmap (MfE, 2017; 2020);
- Department of Conservation Managing fire in the natural estate (DOC, 2005);
- Forest Owners' Association strategy (FOA, 2019; Forest Research Committee of the Forest Growers Trust Board Inc., 2021); and
- National Wilding Conifer Management Programme (MPI, 2014).

Northern Wānaka/Albert Town Community Case study

Wildfire and climate change studies have identified Central Otago as having high wildfire risk. A combination of highly combustible fuels, limited road access, dry summers and limited water resources for fire suppression in areas at some distance to the lakes have long made the area a high risk for extreme fire. This risk is likely to be accentuated under climate change (see Updating of projections of fire risk with climate change, Results and discussion section). Parts of the region are growing rapidly, with recent subdivision developments bringing new residents and short-term national and international visitors who may lack wildfire awareness and preparedness into this expanding area of Otago. The majority of new housing developments in Central Otago, as well as many subdivisions in other parts of Aotearoa New Zealand, aim at buyers in the medium to high socio-economic groups.

Queenstown Lakes is one of the fastest growing districts in Aotearoa New Zealand (Statistics New Zealand, 2020). Coupled with extensive growth in international visitors, the resident population has tripled since the early 1980s and is projected to increase 54% between 2011 and 2031 (Queenstown Lakes District Council, 2021). The social science component of this research is focused on a case study in the northern Wānaka/Albert Town area, 70 km northeast of Queenstown (Figure 2). Northern Wānaka/Albert Town provides an extreme example of RUI communities at risk in the Aotearoa New Zealand fire environment and an opportunity to study wildfire mitigations for residents within suburban developments in a high-risk RUI zone where further development is likely. This area contained approximately 2,418 occupied dwellings and an usual resident population of approximately 6,564 according to Census 2018 (Table 2; Statistics New Zealand data, 2019). The extent of holiday homes is unknown; however, fully a third of private dwellings were not occupied on census night. It is a high socio-economic community with principally Aotearoa New Zealand European residents with tertiary education. The location of subdivisions relative to potential significant wildfires and the relatively lack of wildfire considerations within local government planning, represents a common issue nationally and globally.

Particular attention has been concentrated on the community with homes nestled in highly flammable regenerating kānuka (*Kunzea ericoides*) vegetation on the lower slopes of Mt Iron within northern Wānaka/Albert Town. This is a high wildfire risk area and a focus of concern for agencies and the community.

Despite the high wildfire risk and frequency of wildfires in the surrounding area, such as Closeburn near Queenstown (2005) and Lake Ōhau (2020), the northern Wānaka/Albert Town community has not had the direct experience of a significant wildfire. However, a few local fires during the period 2012-2019 have been reported, including one on the slopes of Mt Iron in 2012[3].

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[3] 2012 Mt Iron, https://www.nzherald.co.nz/nz/residents-flee-after-wanaka-fire/FKJYMJ5VRDA6KQXR52QX6RACNQ/, https://www.stuff.co.nz/national/6219743/Terrified-residents-flee-Wanaka-bush-fire

2014 burn-off near Wanaka, https://www.stuff.co.nz/dominion-post/news/10648109/Morgan-says-sorry-after-Wanaka-burnoff

2017 Dublin Bay, https://www.stuff.co.nz/national/90246660/large-scrub-fire-burning-near-wanaka

2018 Lake Hawea, https://www.newshub.co.nz/home/new-zealand/2018/11/fire-crews-responding-to-scrub-fire-at-lake-hawea.html

2018 Mt Alpha/Mt Roy, https://www.stuff.co.nz/national/100311850/massive-fire-burning-on-outskirts-of-wanaka, https://www.stuff.co.nz/national/100688107/500000-firefighting-costs-estimate-for-mt-alpha-fire-in-wanaka

2019 Diamond Lake, https://www.stuff.co.nz/national/116396712/large-fire-burning-on-edge-of-national-park-near-wanaka

Figure 2: Case study area with survey zones labelled from allied FENZ survey (1. Mt Iron, 2. Clutha River, 3. Sticky Forest, 4. Elsewhere within northern Wānaka and 5. Elsewhere in Albert Town).

Table 2: Northern Wanāka/Albert Town case study area, 2018 Census data (Statistics New Zealand, 2019a, 2019b).

	2018 Census*
Population	
Usual resident population	6,564
Dwellings	
Total private dwellings	3,630
Occupied dwellings	2,418
Home ownership	
Own	71.4%
Rent or otherwise do not own	28.6%
Gender	
Female	50.5%
Male	49.5%
Gender diverse	0%
Ethnicities**	
New Zealand European / European	93.2%
Māori	5.6%
Asian	4.0%
All other ethnicities	3.2%
Education	
Less than secondary school	8.5%
High school or secondary school qualification	34.9%
Trade qualification or tertiary school certificate or diploma	23.8%
Bachelor's degree	18.6%
Postgraduate degree or higher	14.3%

* Based on the combined values for the Wānaka Waterfront, Wānaka North, and Albert Town Statistical Area 2 zones.

** Totals exceed 100% because participants were able to report multiple ethnicities.

Methods

The research has been divided into four subprojects: Changing wildfire risk with climate change; Mapping of the RUI at-risk communities; Northern Wānaka/Albert Town community case study; and Wildfire mitigations for homeowners and communities.

Changing Wildfire Risk with Climate Change

In an effort to provide improved estimates of potential future fire risk for Aotearoa New Zealand, the latest global climate change simulations downscaled for the whole country were used to provide updated estimates of projected changes in wildfire risk. The updated analysis uses the latest climate scenarios (from the Intergovernmental Panel on Climate Change's Fifth Assessment Report (IPCC AR5) (see MfE, 2018), and the application of a fire weather risk algorithm explicitly run with these downscaled regional climate projections for Aotearoa New Zealand at a high spatial resolution.

These detailed regional projections of climate changes have been produced by the National Institute of Water and Atmospheric Research's (NIWA) downscaling output from the IPCC AR5 global climate models (GCMs) on a 5 km grid covering Aotearoa New Zealand (MfE, 2018). The projections incorporated four future climate emissions scenarios known as representative concentration pathways (RCPs), these being RCP2.6, RCP4.5, RCP6.0 and RCP8.5. They are based on their approximate total radiative forcing at the year 2100 relative to 1750. These RCPs include one mitigation pathway (RCP2.6, which requires removal of some of the CO2 present in the atmosphere), two stabilisation pathways (RCP4.5 and RCP6.0), and one pathway with very high greenhouse gas concentrations (RCP8.5). Regional Climate Model (RCM) simulations for all four RCPs were conducted with six GCMs (HadGEM2-ES, CESM1-CAM5, NorESM1-M, GFDL-CM3, GISS-E2-R & BCC-CSM1.1), which were selected as they validate well in the Aotearoa New Zealand region when compared against historical observations but also span a wide range of climate sensitivity. Data from these GCM projections have been bias-corrected to minimum and maximum temperature and precipitation and downscaled using local topography and wind direction (Pearce et al., 2020; Scion, 2020; Melia, et al., under review).

As well as looking at traditional measures of fire climate severity, such as fire danger ratings from the Fire Weather Index (FWI) System used in Aotearoa New Zealand (Anderson, 2005), this study also used daily and seasonal severity ratings (Harvey et al., 1986) calculated from the FWI to define fire season length and fire intensity 'ranks' (after British Columbia Forest Service, 2019; see Table 3). These were in turn used to determine return intervals for extreme fire danger conditions.

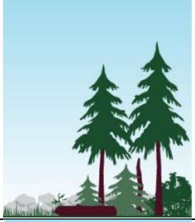
Mapping of the Rural-Urban Interface at-risk Communities

The confluence between wildfire risk and urban and rural landscapes can be identified by using the intersection of human population and wildfire prone areas to highlight the most at-risk locations. A literature search summarised existing methods developed to-date for quantifying and mapping wildfire risk for Aotearoa New Zealand, including the identification of the RUI; e.g. the NZ Wildfire Threat Analysis System, Wildfire Prone Areas, FireSmart communities, and Strategic and Tactical Fire Management Planning/Wildfire Risk Management Planning. Findings were then compared with more recent international approaches to identify a best approach for mapping of the RUI for Aotearoa New Zealand, and a series of pilot studies were conducted to test the methodology developed (Luff, 2020; Pearce et al., 2020).

A simple methodology was identified that defines the extent of the RUI using the new national building footprint dataset and Land Cover Database (LCDB)[4] vegetation types, together with internationally recognised definitions for 'interface' and 'intermix' areas based on building density and proximity to

[4] Despite a more recent version (LCDB5) of the Land Cover Database being available, LCDB4 was preferred here to LCDB5 which amalgamated some key vegetation types needed for fire modelling and still used outdated imagery from late 2018 which fail to capture more recent urban expansion into the rural environment.

Table 3: Fire behaviour severity rank classes (after British Columbia Forest Service, 2019).

Rank	Fire Behaviour and Characteristics	Firefighting Tactics	Graphical Illustration
Rank 1 FWI > 3, DSR > 0.2	Smouldering ground fire • No open flame • White smoke • Slow (i.e., creeping) rate of fire spread	• Direct attack with ground crews using hand tools and water delivery systems (i.e., pumps and hose)	
Rank 2 FWI > 10, DSR > 1.6	Low vigour surface fire • Visible and open flame • Unorganised or inconsistent flame front • A slow rate of spread	• Direct attack with ground crews using hand tools, water delivery systems, or heavy equipment • Hand constructed control lines and lines that have been cleared of combustible material will likely be successful	
Rank 3 FWI > 17, DSR > 4.1	Moderately vigorous surface fire • Organised flame front – fire progressing in an organised manner • Occasional candling may be observed along the perimeter and/or within the fire • Moderate rate of spread	• Hand constructed control lines alone are likely to be challenged • Ground crews conducting direct attack may require air support from fixed-wing air tankers or helicopters conducting bucketing operations • Control lines constructed by heavy equipment will generally be effective	
Rank 4 FWI > 24, DSR > 7.5	Highly vigorous surface fire with torching, or passive crown fire • Organised surface flame front • A moderate or fast rate of spread on the ground • Short aerial bursts through the forest canopy • Short-range spotting	• Ground operations may not be successful at the head of the fire • Indirect tactics may be required to bring the head of the fire under control • Air operations may be required to support ground personnel	
Rank 5 FWI > 31, DSR > 12	Extremely vigorous surface fire or active crown fire • Black to copper smoke • Organised crown fire front • Moderate to long-range spotting and independent spot fire growth	• The limited options available include indirect attack and planned ignitions to remove fuel in the path of this type of fire behaviour • Ground operations are often restricted to fighting the least active sections of the fire	
Rank 6 FWI > 38, DSR > 17	A blow-up or conflagration • Organised crown fire front • Long-range spotting and violent fire behaviour probable • Possible fireballs and whirls • A dominant smoke column may develop which influences fire behaviour	• Firefighting under these conditions is extremely dangerous. • Suppression efforts will be well away from active fire behaviour including large-scale ignition operations to steer the fire	

flammable vegetation. Though often both described as the RUI, the interface is where dense urban development directly abuts vegetation while the intermix is where development slowly fades from scattered vegetation amongst houses and lifestyle properties to scattered houses amongst mostly rural vegetation (Figure 3). This methodology was used to determine the extent of the RUI for three pilot study areas used in previous studies (Wellington, Christchurch and Rotorua) (presented in Appendix A), followed by mapping of the national RUI extent across the entire country using this same methodology.

This has led to preparing the best current map of at-risk Aotearoa New Zealand RUI communities in the northern Wānaka/Albert Town area for use by regional and district agencies to use with the community.

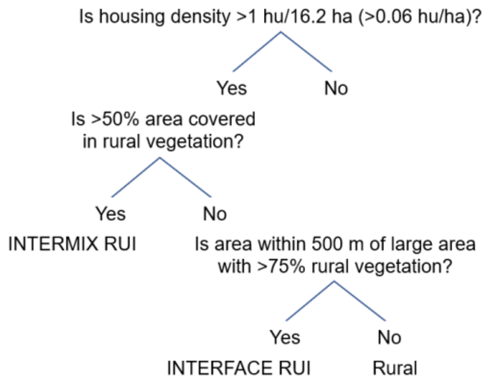


Figure 3: Method for distinguishing between intermix and interface RUI (Stewart et al., 2007). ('Hu' = housing unit).

Northern Wānaka/Albert Town Community Case Study

The northern Wānaka/Albert Town Community case area was selected in discussion with FENZ national and local staff involved in rural fire management. The specific target area was determined based on advice from FENZ officials and a wildfire consultant from the Otago region during an online workshop on 17 June 2020. It was decided that suburban residents on the urban side of the RUI should be targeted to understand elements of social wildfire risk in a context where wildfires have not occurred in recent years. The motivation for this research was to enable fire, civil defence and emergency management and land managers to better understand RUI audiences, identify appropriate community engagement methods (for communicating wildfire risk mitigation options) and to further develop RUI engagement materials and processes that are suited to their needs.

Data collection within the case study area primarily centred on interviews and focus groups with key agency and community stakeholders and groups of RUI residents in November 2020 and April 2021. Sixty-five participants took part through interviews, focus groups and workshops. All participants were supplied with a project information sheet assuring them of the confidential nature of the research and reported results, and were asked to sign a consent form to participate in the research (Appendix B). Participants included: 35 local residents (such as residents' associations, developers, early childhood centre and holiday park staff, and Māori residents); 27 agency staff (Otago FENZ, Queenstown Lakes District Council (QLDC), Otago Regional Council (ORC), CDEM Otago and Department of Conservation (DOC) staff); one wildfire consultant; and 2 elected QLDC Councillors.

Summary of key agency and community stakeholder engagement (some individuals were involved in more than one discussion)

- June 2020 – online fire agency workshop – 4 FENZ staff from Otago District and 1 wildfire consultant.
- 23 – 30 November 2020 – interviews/focus groups
    - 21 agency staff (two on-line) – FENZ Otago District, QLDC, ORC, CDEM Otago and DOC staff;
    - 2 elected councillors;
    - 28 residents – including 2 developers and 1 landscape architect; and
    - 1 pan-Māori organisation representative, Mana Tāhuna Charitable Trust.
- 28 April – 3 May 2021 – interviews/workshops
    - 11 agency staff - FENZ Otago District and national and QLDC;
    - 2 elected councillors (one on-line);
    - 1 developer;
    - 1 landscape architect;
    - 8 community resident association representatives;
    - 1 pan-Māori organisation representative, Mana Tāhuna Charitable Trust; and
    - 2 leaders of local Māori organisations.

The first phase of the case study involved key stakeholder and community engagement. It was focused on identifying influences behind wildfire risk perception and mitigation in suburban areas of the RUI, and understanding how to encourage complex, diverse urban fringe neighbourhoods to undertake better wildfire preparation (June and November 2020). The second phase of engagement extended from the first, and allowed a discussion of the relevance of a range of possible wildfire preparedness mitigations (see next subproject below) for the northern Wānaka/Albert Town area to be discussed with Otago FENZ and QLDC staff, councillors and a range of key community stakeholders (April/May 2021).

Dialogue with stakeholders was combined with lessons learned from previous social research into rural and lifestyle block residents to identify key issues and to capture wildfire specific lessons on risk perceptions, evacuation behaviour and preparedness to address the knowledge gap (e.g. Jakes et al. (2010); Langer & Hart, 2014; Langer & McGee, 2017; Langer & Wegner, 2018).

Throughout this case study, the research team worked collaboratively with local representatives from FENZ, QLDC, Emergency Management Otago, DOC, and the Wānaka Community Board who have established a Mt Iron Wildfire Risk Reduction Project to help support the evaluation and implementation of risk reduction actions. This specific agency-led project is committed to working in partnership with the local Mt Iron community to reduce the risk and improve the levels of readiness and preparedness. The Mt Iron Wildfire Risk Reduction Project supported Scion's research and is currently launching a Community Response Group made up of community minded volunteers.

Wildfire Mitigations for Homeowners and Communities

In order to provide advice for homeowners to prepare themselves and their homes to reduce their risk from wildfire, the best-practice mitigation and preparation recommendations from around the English-speaking world were analysed. Publications from Aotearoa New Zealand, Australia, Canada and the United States were reviewed and all the recommendations relevant to household and community risk reduction and mitigation actions compiled. After reviewing 123 publications, saturation was reached — that is, we believed that we had compiled the full range of recommendations being made worldwide. This resulted in an initial list of over 1000 overlapping recommendations.

The recommendations were coded and grouped by topic, and then any repeating or overlapping concepts were merged into an initial synthesis list of approximately 250 recommendations. During this process, the first round of revision was undertaken to suit Aotearoa New Zealand contexts and ensure they do not conflict with relevant legislation or codes.

An internal workshop was held with Scion's lead fire scientist to revise the list according to expert knowledge and lessons from previous research and to make further revisions for the Aotearoa New Zealand context. At this stage, some recommendations which were considered counter-productive, ineffective or otherwise counter to Aotearoa New Zealand practices were removed. However, all recommendations produced by FENZ and its predecessors were retained for discussion purposes.

The draft recommendation list was shared with FENZ national representatives for initial review in late April 2020. Additional feedback was also collected through in-person workshops and interviews with FENZ regional and national and QLDC staff, and representatives of two local Māori organisations and the local community in Queenstown/Wānaka during the period 28 April – 3 May 2020. This involved discussing the practicality and likely uptake of the mitigations by RUI residents in the northern Wānaka/Albert Town community case study area. Revisions to the list were made following feedback (see Appendix C). Further evaluation by FENZ is on-going.

Results and discussion

Changing Wildfire Risk with Climate Change

Climate change predominantly increases the risk of wildfires by increasing temperatures and reducing moisture. Higher temperatures reduce relative humidity and prolong droughts, making fire fuels more available. Changing rainfall patterns also result in increased rainfall in some areas, but drier conditions in others.

Previous studies assessing the future wildfire risk in Aotearoa New Zealand have found that climate change will increase fire risk in many regions (Pearce et al., 2005; Pearce et al., 2011). However, the most recent of these studies (Pearce et al., 2011; Scion, 2011; Watt et al., 2019) relied on climate simulations that are now obsolete and used sparse spatial resolution with outdated statistical techniques. Although they used a range of global climate models and emission scenarios, the uncertainty associated with projected changes in fire risk is also poorly understood. Therefore, the exact spatial footprint and details around potential changes in fire risk are not known with robust confidence due to their out-of-date data and basic methodology.

Updating of Projections of Fire Risk with Climate Change

This research has updated our knowledge on wildfire risk for Aotearoa New Zealand and the effect of climate change. We have used observations of weather and fire conditions to generate highly detailed climate model simulations to simulate present and future fire weather conditions (Pearce et al., 2020; Scion, 2020). The updated analysis used the latest dynamically downscaled climate scenarios (IPCC AR5) and application of the fire weather risk algorithm. The primary advantage of the projections produced is the increase in detail and robustness of the spatial resolution presented, as the fire danger projections are described explicitly in every 5x5 km grid box. This has provided better estimates of projected changes in fire danger, both in terms of Fire Weather Index[5] (FWI) and Daily Severity Rating[6] (DSR) values, as well as fire season length[7] (SL) (Figure 4).

While results shown in Figure 4 are not entirely comparable due to the different methods used to define fire season length, they do indicate the improved spatial resolution of the latest projections compared to those of the previous study of Pearce et al. (2011) and reproduced by Watt et al. (2019). The results from this latest study also clearly show the increase in areas of the country projected to experience significant numbers of days each fire season that could produce severe fire behaviour, with large areas of the South Island in particular predicted by 2080-2099 to see more than 40 days/season of Rank 4 (Highly vigorous surface fires with torching or passive crown fires) with DSR values exceeding 7.5.

This component of the study has found that climate change will increase the frequency, severity and season length of fire weather conditions until at least mid-century, regardless of climate mitigation efforts represented by the different emissions pathways (RCPs). The highest fire dangers were found in the currently seasonally drought-prone and arid locations of Aotearoa New Zealand. For many regions, the fire risk is likely to become appreciably worse through the rest of the century compared to the last two decades, implying an increased need for awareness and preparedness. For the first time, we have found that conditions that led to the devastating 'Black-Summer'[8] fires in Australia during 2019-2020 are likely to occur every 3-20 years for areas of the Mackenzie Country, Central Otago and Marlborough. More specifically, an average of a 32% increase in fire season length is expected by 2095 in our northern Wānaka/Albert Town case study area in Central Otago.

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[5] Fire Weather Index (FWI) is dependent on four atmospheric variables: temperature, precipitation, relative humidity and wind speed.

[6] The Daily Severity Rating (DSR) is a numeric rating of the difficulty of controlling fires.

[7] The Season Length (SL) is the number of days in a year where the FWI exceeds the thresholds of producing a typical fire behaviour and firefighting response.

[8] 'Black summer' conditions are a combination of the two Van Oldenborgh et al. (2020) criteria: 1) seven days mean FWI exceeding 54, and 2) rolling 30-day DSR exceeding 20.

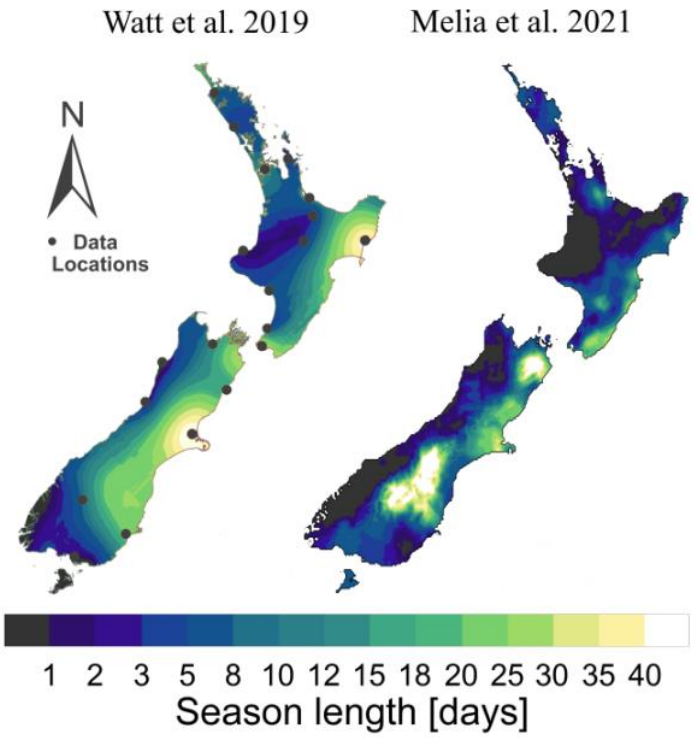

Figure 4: Projected 2080-99 fire season length qualitatively compared to projections from the different studies. The Pearce et al. (2011) projections reproduced by Watt et al. (2019) show the season length of very high and extreme fire danger under the CMIP3 AR4 SRES A1B emissions scenario. The updated projections show the fire season length for Rank 4 fire behaviour (highly vigorous surface fires with torching or passive crown fire activity; Table 3) in the CMIP5 AR5 RCP6.0 scenario.

Like many countries, climate change is predicted to increase the severity of fire seasons with more days with high fire risk over a longer period of time, depicted here as the mean of the daily severity rating values across the fire season (Figure 5). The hotspots, with a Seasonal Severity Rating (SSR[9]) >360, were found in areas of Central Otago and inland South Canterbury, northern Marlborough, South Wairarapa and Hawke's Bay. The greatest absolute increases in fire danger and fire season length are likely to occur in those locations with the currently most severe fire climates (in central Canterbury, Hawke's Bay and Marlborough). Intermediate and less severe locations may still see comparatively significant increases (including doubling or trebling of the number of days each year with extreme fire behaviour potential) but over a longer time period (by 2080 compared with 2050 for more severe locations).

A scenario (RCP2.6) in line with the Paris Climate Accord 2015 global mean temperature increase[10] shows a recovery in wildfire trends by 2100. This contrasts with a world under RCP8.5 conditions where wildfire risk is projected to increase on average 10% per decade. Trends to the mid-peak and decline RCP4.5 and RCP6.0 scenarios show increases of less than 5% on average per decade, with RCP6.0 showing more rapid increases on the South Island but approximately equal increases for the North Island (with RCP4.5 showing increases over a slightly larger area).

[9] Seasonal Severity Rating (SSR) is the sum of the daily DSR values for the entire year, rather than for a pre-prescribed fire season.

[10] The Paris Climate Accord global mean temperature goal is to hold global average temperature increase to "well below 2°C above preindustrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels".

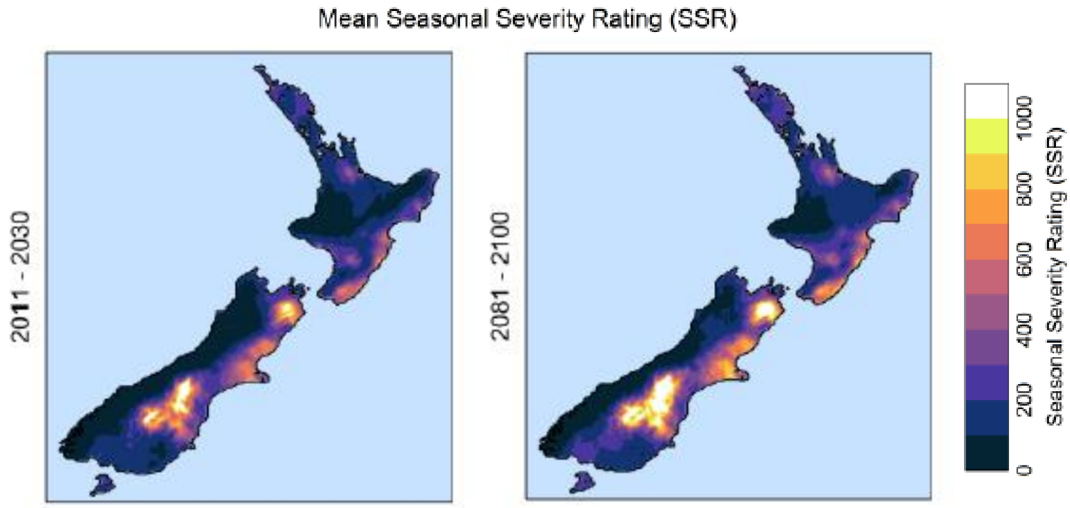

Figure 5: Mean Seasonal Severity Rating (SSR) for 2011-2030 and 2081-2100.

The worst 1 in 10-year conditions, defined as the 90th percentile, were examined as the general projections showed marked inter-annual variability. These were obtained by conducting simulations of fire dangers for 2280 individual years for the period from 2015 to 2100. The magnitude and the trend are approximately twice as bad for these 1 in 10-year events as for the mean. Areas that are added to the 'hotspot' class for 1 in 10-year probabilities include Hurunui, northern Tasman, coastal Manawatu-Wanganui and Taranaki, remaining areas of the East Coast, coastal Bay of Plenty, northern Coromandel and the Far North. By the end of the century under RCP8.5 conditions, an average year will be equivalent to the current 1 in 10-year conditions.

The time of emergence (TOE) is a key concept increasingly being used for climate science and adaptation to identify when climate change effects become apparent over existing climatic conditions (Harrington et al., 2016; Hawkins et al., 2020). Abatzoglou et al. (2019), who used RCP8.5 in a global study looking at emergence from a 'quasi pre-industrial' baseline, found climate change emergence in the South Island, although not in the North Island. This is particularly important for climate adaptation as we assume wildfire practitioners are calibrated (currently adapted) to the present fire climate of their region. The TOE of a new fire climate describes when on average the fire climate for that region will be 'noticeably' worse.

TOE calculations show that a 'new wildfire climate' is likely to emerge in the 21st Century for much of Aotearoa New Zealand (Figure 6). Much of the North Island is expected to experience an increase in background Rank 1 conditions (Table 3), which is where a pine forest landscape transitions into being flammable. Isolated pockets of Ranks 2 and 3 emergence exist on the East Coast and Waikato. Rank 2 conditions emerge in the southern parts of the North Island, with Ranks 3 and 4 emerging for Palmerston North surrounds, and up to rank 5 and 6 emergence in parts of the Wairarapa indicating potential for extremely vigorous surface or crown fires that would be difficult, if not impossible to control. In the South Island, much of the West Coast fails to meet TOE conditions due to a lack of determination of a robust fire season length. Emergence is concentrated to the lee side of the Southern Alps with large parts of Marlborough, Canterbury and Otago projected to experience Rank 6 emergence (the most extreme) and not limited to just remote rural areas.

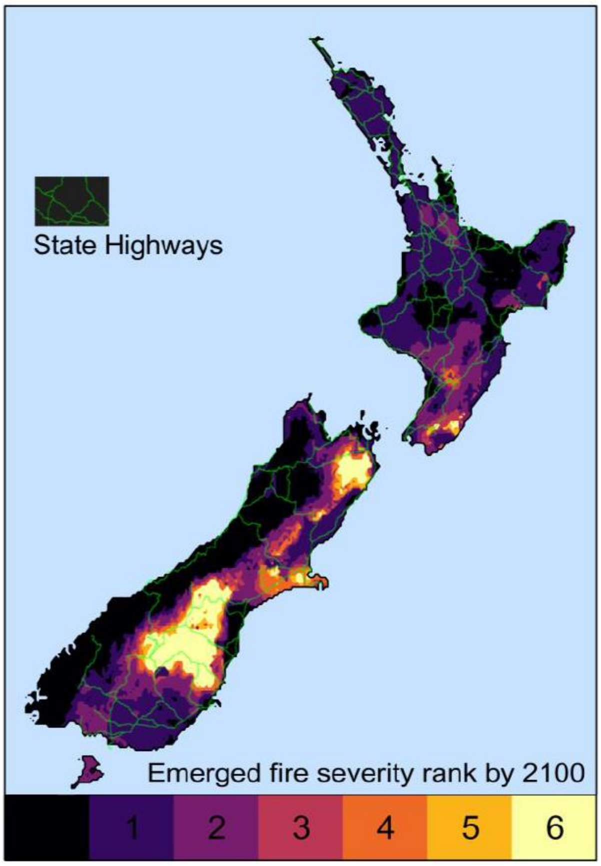

Figure 6: Areas projected to experience a significant change in wildfire risk season length up to the specified fire rank severity from current levels to 2100. Note that shaded areas also include all fire ranks below, e.g., area where Rank 6 has emerged will also experience emergence in Ranks 1-5.

The emergence of this new wildfire climate during the next 30-80 years will have significant implications for climate adaptation and emergency readiness. Detailed analysis of fire weather, both since 2015 and from the 21st Century climate simulations, shows that wildfire risk conditions similar to those experienced during the 2019-2020 Australian 'Black-Summer'8 currently occur in Aotearoa New Zealand, with a return period of fewer than 20-years in select districts (Figure 6). Somewhat unexpectedly, this analysis reveals for the first time, that there are select locations in Aotearoa New Zealand that reach the Australian 'catastrophic' or 'code red' threshold every few years (see Figure 7). The observed highest risk-lowest return period areas have return periods lower than five years and are found in the Mackenzie Basin and Central Otago regions – around Lake Tekapo (on State highway (SH) 8), Lake Aviemore and the Waitaki River (SH83), and the areas around Lake Dunstan (following SH6 and SH8) and the settlement of Cromwell.

However, the short observational record used for the baseline for current fire climate offers only the briefest of glimpses to the real risk picture as only a return period of fewer than five years is calculable. The true power of observationally calibrated MAVRIC_FWI RCM projections used in the analysis is exemplified in the right-hand map in Figure 7, where the full spectrum of the behaviour of the Australian 'Black Summer' conditions is revealed by sampling of the 2280 simulated years. This again highlights the Central Otago districts of the south-central South Island (roughly following SH80, SH8 Twizel through Alexandra and SH6 Wānaka to Queenstown) as areas where 'Black Summer'-like conditions will occur at frequencies of less than 5 years. One in 50-year return periods or less for 'Black Summer' type conditions are also simulated for the areas around Christchurch, Marlborough, Kaikōura and Hastings.

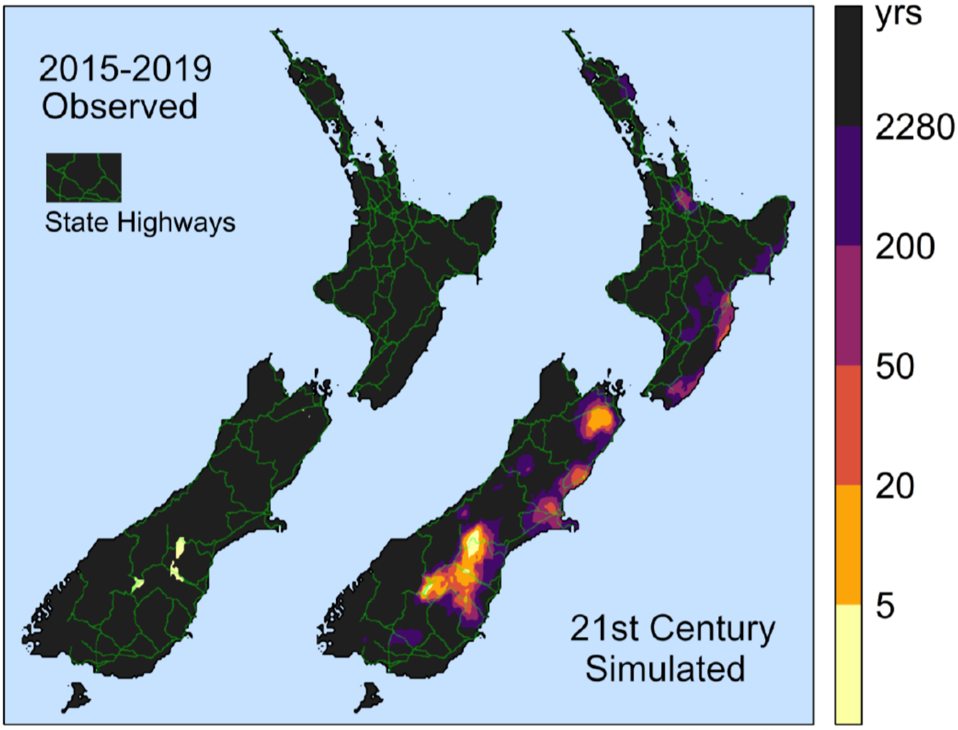

Figure 7: Observed (left) and simulated (right) 21st century annual return period of an Australian 2019/20 style 'Black Summer' fire risk[8] from all simulations.

Mapping of the Rural-Urban Interface

Definition of the Rural-Urban Interface

Since knowledge of the extent of the RUI is useful for comparison across locations and time periods, it is important to define it using a set of standardised definitions. Despite the extensive literature written on the topic, a commonly accepted definition for the RUI (or WUI, wildland-urban interface as it is referred to in the United States) is yet to be established (Stewart et al., 2007). The original definition given to the RUI/WUI was "any point where fuel feeding a wildfire changes from natural [wildland] fuel to man-made [urban] fuel" (Butler, 1974, cited in Platt, 2010). The theoretical understanding of the term progressively evolved until it was formally defined in the US Federal Register as "where humans and their development meet or intermix with wildland fuel" (USDA & USDI, 2001, pp. 752-753). This general definition has been widely referenced in the literature since its publication. However, the Federal Register definition has not been officially adopted either in the US or Aotearoa New Zealand and studies continue to redefine its parameters for different usages and contexts. It is important to note that the RUI refers to a 'community' of buildings in proximity to flammable vegetation in rural or urban interface areas, rather than isolated houses surrounded by vegetation (Figure 8).

The RUI is commonly broken into three contributing components, including human presence, wildland vegetation and a buffer distance that represents the potential for effects (i.e. wildfire or associated ember transport) to cross boundaries and impact neighbouring lands (Stewart et al., 2007). Several studies (Haight et al., 2004; Radeloff et al., 2005; Stewart et al., 2007) define the human presence component in terms of presence of 'structures' (buildings) using the building density threshold value of '>1 structures per 40 acres' (6.17 structures/km2) set by the USDA and USDI (2001). Platt (2010) explains that to meet this density threshold, structures in the area must be within a 1,890 ft. (576 m) radius of each other. At this distance, a set of 40-acre square blocks with one structure at the centre of each would be the minimum required density to meet the threshold.

Figure 8: Rural-urban interface and intermix developments showing examples of rural-urban development endangered by wildfire. This site shows areas affected by the 2017 Port Hills wildfire.

Stewart et al. (2007) define wildland vegetation as "all types of vegetative cover except those that are clearly not wild, such as urban grass, orchards, and agricultural vegetation". For areas that meet the building density threshold, if at least 50% of the area represents wildland vegetation then the RUI is classed as 'intermix'. Also, according to this study, areas that have less than 50% wildland vegetation but are situated within a 1.5-mile (2.4 km) buffer distance of a 5 km2 area of at least 75% wildland vegetation are classed as 'interface' (Figure 9). This buffer distance is considered representative of the distance an average firebrand can fly and potentially reach a structure (Summerfelt, 2003; Stewart et al., 2007).

Two studies (Radeloff et al., 2005; Stewart et al., 2007) conducted a sensitivity analysis to test the robustness of RUI area estimates based on the above threshold values for housing density, vegetation density and buffer distance. Both concluded that the values provide a robust RUI assessment, validating the use of these parameters (see Luff, 2020, and Pearce et al., 2020 for more details). However, sensitivity analysis carried out by Pearce et al. (2014) found that a buffer distance of 500 m is likely a more suitable value for Aotearoa New Zealand. The reduced distance represents a more accurate estimate of spotting distances for New Zealand plant species typically found in RUI areas, including gorse, mānuka scrub, and pine trees (Pearce et al., 2014). Since this is an Aotearoa New Zealand study, the 500 m buffer distance has been used as a parameter for the RUI mapping method used in this analysis.

A study by Anderson et al. (2008) analysed Aotearoa New Zealand wildfire records from 1991-2007 to determine trends in fire occurrences. The results found that of the total area burned, 54% was made up of grasslands, 40% scrublands and only 6% forests. Therefore, wildland vegetation includes grass and scrub land cover types, as well as forests, for the purpose of this study.

Review of Existing RUI Mapping Methods

Since the RUI is the interface of human development with wildland vegetation, it can be computed by finding the spatial intersection of wildland vegetation with areas of appropriate building density. Throughout the literature, a significant number of international studies have developed their own adaptations of RUI definitions and Geographical Information Systems (GIS) mapping techniques. Pearce et al. (2014) tested the application of four methods for spatially identifying RUI areas, with these and more recent international methods also being reviewed by Luff (2020) who confirmed these remain the most relevant approaches for Aotearoa New Zealand.

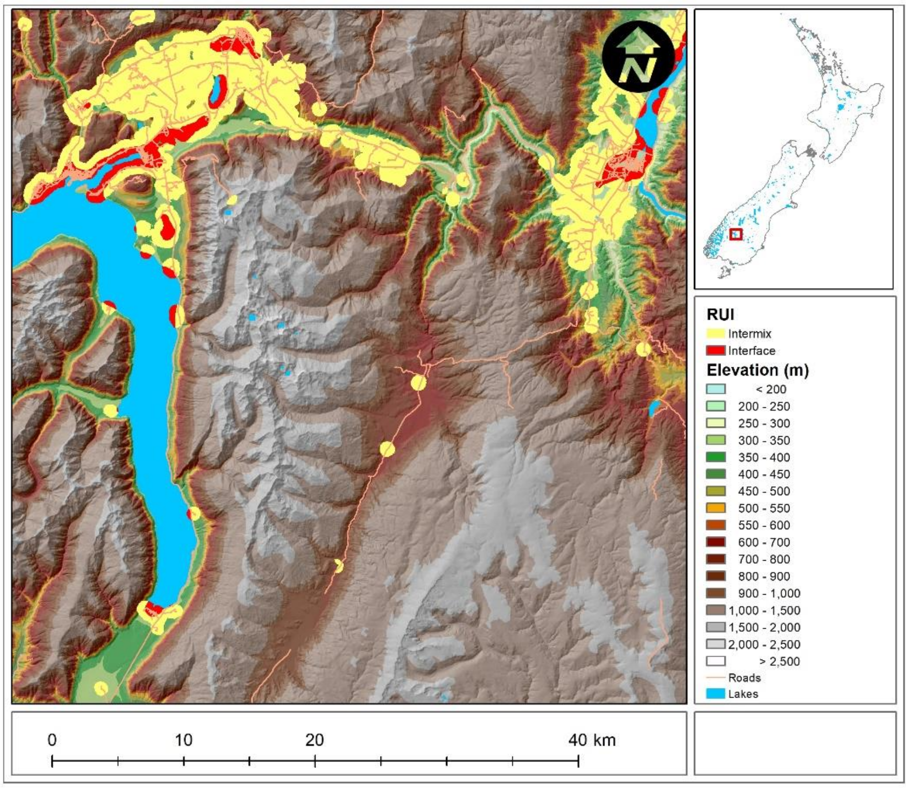

Figure 9: RUI in the Queenstown area. The interface (red) is where dense urban development directly abuts vegetation, while the intermix (yellow) is where development slowly fades from scattered vegetation amongst houses and lifestyle properties to scattered houses amongst mostly rural vegetation. This map should be treated as interim, due to the need for validation to ensure accuracy and currency.

Three of these methods (Haight et al., 2004; Theobald & Romme, 2007; Zhang et al., 2008) use census meshblock data for housing density together with vegetation land cover data to identify the RUI and define its categories. Meshblocks are aggregations of point-based features that are bounded by physical features such as roads and streams, causing large variation in size and limited resolution in more rural areas (Bar-Massada et al., 2013). This zonal approach provides a useful gauge to the extent of RUI areas, but the variable nature of the data itself brings limitations to the precision of density values.

The limitations of census-block data are due to the size of each unit being dependent on population and housing density, trending towards larger units where people and houses are more widely spread. This can result in large census blocks being excluded from the RUI when they contain a small area of clustered homes that is outweighed by large uninhabited spaces (Stewart et al., 2009).

The fourth tested method (Lampin-Maillet et al., 2009) combined individual building footprint data with vegetation cover data to identify the RUI based on precise building locations and the distance between buildings and vegetation structure. Pearce et al. (2014) suggested that the Lampin-Maillet method provides a better description of the true RUI area compared to the meshblock-based approaches; however, the building footprint data was not available for every Aotearoa New Zealand region at the time their report was published. Since then, a comprehensive national building footprint data layer has been developed and made available, permitting a precise estimation of the RUI in Aotearoa New Zealand and avoiding the use of subjective definitions based on zonal density. The Lampin-Maillet method is more rigorous in its identification of RUI buildings so that it will recognise the most isolated of dwellings that fit the method criteria. However, the premise of a RUI map is to identify the communities that are at risk due to the close proximity to vegetation fuels. Therefore, including individual homes makes the RUI classification less useful for targeting appropriate communities for fire safety programs and could put a strain on the budget constraints of fire managers (Bar-Massada et al., 2013).

Bar-Massada et al. (2013) developed a hybrid method that utilises the building density threshold from the zonal approach but calculates building density values based on building footprint data as opposed to meshblock data, resulting in the inclusion of only appropriate communities. This technique computes the density of structures and wildland vegetation of a 'neighbourhood' around each map cell within a radius 'r' by using a moving window analysis to create a series of raster maps, which are then combined to form the RUI map. A notable advantage of this method is that only two different datasets are required to determine the RUI (building footprint and vegetation cover).

To assess the sensitivity of RUI extent to the neighbourhood radius size 'r', Bar-Massada et al. (2013) further tested and compared 10 values of 'r' ranging from 100 to 1000 m. The results showed that the choice of neighbourhood size 'r' had a significant effect on the subsequent RUI extent. To be consistent with the density threshold published in the Federal Register (USDA & USDI, 2001), the maximum radius of 576 m recommended by Platt (2010) was chosen for use in this analysis going forward.

Several other alternative approaches were also identified from the international literature (e.g. Lu et al., 2010; Haas et al., 2013; Johnston & Flannigan, 2018). However, despite the extensive range of RUI mapping techniques present in the literature, it is widely agreed that there is no single method that satisfactorily produces a 'true' or 'best' representation of the RUI area over a region or country (Pearce et al., 2014). Choosing the right method depends on the purpose for which each method is used, and the availability and quality of data and analysis on which it is based (Stewart et al., 2009). It is therefore important that all assumptions and limitations associated with any method should be made explicit as part of its implementation.

The review by Luff (2020) therefore identified the Bar-Massada et al. (2013) method as the best currently available for identifying the RUI for Aotearoa New Zealand. A simple GIS mapping methodology was developed that utilises the new national building footprint dataset and LCDB4 vegetation types, together with the internationally recognised definitions for 'interface' and 'intermix' areas based on building density and proximity to flammable vegetation (with the exception of distance to vegetation, where 500 m was used instead of 1.5 mi (2.4 km)). This methodology is outlined in detail in Appendix A.

The methodology was used to determine the extent of the RUI for three pilot study areas – Wellington, Christchurch and Rotorua. The results were successfully compared with those from the previous study by Pearce et al. (2014); these results are contained in Luff (2020) and Pearce et al. (2020). This same methodology has also now been used to map the RUI for the Queenstown and Wānaka case study areas (Figures 9 & 10), and also for the national extent with maps produced for each of the North and South Islands (Figure 11). However, **the results from this mapping should be considered interim and treated with caution, as validation is still required** by operational personnel to ensure they are accurate and reflect reality, especially given known issues associated with the currency and accuracy of the underpinning landcover and building datasets from which they are derived.

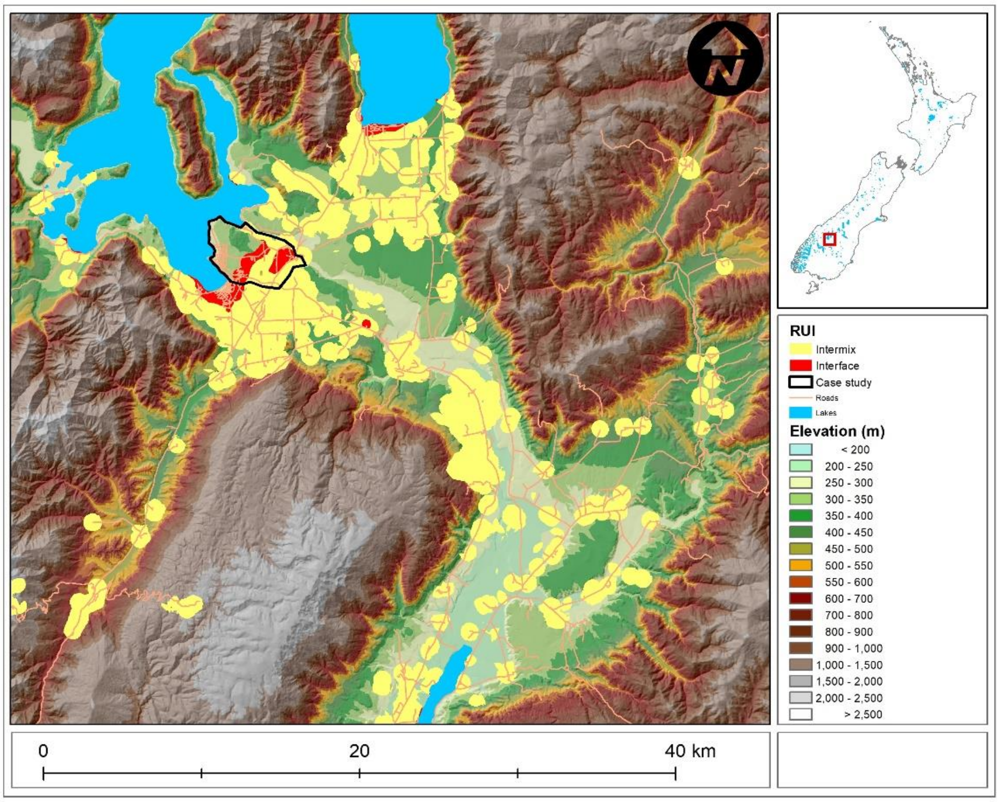

Figure 10: RUI in the Wānaka area identified using the new mapping methodology. Interface (red) and intermix (yellow). The northern Wānaka/Mt Albert Community case study is shown within the black outline. This map should be treated as interim, due to the need for validation to ensure accuracy and currency.

Impact of RUI Growth

A study in the United States found that human activity is responsible for the cause of approximately 80% of all wildfires (Nagy et al., 2018). Similarly, human causes were found to be responsible for more than 99% of fires in Aotearoa New Zealand (Anderson et al., 2008). As the RUI represents areas where humans (and their activity) meet flammable vegetation, it therefore creates an area of significantly increased wildfire ignition risk.

A study in Central Spain showed that spatial patterns of wildfire ignition are strongly associated with areas of human activity, with proximity to roads and urban areas being the most influential factors (Romero-Calcerrada et al., 2008). This evidence is further supported by Lampin-Maillet et al. (2009), who found that fire ignition density was twice as high in RUI areas. This suggests that as the RUI expands, so will the number of wildfire ignitions (Radeloff et al., 2018).

Radeloff et al. (2018) revealed that the RUI area in the United States grew by 33% from 1990 to 2010. This result suggests that RUI growth is strongly propelled by social and economic reasons, including the affordability of rural houses (or lifestyle blocks) that provide ready access to nature and recreation while being only a short distance from urban settings. In 1998, Aotearoa New Zealand had a total of just over 100,000 lifestyle properties. By 2011 this number had risen to 175,000 (an increase of 75%) (Andrew & Dymond, 2012). Furthermore, the population of rural areas with moderate urban influence (the RUI) in Aotearoa New Zealand was projected to increase by 21% between 2001 and 2021, compared with a national average for urban areas of 16% (Bayley & Goodyear, 2005).

As is evident in the population projections, migration to rural land is very popular in Aotearoa New Zealand. Jakes et al. (2010) found that landowners who had recently moved to rural areas were less prepared for a wildfire event than long-term lifestyle block owners due to a lack of experience coming from an urban setting.

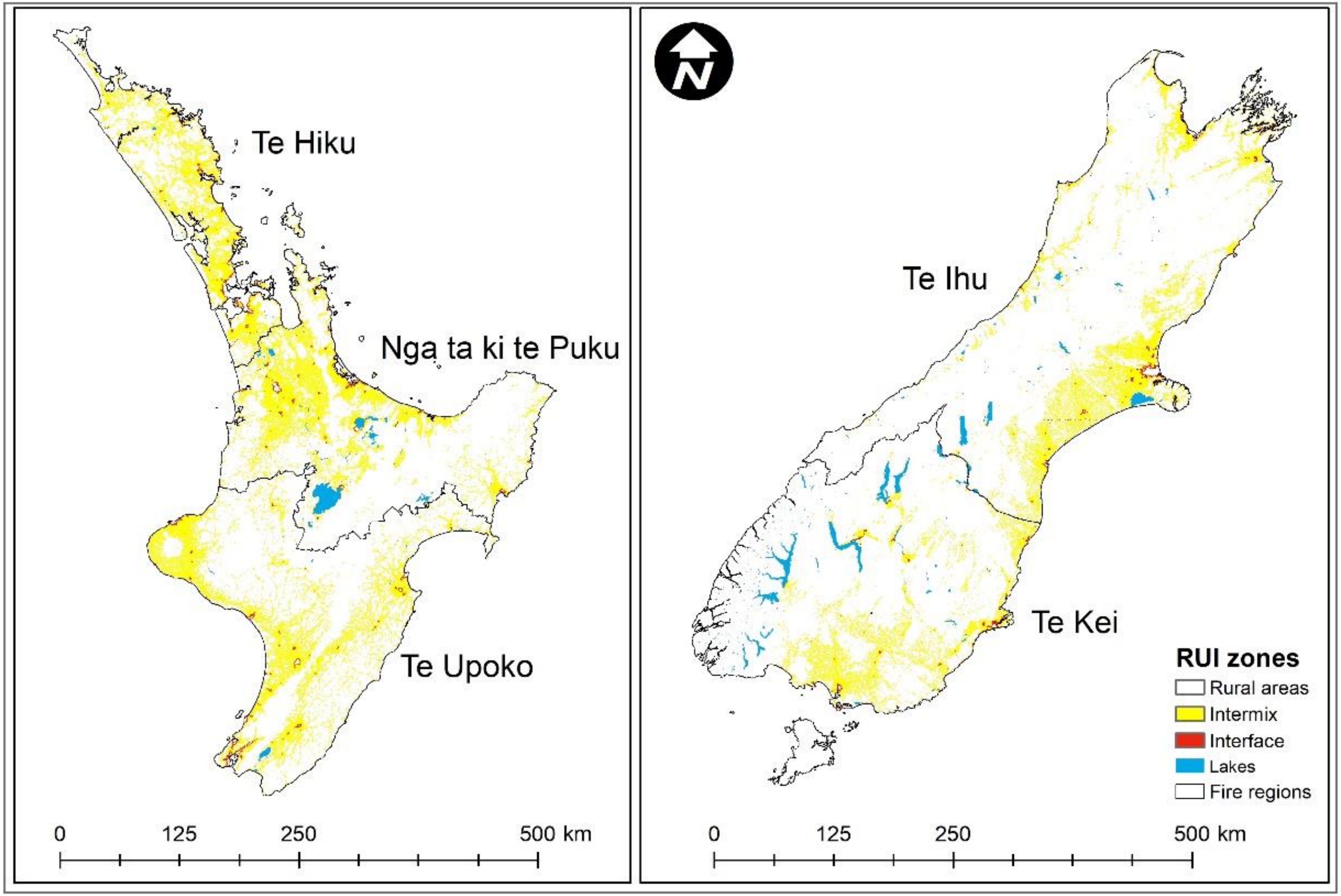

Figure 11: RUI areas across FENZ fire regions in both North and South Islands identified using the new mapping methodology. Interface (red) and intermix (yellow). These maps should be treated as interim, due to the need for validation to ensure accuracy and currency.

RUI growth is also present through urban fringe developments (e.g. Port Hills) (see Figure 8), which again puts less experienced suburban landowners into high-risk areas. Langer et al. (2018) suggest that these communities require special focus by fire managers to ensure residents are aware of the risk of wildfires and that fire management is appropriate to their context.

It is important that RUI growth is regularly monitored so that fire managers become aware of new changes to the high-risk environment, enabling them to interact appropriately to audiences of different experience.

The RUI mapping analysis undertaken here has, for the first time, provided estimates of the area of Aotearoa New Zealand falling within the RUI – both within the interface, and the surrounding intermix (Figure 11) – and therefore at high risk from wildfires. This shows that nearly 17% of the country (over 4.6 million ha) falls within the RUI (Table 4). This is made up of around 0.8% (almost 221,000 ha) of higher density interface, and 16.1% (nearly 4.4 million ha) in the less densely populated, more rural intermix.

As expected, with its higher population, the area of RUI (both interface and intermix) is higher in the North Island compared to the South Island. Regionally, the proportion of both interface and intermix is highest in the north of the North Island (FENZ Region 1, Te Hiku) at 2.4% and 31.8% respectively, and lowest in the south of the South Island (Region 5, Te Kei) at 0.4% and 9.5% (Table 4). The areas of total RUI in Regions 2, 3 & 4 (Nga ta ki te Puku, Te Upoko and Te Ihu) are similar at just over 1 million hectares, but due to the difference in sizes of these regions, the percentages are quite different, with Region 4 (Te Ihu) as the largest region having a considerably lower proportion of the region in RUI (12.4%) than these other two regions (22%), although not as small as Region 5 (Te Kei) at just 9.9%.

When considered at the FENZ district level, districts in Region 1 (Te Hiku) again have some of the largest percentages of RUI. The Waitemata district in particular has over half its total area (53.6%) in either intermix or interface, with Northland and Counties Manukau about a third (31.3% and 36.8% respectively; Table 5). Interestingly, the Auckland district has no intermix but over 40% of its area in interface, likely as a result of this highly urbanised region being dominated by higher density buildings that are more than 500 m inside the urban area and away from large areas of flammable vegetation. Counties Manukau (3.9%), on the boundary of Auckland city, and Wellington (2.2%) also have comparatively large areas of interface. After Waitemata (49.5%), the Waikato district (in Region 2, Nga ta ki te Puku) and somewhat surprisingly, Taranaki district (in Region 3, Te Upoko) have the next highest proportion of intermix (over 30%).

Table 4: Percentage of total area and area (ha) of intermix and interface within FENZ fire regions. These figures should be treated as interim, due to the need for validation to ensure accuracy and currency.

Fire regions	RUI zones	% of total area	RUI area (ha)
Te Hiku (Region 1)	Intermix	31.8	651,333
	Interface	2.4	48,784
Nga ta ki te Puku (Region 2)	Intermix	21.3	995,246
	Interface	1.0	48,855
Te Upoko (Region 3)	Intermix	21.2	1,065,872
	Interface	0.9	42,901
Te Ihu (Region 4)	Intermix	11.8	1,013,451
	Interface	0.6	52,297
Te Kei (Region 5)	Intermix	9.5	661,124
	Interface	0.4	27,837
Total New Zealand		**16.9**	**4,607,700**

Table 5: Percentage of total area of intermix and interface within FENZ fire districts, as a percentage of FENZ region area, and as a percentage of the total area of intermix, interface and total RUI across the country as a whole. These figures should be treated as interim, due to the need for validation to ensure accuracy and currency.

Fire region	District	Within District (% of total area)		Within Region (% of region area)		Across Country (% of Intermix/Interface/RUI)		
		Intermix	Interface	Intermix	Interface	Intermix	Interface	Total RUI
Te Hiku (Region 1)	Northland	29.5	1.8	19.9	1.2	9.0	10.7	9.0
	Waitemata	49.5	4.1	7.4	0.6	3.3	5.4	3.4
	Auckland	0.0	42.3	0.0	0.0	0.0	0.0	0.0
	Counties Manukau	32.2	3.9	5.7	0.7	2.6	6.1	2.7
Nga ta ki te Puku (Region 2)	Waikato	34.5	1.3	11.9	0.5	12.1	9.1	12.0
	Bay of Plenty	18.1	1.2	8.4	0.6	8.5	11.2	8.7
	Tairawhiti	10.2	0.5	1.9	0.1	2.0	1.8	2.0
Te Upoko (Region 3)	Hawkes Bay	18.0	0.5	6.1	0.2	7.1	4.1	6.9
	Taranaki	31.7	0.9	5.0	0.1	5.8	3.3	5.7
	Manawatu-Whanganui	19.0	0.5	6.5	0.2	7.6	3.9	7.4
	Wellington	20.8	2.2	3.3	0.4	3.8	8.1	4.0
Te Ihu (Region 4)	Nelson Marlborough	9.9	0.9	2.5	0.2	4.8	8.7	5.0
	West Coast	4.6	0.4	1.3	0.1	2.4	3.6	2.4
	Canterbury	18.4	0.9	4.6	0.2	8.6	8.5	8.6
	Mid-South Canterbury	17.7	0.4	3.9	0.1	7.3	2.9	7.1
Te Kei (Region 6)	Otago	9.7	0.6	5.9	0.4	7.9	9.3	7.9
	Southland	14.1	0.3	5.5	0.1	7.2	3.2	7.0

Confluence of the RUI and Fire Risk with Climate Change

The original intent of this part of the project was to overlay the projected changes in fire risk with climate change from the updated analysis onto the extent of the RUI identified from the second part of the study, with the aim of identifying the areas of the country where people and property are likely to be most at risk from future wildfires. However, issues encountered with access to the computing resource required to deal with the national building footprint dataset which delayed the RUI mapping, and a need for validation of the results from this mapping, meant it was not possible to complete this part of the project as originally intended. This also applied to plans to overlay spatial datasets for social components of wildfire risk such as vulnerability and resilience (for example, components of the NZ Resilience Index; MCDEM, 2019; Stevenson et al., 2019), as had previously been recommended by Pearce et al. (2014) in their attempt to identify wildfire prone areas. This work will be continued by Scion in conjunction with FENZ beyond the timeframe of this project (e.g. via the more recent MPI-funded SLMACC project, 'Triple Bottom-line Impacts from Wildfires').

However, it is possible to use some of the results from the project to begin to answer this question. Figure 12 shows the projected changes in the number of days per year exhibiting extreme fire potential, in this case defined as the potential for active crown fire in forest fuels (which occurs with daily DSR values >11.8, equivalent to FWI values >31), for main population centres across the country. The urban areas with the most severe fire climates under current climate – Rolleston and Christchurch – are predicted to have their fire seasons extended by 13-14% (1-2 days/year) by 2050, whereas fire season length for centres with more moderate fire climates – e.g. Wellington and Nelson – will increase by 23-28% (<0.5 day/year) from currently, and then only by 2080. The urban areas with the lowest fire climate severities – e.g. New Plymouth and Auckland – will see the greatest percentage increases (of 121-133%), which equate to a more than doubling of the current number of days with extreme fire behaviour potential; however this only amounts to an increase from about 0.1 to 0.2 days per year (or from 1 to 2 days per decade).

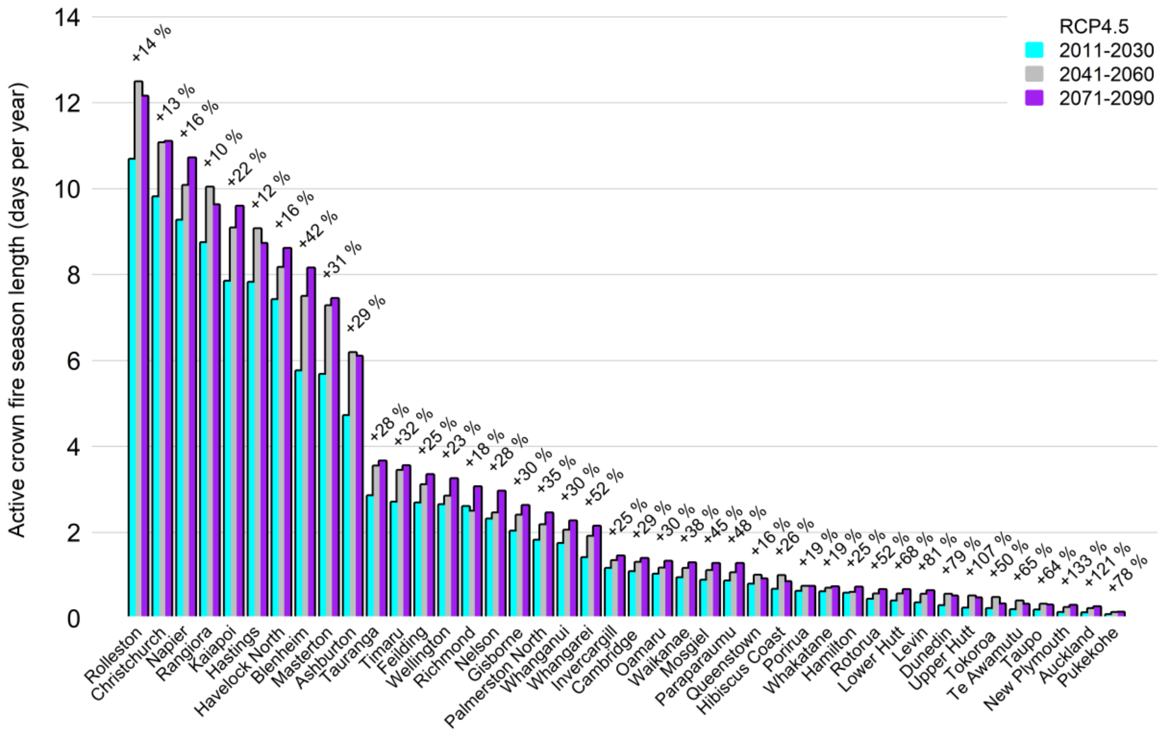

Figure 12: Projected changes in fire season length for major New Zealand settlements (with a population greater than 10,000) under RCP4.5 conditions, based on number of days per year exhibiting active crown fire potential (with DSR >11.8, equivalent to FWI >31). Quoted percentage changes are from 2020 – 2080.

For the most part, the main centres showing the greatest absolute changes appear to agree well with those regions identified in previous studies (e.g. Pearce et al., 2011/Scion, 2011; Watt et al., 2019) – and which are generally located in regions with the most severe fire climates under current conditions (i.e. Canterbury, Hawkes Bay and Marlborough). There are some interesting differences identified in the present analysis, however, including Masterton (Wairarapa) and Tauranga (Bay of Plenty) which did not feature as strongly in previous studies, and Dunedin (North Otago) which showed greater increases in the previous studies compared with the present analysis.

The RUI fire occurrence mapping analyses undertaken for the three pilot studies by Luff (2020) found that a wildfire is 1.9 times more likely to occur in the RUI. This was something of an expected outcome, as by definition the RUI is an area of increased wildfire risk due to the presence of more people that can start fires. Interestingly, the results showed that a wildfire was only 1.1 times more likely to occur inside the RUI for the Christchurch pilot study, which is significantly less than the likelihood for the Rotorua and Wellington pilot studies (2.7 and 2.4 times more likely, respectively). It appears that this is due to the larger RUI extent identified for the Christchurch study (61% of the total pilot study area), compared to the RUI extents identified for Rotorua (27%) and Wellington (32%). Luff (2020) also hypothesised that Christchurch's larger RUI extent is likely due to the high coverage of the grassland and cropland vegetation fuel classes to the west and north of Christchurch city, which represent the agricultural land-uses commonly seen in the Canterbury region.

Northern Wānaka/Albert Town Community Case Study

We were directed to our case study in northern Wānaka/Albert Town, northeast of Queenstown with its extreme wildfire risk and rapid housing development by FENZ to try and understand current wildfire risk perceptions and preparedness and explore means of encouraging the community to undertake better wildfire preparations.

Within northern Wānaka, extreme wildfire risk is most evident on the slopes of Mt Iron (Figure 13). More than 250 homes have been built on steep slopes (>15 degrees), mostly facing the prevailing north-westerly winds. The combination of slope and wind mean a wildfire would likely spread rapidly. Some have only one evacuation route on the steep, narrow roads which must be shared and with firefighting access. Wildfire susceptible designs and materials are common with most houses in the area built using highly flammable oiled cedar or other wood cladding to suit the local alpine aesthetic. Hundreds of residents and visitors walk tracks daily in the recreation area above the residential houses. In the worst-case scenario where a wildfire was to start at the north-western base of Mt Iron during a north-westerly wind and spread quickly uphill, hundreds of people could become trapped within minutes.

Additional high wildfire risk areas with development adjacent to highly flammable vegetation are located along the southern bank of the Clutha River and near the Sticky Forest (see Figure 2). Housing elsewhere in northern Wānaka/Albert Town is further from dense vegetation but would likely be exposed to ember attack from wildfires in the highest risk zones.

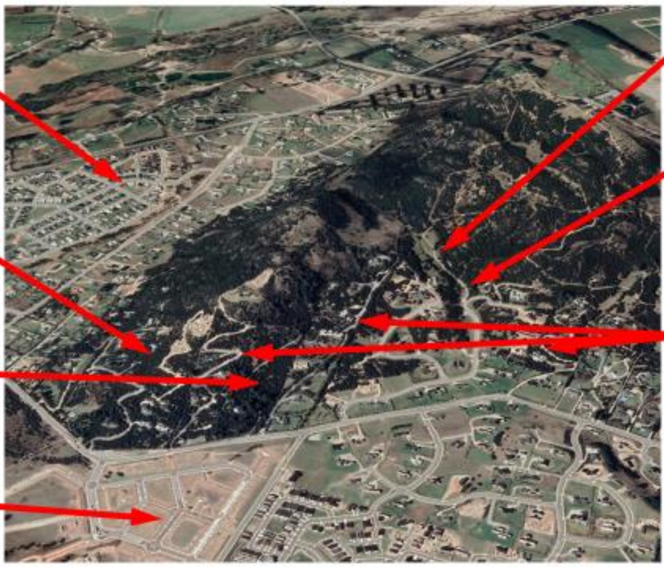

Figure 13: Wildfire issues in Mt Iron community.

Regulatory, planning, development and construction decisions have addressed biodiversity, soil and water protection, and amenity values without giving adequate consideration to the associated wildfire risk. The homes of the Mt Iron community are nestled amongst highly flammable regenerating native kānuka. Kānuka is classified as Threatened – National Vulnerable, and the area has been designated a Significant Natural Area, meaning clearing kānuka for defensible space or replacement with alternative less flammable native vegetation as green fire breaks requires a resource consent and may be limited. Covenants further restricting vegetation clearance were placed on many parcels during subdivision. In addition, part of Mt Iron is classified as an Outstanding Natural Feature essentially prohibits development in much of southern Mt Iron. District plan policies and community expectations require that buildings be largely concealed by vegetation to maintain the visual character of area.

The northern Wānaka/Albert Town is undergoing continuing development; with new subdivisions and ongoing construction of residential homes. Similar to other areas, consent applications are required for new houses and extensions.

In our interviews and focus groups with key community stakeholders we learned of the high wildfire awareness and anxiety of Mt Iron's permanent residents, which has been amplified by a wildfire that destroyed 48 houses (or half the village) at Lake Ōhau 70km away, 8 months earlier (November 2020). However, in most cases, the residents only became aware of the extreme wildfire risk after having purchased or built their homes. The residents reported that they have voiced their concern of the potential threat to lives and property to local agencies (primarily FENZ and QLDC). Their concerns focus on issues such as restrictions to remove protected native kānuka vegetation around their properties, flammability of cedar cladding of their houses and access for fire trucks on the same one-way evacuation routes for residents, and the added issue of large numbers of recreational walkers on Mt Iron daily.

Mt Iron permanent residents have started taking individual household and collective community preparedness actions and are considering additional actions – see below.

Wildfire perceptions and preparedness: Mt Iron permanent residents

Actions taken

- Recognised need to be prepared and informal plans to evacuate;
- Increasingly know neighbours and discuss evacuation routes;
- Neighbourhood resident associations becoming vocal requesting agencies install early warning systems and approve kānuka vegetation clearance; and
- Some vegetation clearance, plastic household water tanks, garden irrigation and parking cars facing downhill.

Proposed actions

- Further vegetation management on properties;
- Continued discussion of possible community collective consent application to replace kānuka;
- Community seek early warning system installation;
- Consideration of homeowner and neighbourhood vegetation drenching systems;
- Few internal bunkers have been built within house/garages – consideration of others; and
- Rectify unnamed road and jumbled house numbers.

Remaining concerns include

- Restrictions on clearing kānuka;
- Fire danger publicity could affect ability to insure;
- Some narrow roads, inaccessible driveways, cul du sacs and no alternative access to evacuate;
- National and district level planning which does not adequately consider wildfire risk;
- Relative lack of wildfire risk mitigation guidance appropriate for urban fringe properties within Aotearoa New Zealand; and
- Costs and difficulty of retrofitting homes to address wildfire mitigations after construction has been completed.

Wildfire perceptions and preparedness: vulnerable wider community

The increasing development of the RUI area and an influx of people in the region has brought with it communities with diverse backgrounds, including recent migrants to Aotearoa New Zealand and large numbers of domestic and international visitors (pre-Covid-19). The wider northern Wānaka/Albert Town area includes a high proportion of holiday homes with intermittent use, short and long-term rentals, and a popular holiday park with short term and semi-permanent residents. The wildfire awareness and preparedness measures of this wider community differ from residents of Mt Iron itself. A lower fire risk awareness seems apparent and reports of use of fireworks and braziers, and inappropriate disposal of cigarette butts, continue, despite a year-round fire ban in the Mt Iron 'red zone'. In addition, there is an added consideration for wildfire response planning to evacuate children from pre-schools and a primary school in the area.

Limitations that have resulted from development planning and roading decisions, and apprehension about their on-going ability to insure, remain. In addition to community and homeowner contexts, local planning considerations are also likely to be important influences on if and how communities prepare for wildfire. Local government planning and the Resource Management consenting process require balancing many factors and priorities, some of which can cause challenges for ensuring wildfire preparedness (for example, biodiversity, soil and water protection, landscape amenity). Access into and out of new developments and covenants on vegetation cover such as flammable kānuka are two such issues.

Māori community in region

Only 5.6% of the current population are recorded as Māori (compared to 16.7% national average) (Statistics New Zealand, 2019a, 2019b), of whom about 40% whakapapa to Ngāi Tahu and about 33% are homeowners (Mana Tāhuna Charitable Trust estimates). Māori in the region are mostly mataawaka (Māori living in an area but who are not mana whenua) with relatively few mana whenua (Māori of the hapū customary land rights) and no marae in the area. Even those who whakapapa to Ngāi Tahu are not necessarily from the rūnanga associated with the Queenstown Lakes area.

Past social wildfire research by team members has brought some knowledge of fire (ahi) and its use by Māori (Stone & Langer, 2015), their awareness and safe use of fire (Langer & McGee, 2017) and the preparedness, experiences and actions (McGee & Langer, 2019) of a predominantly Māori community following an extreme fire in the Far North. More recent studies by the team include a study of the Māori community affected by the 2016 Kaikōura earthquakes (McCarthy and Langer, 2019) and a hapū in the Hokianga, Far North (publication planned), providing extensive understanding of cultural values within natural hazard settings.

A small proportion of the community who identify as Māori from Ngāi Tahu and other iwi from around the country bring their own traditional knowledge of fire which has been passed down from one generation to the next. Examples include knowledge that north-westerly wind brings fire; cooking should be done at night when the air temperature is cooler; and fires should be lit near a water source rather than near habitation.

Although no marae or communal meeting ground exists in the Queenstown/Wānaka area, networks and active communication are strong. The Mana Tāhuna Charitable Trust (a Queenstown based pan-Māori organisation, which was recently formed to support whānau (families) through the response to Covid-19 with support from Ngāi Tahu) aims to improve the wellbeing of Māori within the Tāhuna community. The Hawea Māori community also has a strong network that meets regularly, e.g., each Sunday at their community hall in Hawea. These groups bring the opportunity for agencies to extend their engagement and transfer knowledge with the wider community which could lead to individual and collective wildfire preparedness actions.

Wildfire Mitigations for Homeowners and Communities

From the greater than 1000 mitigation recommendations for household and community evaluated from over 120 national and international publications, a total of 171 wildfire risk reduction and mitigation recommendations have been developed to provide advice for homeowners to prepare themselves and their homes to reduce their risk from wildfire (https://www.ruralfireresearch.co.nz/).

The recommendations have been divided into five categories that apply to people at different stages of preparation and response:

- when building or remodelling a home;
- when landscaping or designing their defensible space;
- when preparing for each wildfire season;
- when making a wildfire plan; and
- when a wildfire occurs.

Where appropriate, some recommendations may be repeated in multiple categories. The full list of recommendations reviewed is included in the spreadsheet for reference.

It is critical to note that the recommendations presented are based primarily on the consensus of advice internationally, expert insight, anecdotal evidence and correlation of a limited number of variables (e.g. Syphard & Keeley, 2019). Other than those materials and designs which may be tested in a laboratory, it is not currently possible to provide a definitive scientific assessment as to the effectiveness of most recommendations, to prioritise them for action, or to define objective thresholds for how they should be applied (e.g. precisely how many metres of vegetation clearance should be recommended). In addition, the recommendations may conflict with competing priorities, such as ecological protection or urban growth, and may not be appropriate in local contexts. The feedback provided by Mt Iron residents highlighted that most of the mitigations were still impractical to retrofit, expensive or ineffective in their extreme case; however, several could be applied for future construction. Therefore, it is necessary for FENZ to determine which recommendations they wish to promote in which contexts.

Prefaces to these recommendations

The recommendations developed must not be presented to communities in isolation. They form only one part of what must be a coordinated communications effort that also includes educating communities, homeowners and residents about wildfire and what factors shape their individual and collective risk. This should include:

- The principles of how wildfires spread and what factors affect the rate and direction of spread;
- The limits of firefighting capacity and capability against fires of different intensities; and
- What to consider when making an evacuation plan, including information about the speed of wildfire spread, likelihood of traffic congestion, difficulty of driving through smoke, etc.

In addition, the following information must be included as preface to the recommendations to explain how they should be interpreted and applied (Figure 14).

Our overall intent with these recommendations

- These recommendations can help you improve the chances that you and your home will survive a wildfire, but remember that no amount of risk reduction can guarantee safety. Some wildfires may overcome even the strongest mitigations and the best efforts of firefighters.
- Always evacuate if a wildfire threatens your home, and do not wait for an official warning to evacuate if a fire is nearby. Only shelter in place as a last resort if escape is no longer possible.
- No single action is enough. The recommended actions are intended to work together to collectively reduce your wildfire risk. Even major mitigation actions, such as installing exterior sprinkler systems will not be effective unless taken alongside other measures.
- The recommendations describe the ideal and will not all be feasible or practical in all situations. If more susceptible sites, construction materials, designs or landscaping cannot be avoided, compensate by taking greater precautions in other ways. Consider the intent of the recommendations and consult with Fire and Emergency NZ representatives, fire engineers or other experts to find alternative solutions that will work for you.
- Be sure to follow the Building Code and all applicable local regulations. Work with your local council to ensure you remain compliant.

Figure 14: Introductory information for the list of wildfire mitigations.

Recommendations and Conclusions

With climate change and growing development in the RUI increasing the risk of wildfire to communities, improving wildfire awareness and preparedness among homeowners and communities is essential. Wildfire preparedness mitigations suitable for suburban contexts have been developed for agencies to guide homeowners and communities in constructing or remodelling a home, landscaping or designing defensible space, preparing at the start of each wildfire season, planning a wildfire response and during a wildfire event. Agencies should undertake engagement to share the recommendations with RUI residents and enable their uptake.

- Make the findings of this study widely available to Government agencies including FENZ, NEMA, DOC, Land Information New Zealand (LINZ), MfE, regional and district councils, and to stakeholder organisations such as the New Zealand Forest Owners Association (FOA) and Federated Farmers NZ.
- Further review the wildfire preparedness mitigations to provide recommendations to RUI homeowners and communities nationally.
- Translate the wildfire preparedness mitigation recommendations for homeowners and the community into easily understood instructions.
- Provide easily understood guidance about the wildfire preparedness mitigations to homeowners and the community.
- Ensure that agencies engage and work in partnership with homeowners and the community to encourage residents to implement wildfire preparedness mitigations on their properties.
- Ensure that agencies pay particular attention to working with residents to raise awareness of wildfire risk and preparedness in the RUI in the areas identified as particularly wildfire prone under climate change.
- Encourage agencies to investigate raising the wildfire awareness and preparedness measures of short-term residents.
- Extend community engagement and transfer knowledge to Māori community groups, such as the Mana Tāhuna Charitable Trust and the Hawea Māori community (e.g., attending hui at the community hall) to benefit from their strong networks to encourage individual and collective wildfire preparedness actions.

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Table of Acronyms

ArcGIS	ArcInfo Geographical Information System software package
CDEM	Civil Defence and Emergency Management
DOC	Department of Conservation
DSR	Daily Severity Rating
FENZ	Fire and Emergency New Zealand
FOA	New Zealand Forest Owners' Association
FWI	Fire Weather Index
GCM	Global circulation model
GIS	Geographical Information Systems
Hu	Housing unit
IPCC AR	Intergovernmental Panel on Climate Change Assessment Report
LCDB	Land Cover Database
LINZ	Land Information New Zealand
MAVRIC	Mean And VaRIance Correction bias correction method
MBIE	Ministry of Business, Innovation and Employment
MCDEM	Ministry of Civil Defence and Emergency Management
MfE	Ministry for the Environment
MPI	Ministry for Primary Industries
NEMA	National Emergency Management Agency
NIWA	National Institute of Water and Atmospheric Research
ORC	Otago Regional Council
QLDC	Queenstown Lakes District Council
RCM	Regional Climate Model
RCP	Representative concentration pathway
RUI	Rural-urban interface
SH	State highway
SL	Season length
SLMACC	Sustainable Land Management and Climate Change Fund
SSR	Seasonal Severity Rating
TOE	Time of emergence
UNDRR	United Nations Office for Disaster Risk Reduction
USDA	United States Department of Agriculture
USDI	United States Department of the Interior
WUI	Wildland-urban interface
WWRP	World Weather Research Programme (High Impact Weather Implementation Plan)

Appendix A

Mapping of the Rural-Urban Interface methodology

Following the methodology, three datasets were used:

1. Structure location data was obtained from the 'NZ Building Outlines' dataset, which provides vector building footprints of all structures larger than or equal to 10 square meters observed in aerial imagery (Figure 15) (Land Information New Zealand, 2020).

Figure 15: Example of building footprints used to generate RUI maps.

2. Vegetation cover data was obtained from the 'LCDB v4.0' dataset, which contains vector data showing a thematic classification of Aotearoa New Zealand's land cover (Land Resource Information System, 2020).

3. Wildfire occurrence records were provided by Scion, including a combination of data collected from 1990 – 2008 by the Department of Conservation (DOC) and from 2012 – 2018 by Fire and Emergency New Zealand (FENZ).

GIS software ArcGIS 10.7 was used to process the data and create maps according to the following method.

Method

Creating the RUI map

After reviewal of the methods outlined in the literature review and assessment of the intended implementation and availability of data, the most appropriate mapping technique was determined to be the Bar-Massada method (Bar-Massada et al., 2013). The following steps are based on this method; however, the specific ArcGIS model was adapted to suit Aotearoa New Zealand context and data accessibility.

A detailed explanation of the technical procedure developed for this study is described below.

Step 1: Create Building Density Raster (R1) – where each cell1[11] represents whether the building density threshold of 6.17 buildings/km^2 is met. The number of buildings within a 576 m radius of the cell decides whether the cell meets the building density threshold (Figure 16). This calculation was iterated through each cell in the case study area.

a) First, the building footprint data layer must be converted from polygon to point format using the Feature to Point tool.

b) Next, the building points are put into the Point Statistics tool to create a raster in which each cell value represents the total number of points within the neighbourhood radius r.

[11] 1 cell = 30x30 m

c) Using the Raster Calculator tool, the raster cell values (N) are recalculated to get the building density d (buildings/km²) using the equation[12]:

$$d = \frac{N}{\pi r^2} \times 1{,}000{,}000 \quad [1]$$

d) The resulting density raster is then reclassified using the Reclassify tool so that the call value is 1 for cells that had a density greater than 6.17 buildings/km² and 0 otherwise.

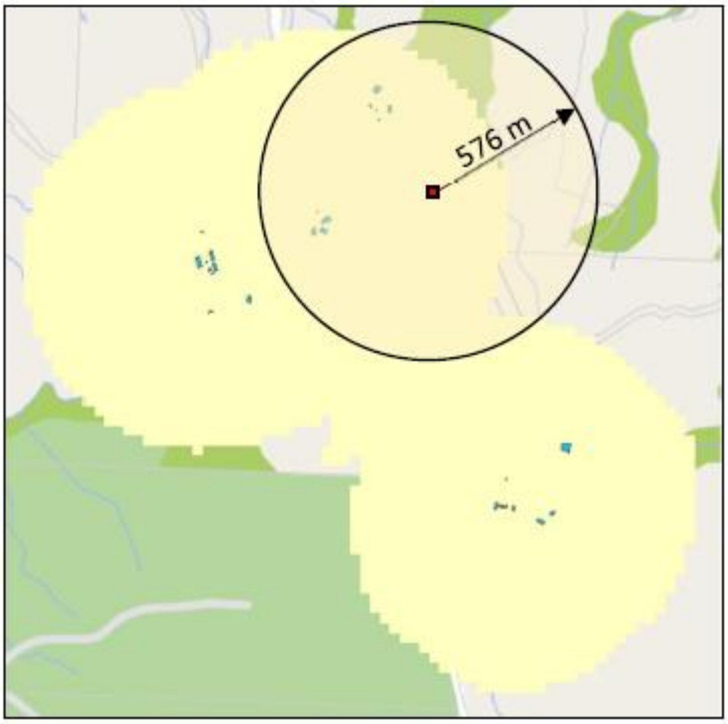

Figure 16: Example showing how building density is calculated for each cell using the moving window analysis. Yellow areas meet the required building density threshold (>6.17 buildings/km²).

Step 2: Create Intermix Vegetation Cover Raster (R2) – Where each cell represents whether the wildland vegetation density of 50% is met. Table 6 shows which specific land covers from the LCDB classification were counted as wildland vegetation.

a) The LCDB layer is converted to raster format using the Feature To Raster tool.

b) Using the Reclassify tool, the raster is reclassified so that the cell value is 1 for cells that are classed as wildland vegetation and 0 otherwise (according to Table 6).

c) The reclassified wildland vegetation raster is put into the Focal Statistics tool to create a raster in which each cell value represents the sum of original cell values within the neighbourhood radius r.

d) Using the Raster Calculator tool, the cell values are recalculated to represent the percentage vegetation cover (%) within the neighbourhood radius r using the equation[13]:

$$\% = \frac{N}{\pi r^2 / 900} \times 100 \quad [2]$$

[12] 1,000,000 = correction factor to get density in km².
[13] 900 = area of one cell (30 m resolution).

e) The vegetation percentage raster is reclassified using the Reclassify tool so that cells with ≥50% vegetation are assigned a value of 1, while cells < 50% are assigned 0.

Table 6: Reclassification of LCDB land cover types for wildland vegetation raster.

Wildland Vegetation (1)	**Non-Wildland Vegetation (0)**
Indigenous Forest Exotic Forest Urban Deciduous Hardwoods Forest - Harvested Short-rotation Cropland Orchard / Vineyard / Other Perennial Crops High Producing Exotic Grassland Low Producing Grassland Tall Tussock Grassland Depleted Grassland Herbaceous Freshwater Vegetation Herbaceous Saline Vegetation Flaxland Fernland Gorse / Broom Mānuka / Kānuka Matagouri / Grey Scrub Broadleaved Indigenous Hardwoods Sub Alpine Shrubland Mixed Exotic Shrubland	Built-up Area (Settlement) Parkland / Open Space Surface Mine / Dump Transport Infrastructure Sand / Gravel Gravel / Rock Landslide Permanent Snow / Ice Alpine Grass / Herbfield Lake / Pond River Estuarine Open Water

Step 3: Create Interface Vegetation Cover Raster (R3) – Where each cell is distinguished based on whether it is within the buffer distance of 500 m of large areas of wildland vegetation.

a) A copy of the LCDB vector layer is reclassified using the Reclassify tool according to Table 6.

b) Using the Dissolve tool, the contiguous polygons in the LCDB layer are joined together to create polygons representative of patches of continuous wildland vegetation.

c) The area of each polygon is calculated and appended to the attribute table.

d) Using Select By Attributes, all polygons with an area less than 5 km^2 are removed from the layer.

e) A 500 m buffer is applied around each of the remaining polygons using the Buffer tool.

f) Using the Feature To Raster tool, the buffered polygon layer is converted to raster form.

g) The resulting raster is then reclassified using the Reclassify tool so that all cell values are 1 (representing the wildland vegetation footprint + 500 m radius).

Step 4: Combine all 3 Raster Layers to Create RUI Map

a) R1 is combined with R2 to create raster T1 using the Combinatorial Or tool, which creates a different cell value for each unique combination of input values. The cell values are classified appropriately (Figure 17).

b) The resulting raster is combined with R3 to create another raster (T2) with a value for each combination using the Combinatorial And tool. The cell values are classified appropriately (Figure 18).

c) The symbology of T2 is edited so that only the Intermix and Interface RUI types are visible.

d) T2 is overlaid onto the imagery of the elected study area.

A flowchart illustrates steps 1-4 of the methodology (after Bar-Massada et al., 2013) (Figure 19).

Rowid	VALUE	COUNT	R1	R2	RUI Type
0	0	299580	0	0	Non-RUI
1	1	731101	1	0	Possible Interface
2	2	306283	0	1	Non-RUI
3	3	166833	1	1	Intermix

Figure 17: Input value matrix and classification for step 4a.

Rowid	VALUE	COUNT	R1,R2	R3	INTERFACE
0	0	299580	0	0	No
1	1	731101	1	1	Yes
2	2	306283	2	1	No
3	3	166833	3	1	No

Figure 18: Input value matrix and classification for step 4b.

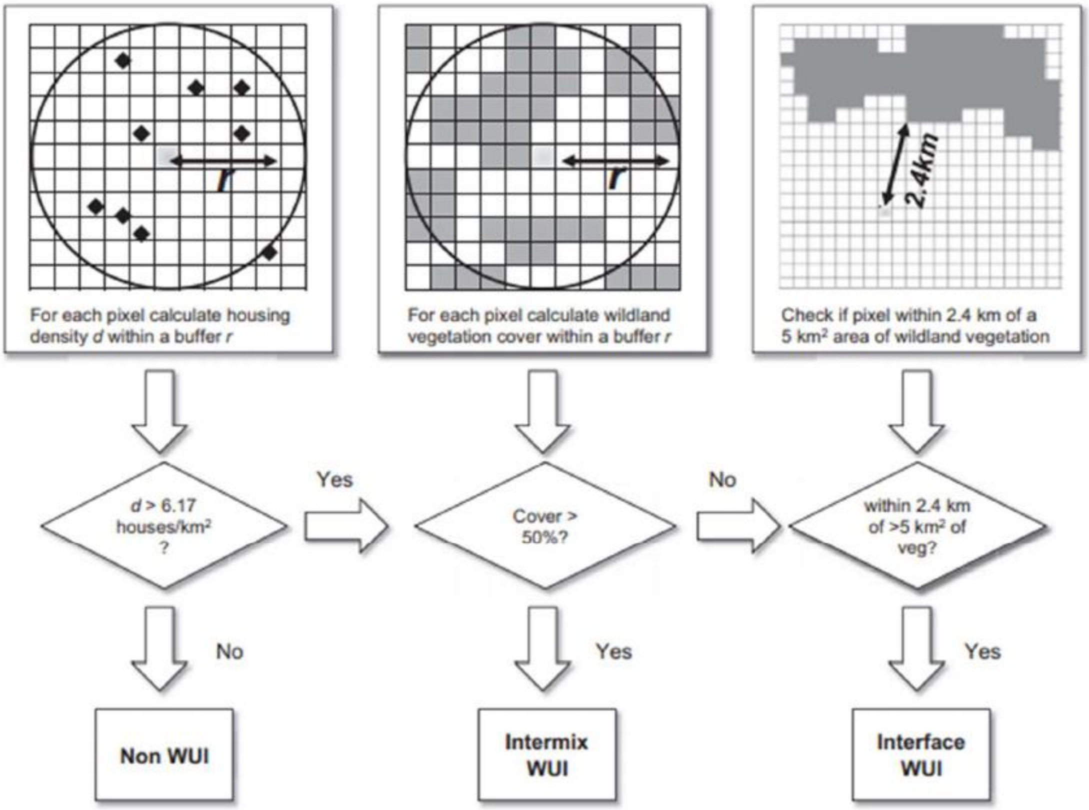

Figure 19: A flowchart illustrating steps 1-4 of the methodology (after Bar-Massada et al., 2013).
[NB. The value for the buffer radius 'r' in step 2 is 576 m as per Platt (2010); and the distance from vegetation in step 3 has been modified from 2.4 km to 500 m following the recommendation of Pearce et al. (2014)].

Appendix B

Wildfire risk perception and preparedness and

Adaption and mitigation of wildfire risk due to climate change in the rural-urban interface

Resilience to Nature's Challenges, High Impact Weather Research Programme and Sustainable Land Management and Climate Change Fund research (SLMACC)

April 2021

Community Interview: Participant Information Sheet

Researchers: Lisa Langer and Simon Wegner
Researcher contacts: lisa.langer@scionresearch.com; simon.wegner@scionresearch.com

Thank you for agreeing to take part in our research on wildfire risk perception and preparedness. This study looks at rural-urban interface (RUI) communities while extending knowledge and best practices to adapt to and mitigate wildfire risk due to climate change. The research is focused on the Mt. Iron community within the northern Wānaka and Albert Town areas. Please take a moment to read the following information about the research.

What is this research about?

The aims of the research are to identify influences behind wildfire risk perception and mitigation in suburban areas of the rural-urban interface, and extend knowledge and best practices to adapt and mitigate wildfire risk due to climate change in the wider Queenstown/Wānaka area. This research is funded by the Resilience to Nature's Challenges National Science Challenge and Sustainable *Land Management and Climate Change* Fund (*SLMACC)*.

We carried out interviews and held focus groups with key individuals within relevant agencies and the community in November 2020 and sent out a postal/online survey to the northern Wānaka community in a complementary study funded by Fire and Emergency NZ (FENZ).

The researchers have developed a range of possible wildfire preparedness mitigations from international literature/websites and guidance from Scion's lead fire scientist and national FENZ staff. The relevance of these mitigations for the northern Wānaka area will be discussed with Otago FENZ and Queenstown Lakes District Council (QLDC) staff, councillors and a range of key community stakeholders.

In addition, we are working collaboratively with local representatives from FENZ, QLDC, Emergency Management Otago, Department of Conservation and the Wānaka Community Board who have established a Mt. Iron Wildfire Risk Reduction Project to help support the evaluation and implementation of risk reduction actions. The project is committed to working in partnership with the local Mt Iron community to reduce the risk and improve the levels of readiness and preparedness. The Mt. Iron Wildfire Risk Reduction Project is supporting our research and plans to launch a Community Response Group made up of community minded volunteers.

What will happen when I participate?

You will participate in an interview which is expected to take 1 -1.5 hours, depending on how much information you wish to share. The discussion is designed to learn about your past community engagement experiences in the area and to gain some of your local knowledge of the Wānaka and Queenstown Red Zone communities, their wildfire risk perceptions and preparedness, and means to adapt or mitigate wildfire risk. We will share with you a range of possible wildfire preparedness mitigations and ask your opinion on their practicality and likely uptake.

With your permission, the interview will be audio recorded and may be transcribed to assist with our analysis. Even if you initially agree to being recorded, you may ask for the recording to be paused or stopped at any time. Copies of any notes, recordings or transcripts made from the interview will be provided for you to review, if you request this.

Do I have to take part?

Your participation in this research is entirely voluntary. You may refuse to participate, or you may decline to answer any individual questions. Even if you agree initially, you may withdraw from the research and retract or amend any or all the information you have provided for up to 30 days after the interview. After that period, we will make reasonable efforts to meet any request to retract or amend information, but it may no longer be possible if the information has already been included in analysis or reporting.

How will my data be used?

Findings from the interview will be used to inform the northern Wānaka/Queenstown Red Zone and wider area studies. The findings may be used to provide recommendations and produce a variety of outputs, including a publicly available summary, reports to relevant government authorities, academic papers and presentations.

The knowledge and information you share remains your intellectual property or that of the organisation you represent. By consenting to participate and taking part in the interview, you are granting Scion the limited right to use that information only for the purposes, and under the conditions, described in this information sheet. You may specify if there is any information which you do not wish to have quoted or otherwise shared in detail in publications or other research outputs. You may retract or amend any or all the information you have provided within the time period described above.

How will my privacy be protected?

We will endeavour to ensure information collected from interviews and focus groups is presented in a way that data are not traceable to individuals. Your name and other personal information will not be connected to the data or research outputs; instead, generic descriptions will be used to identify individuals and groups (e.g., “a permanent resident”).

All data collected during this research project will be stored securely at Scion and made accessible only to members of the research team or their subcontractors. The audio recording may be transcribed and coded by professional contractors who will be required to sign confidentiality agreements. Electronic data, such as audio recordings, will be safeguarded by passwords on hard drives and/or cloud-based storage spaces.

Who can I contact with questions or concerns?

If you have any questions or concerns you would like to raise with the research team, please contact:

Lisa Langer, Senior Social Scientist
email: lisa.langer@scionresearch.com
phone: (03) 363 0921 or 021 752 266

Simon Wegner, Social Scientist
email: simon.wegner@scionresearch.com
phone: (07) 343-5305

Veronica Clifford, Team Lead, Rural Fire Research Group
email: veronica.clifford@scionresearch.com
phone: (03) 363 0914

Wildfire risk perception and preparedness and

Adaption and mitigation of wildfire risk due to climate change in the rural-urban interface

Resilience to Nature's Challenges, High Impact Weather Research Programme
Sustainable Land Management and Climate Change Fund research (SLMACC)

April 2021

CONSENT TO PARTICIPATE IN RESEARCH

Researchers: Lisa Langer and Simon Wegner

By signing this form, I confirm that:

- I have read the Community Interview: Participant Information Sheet dated April 2021;
- I understand the nature of the research and what my participation will involve; and
- I have had an opportunity to ask questions, and my questions have been answered to my satisfaction.

I also understand that:

- My participation is voluntary, and I may refuse to participate, decline to answer any questions or stop participating at any time without giving a reason;
- I may retract or amend any or all the information that I have provided up to 30 days after the interview;
- At my request, I will be provided with copies of any notes, recordings or transcripts made during the interview;
- My name and personally identifying information will be kept confidential, and any reference to information collected in the interview will be presented using generic descriptors (e.g., "permanent resident");
- Information collected during this research will be kept securely in a password protected database at Scion and will only be shared with members of the research team.

I …………………………………………………………. (full name) consent to take part in this study.

Email address: ………………………………………………………… (if requesting interview data or research outputs)

Date: …………………………………

Signature: ……………………………

Appendix C

Summary of changes to wildfire mitigation recommendations following feedback

The following changes have been made to the draft wildfire mitigation recommendations following feedback from agencies and stakeholders in the Queenstown and Wānaka case study area.

Changes made

Overall

- The initial comments from the FENZ national office have been addressed; however, additional review by FENZ and others is still needed.
- Recommendations were re-ordered from the original alphabetical categories to more logical structures that allowed better flow between concepts.

When building or remodelling

- While we originally did not include recommendations concerning building bunkers or shelters of last resort inside homes because we did not want to encourage people to shelter in place, the lack of mention was frequently noted by reviews. We have added a recommendation that a shelter be considered in extreme wildfire risk areas but emphasised that this is only to be used as a last resort and only if other mitigations have also been undertaken.

When landscaping

- The community action recommendations were moved from this section into the "When making a plan" section.

When fire season starts

- The "When maintaining" section was re-named "When fire season starts" to emphasise that these actions should be taken at the start of every fire season. Several actions on house preparation from the "When wildfire occurs" were moved or copied into this section.

When making a plan

- The community action recommendations were added to this section.
- A recommendation regarding identifying shelters of last resort was added.

When wildfire occurs

- Introductory text was added to the last-minute house preparation recommendations to be explicit that these should only be attempted if people were certain there was ample time and they had already undertaken long-term mitigation actions.
- Last-minute house preparation actions were prioritised following feedback from the community representatives. The priorities were based on our expert judgement, but as this process occurred after consultation, the prioritisation will need further review by agencies.

Suggested changes not made

- There was a suggestion by some community members to separate recommendations for people who are building and remodelling their homes. This has precedent in some overseas literature and does provide opportunity to discuss which design elements owners of existing houses might prioritise for cost-effective improvement. However, we did not believe there was enough scientific evidence on which to objectively prioritise remodelling actions, and we felt it would be preferable to keep the simplicity of a smaller number of categories.

- There was a suggestion from the community to categorise recommendations by cost, ease of completion and/or required expertise. We felt this would be too dependent on individual context and would add too much complexity; however, it could be considered for future work.
- Our project did not systematically collect recommendations for what to do should evacuation become impossible as this was outside the project scope. However, community representatives suggested that this advice be added in the future.