NEW ZEALAND FIRE SERVICE COMMISSION
Whakaratonga Iwi

Fire Research Report

Describing Wildfire Prone Areas in the New Zealand Context
October 2014

Scion

Identification of wildfire prone areas will help reduce the number and consequences of wildfires by enabling fire authorities and councils to prioritise activities such as fire prevention, fuel reduction and 'FireSmart' communities, and to improve planning and building regulations for high fire risk areas.

This research developed methods to map the risk of wildfire in rural-urban interface areas where flammable vegetation fuels intersect with people and property. Data for a range of environmental and social fire risk factors were overlaid onto mapped extents of the rural-urban interface to identify the most at-risk areas. The methods were successfully tested for two case study areas in Nelson and Rotorua.

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Describing Wildfire Prone Areas in the New Zealand Context:

Final Report

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REPORT INFORMATION SHEET

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EXECUTIVE SUMMARY

Report Title: Describing Wildfire Prone Areas in the New Zealand Context: Final Report
Authors: H.G. Pearce, E.R. Langer, D.R. Harrison & M. Hart

The New Zealand Fire Service Commission, National Rural Fire Authority and rural fire agencies are seeking a method for identifying high risk areas prone to wildfires that can be used to assist in targeting fire mitigation activities. To address this aim, the Commission contracted the Scion Rural Fire Research Group to develop a process for defining and identifying 'Wildfire Prone Areas (WFPAs)'. The objective of the project was to derive a method to assist New Zealand Rural Fire Authorities in selecting and prioritising wildfire prone locations where fire mitigation activities can be undertaken, such as fire prevention, fuel reduction, development of 'FireSmart' communities and other wildfire risk planning.

Findings from international literature were combined with workshop feedback from local fire managers to identify the factors that need to be considered in defining WFPAs in the New Zealand context. The international literature was also used to identify potential methods for mapping rural-urban interface (RUI) areas, where people and buildings are located in close proximity to flammable vegetation. Data layers were also identified for a range of environmental and social fire risk factors that could be overlayed onto maps of the RUI to identify high risk WFPAs. The various RUI mapping methods and wildfire risk factors were then evaluated by conducting pilot studies for two areas of New Zealand.

The methodology proposed as a result of the study comprises two steps in the identification of WFPAs: the mapping of the RUI, and then the overlaying of relevant wildfire risk factors on to this RUI extent. Two alternative methods for completing the first step of mapping the RUI were identified based on the availability of individual building data or broader census mesh-block information. The former is considered to be the better method if the required building point location data are available. However, careful consideration is required in adopting and implementing a prescribed approach, and all users need to understand their purpose, data and methodology limitations, and use resulting maps accordingly.

The two methods were successfully tested in two case study areas (Nelson and Rotorua). These case studies illustrated that while both original methods were suitable for identifying the RUI in New Zealand, and assumptions around applicability of the standard criteria used within each of these methods to define 'interface' and 'intermix' areas are reasonable, results can be improved by making minor changes to values for several of these criteria. Sensitivity analysis showed that a reduction of the distance of buildings (or meshblocks containing buildings of appropriate density) from wildfire vegetation to 200-500 m, for example, produced more reasonable representations of the RUI extent for the New Zealand case studies than the standard 2.4 km set-back assumed in the United States.

Results from various stages of the research were presented to fire managers for review on a number of occasions in an effort to ensure that the project delivered useful and practical outcomes. This resulted in very useful feedback on the conceptual WFPA methodology, and its potential implementation and application, that have been integrated in the study's conclusions and recommendations.

A series of recommendations on further development and testing of the proposed methodology, and potential operational implementation of this methodology, have been made for consideration by the NZ Fire Service Commission and National Rural Fire Authority. These include the following:

- Standard definitions relevant to the use of Rural-Urban Interface and Wildfire Prone Areas terminology in New Zealand, as suggested in this report, should be included in applicable glossaries.
- The methodology for identifying WFPAs described in this report should be included in the National Rural Fire Authority's (NRFA) proposed 'Guideline for Development of Risk Management Plans' as an alternative approach to meeting the national Standard for 'Assessing Fire Hazards'.
- The suggested methodology for mapping WFPAs should be applied at the local or regional scale, rather than nationally. This is because, to produce best results, identification of WFPAs should capture local knowledge and information on wildfire risk factors for which national data sets do not exist. Additionally, other local factors influencing the success of subsequent mitigation activities (such as the presence of local community 'champions') will dictate how identified WFPAs are prioritised.
- The two methods recommended for identifying the extent of the RUI could be applied nationally, and the meshblock-based method in particular can be produced as a standard national data layer. However, further evaluation of the results from the sensitivity testing of threshold values for the criteria used to define the RUI should be undertaken for other areas of the country prior to operational implementation.
- For use in identifying WFPAs, the RUI methods should be supplemented by overlaying wildfire risk factors. These should include a range of environmental, social and infrastructure factors.
- National data sets of environmental risk factors, such as fire behaviour potential (fire hazard layers from the NZWTAS), should be updated using more recent data on fuel types and fire climate, and for a greater range of scenarios (especially for fire climate).
- To produce best results for identification of WFPAs, these national wildfire risk data overlays should be further supplemented with available local knowledge and data (e.g. wildfire occurrence data and information on community networks).
- Research should be undertaken to develop a simple fuel type flammability ranking based on land cover types and modelled fire behaviour potential that can be used to provide a national fuel flammability risk layer.
- Efforts should be made to improve national spatial data sets on wildfire occurrence, as a key input into identification of WFPAs.
- Further research should be undertaken into the mapping of social factors such as community resilience (e.g. networks, adaptive capacity) and include use of local knowledge as well as national (e.g. Census) measures.

Describing Wildfire Prone Areas in the New Zealand Context: Final Report

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List of Abbreviations

BPA	Bushfire Prone Area (used in Australia)
CD	Clustered dwellings (Lampin-Maillet method)
CDEM	Civil Defence and Emergency Management
CERA	Canterbury Earthquake Recovery Authority
DCD	Dense clustered dwellings (Lampin-Maillet method)
DEM	Digital Elevation Model
DOC	Department of Conservation
DSR	Daily Severity Rating
ETS	Emissions Trading Scheme
FRFANZ	Forest and Rural Fire Association of New Zealand
GIS	Geographical Information System
HPT	Historic Places Trust
ID	Isolated dwellings (Lampin-Maillet method)
ISO	International Organisation for Standardization
LCDB	Land Cover Database
LINZ	Land Information New Zealand
LRIS	Land Resource Information System
LUC	Land Use Capability classification
LUCAS	Land Use Carbon Analysis System
NFPA	National Fire Protection Agency
NIVS	National Indigenous Vegetation Survey
NRFA	National Rural Fire Authority
NRFAC	National Rural Fire Advisory Committee (now the Rural Fire Committee of the Commission
NZFS	New Zealand Fire Service
NZLRI	New Zealand Land Resource Inventory
NZTA	New Zealand Transport Agency
NZWTAS	New Zealand Wildfire Threat Analysis System
MPI	Ministry for Primary Industries
RAPID	Rural Address Property Identification
RCs	Regional Councils
RFA	Rural Fire Authority
RFRAC	Rural Fire Research Advisory Committee
RUI	Rural-urban interface
SD	Scattered dwellings (Lampin-Maillet method)
SMS	NZ Fire Service Station Management System
STFMP	Strategic/Tactical Fire Management Plan
TLA	Territorial Local Authority (i.e. District and City Councils)
VBRC	Victorian Bushfires Royal Commission
VDCD	Very dense clustered dwellings (Lampin-Maillet method)
WFPA	Wildfire Prone Area
WTA	Wildfire Threat Analysis
WUI	Wildland-urban interface

1. Introduction

In recent years, Australia has experienced many extensive bushfires that have affected communities. This includes the devastating 2009 Black Saturday fires in the State of Victoria, which resulted in 173 fatalities, and over 2,030 houses and more than 3,500 structures destroyed (VBRC, 2010a). Wildfires in New Zealand have not been as large or devastating, but approximately 3000 wildfires per annum were recorded between 1992 and 2007, and community impacts have been on a similarly smaller scale. However, fire managers predict an increase in the risk of wildfire events in the future that will have the potential to result in fatalities and destruction of houses and other structures. Learnings from Australia, including the 2009 Victorian Bushfires Royal Commission (VBRC, 2010a, 2010b), continue to benefit rural fire planning and management in New Zealand.

One of the outcomes from 2009 Victorian Bushfires Royal Commission was a recommendation that fire agencies identify 'Bushfire Prone Areas' (BPAs). This recommendation was aimed at improving information and understanding of bushfires through better mapping of bushfire risk, and included giving highest priority to the protection of human life within these high fire risk areas, but also to reducing property exposure. Hence the focus is placed on risk to human safety and property, but not other economic or environmental assets as in many fire risk assessment systems such as the New Zealand Wildfire Threat Analysis System (NZWTAS). The NZWTAS provides an assessment of wildfire risk for use in strategic fire management planning based on the overlaying of risk (possible fire causes), hazard (fire behaviour potential) and value-at-risk (Majorhazi & Hansford, 2011). Developed more than a decade ago, the NZWTAS methodology has been criticised for not following recognised risk management principles, and for over-emphasising individual components (such as Hazard, and various Values) (Gibos & Pearce, 2007). However it has been used by most Rural Fire Authorities (RFAs) or regions of New Zealand to provide an initial assessment of wildfire risk.

In the Australian context at least, identification of bushfire risk is intended for use by local government and fire agencies to strengthen planning and building controls in highly bushfire prone areas. Mapping of BPAs is intended to aid in specifying development guidelines and building regulations, including the restriction of development in areas of highest bushfire risk. The VBRC recommendations regarding BPAs have been applied very differently in different parts (states) of Australia; e.g. Victoria has declared the whole state a BPA, whereas other states have only identified areas deemed to be at greatest risk from bushfires.

Through the NZ Fire Service Commission, New Zealand has adopted many of the VBRC recommendations, including those around the need to identify BPAs. As part of the 'New Zealand-ising', this has included renaming BPAs as 'Wildfire Prone Areas' (WFPAs) to better fit with New Zealand rural fire terminology[1]. However, it is not clear what constitutes a WFPA in the New Zealand context, nor what relationship identification and mapping of these areas should have with existing wildfire risk assessment methods such as the NZWTAS.

Under contract to the NZ Fire Service Commission, Scion's Rural Fire Research Group has undertaken a study to develop a methodology for identifying WFPAs in New Zealand. Four progress reports have been completed (Pearce and Langer, 2013a, 2013b; Pearce

[1] In NZ, 'wildfires' includes forest, grassland and scrub fires that can all threaten lives and property, whereas 'bushfire' can have a more restricted meaning around fires in native 'bush' specifically, as well as the more general colloquial usage by the media and public used in New Zealand and Australia.

et al., 2013a, 2014a), while this final report summarises all the components of the study and provides the New Zealand Fire Commission with recommendations for implementing WFPAs in New Zealand.

1.1 New Zealand context and rationale for Wildfire Prone Areas

The number and extent of wildfires in New Zealand is low when compared with many countries. Because of this, residents in rural and semi-rural areas, and those who visit the rural environment, do not expect wildfires to occur and are unlikely to be prepared for a major fire event when one does happen (Jakes & Langer, 2012). This lack of awareness and preparedness is of considerable concern to New Zealand fire managers, who expect the country’s wildfire risk to increase in the future.

Currently New Zealand experiences around 3000 wildfires per year that burn around 6000 ha (Anderson et al., 2008; Doherty et al., 2008). The vast majority (99%) of these fires are attributed to human causes (Doherty et al., 2008; Hart & Langer, 2011). Of wildfires with known causes, the most common reason for ignition is escaped land clearing burns, which account for 20% of the total number of rural fires and almost half (47%) of the total area burnt (on average, about 1670 ha per year). Other significant causes of wildfires include human negligence, such as incendiary causes (6% of the total number of fires, as well as 6% of the area burned), recreational causes (3% of fires) and smoking (1%). The most common indirect human cause is vehicles, accounting for 17% of all fires and 5% of the total area burned. A high proportion of these fires occur on the boundaries of populated centres, where the number of people contributes to a higher likelihood of fire starts, as well as greater risks to life and property.

New Zealand’s risk of wildfires is influenced by maritime weather patterns that infrequently bring the high temperatures, low humidity, strong winds and seasonal drought that increase the risk of wildfire events. However, periods of extreme fire danger occur in many parts of the country during most fire seasons, and these are strongly influenced by climate cycles such as El Nino-Southern Oscillation (Pearce & Clifford, 2008; Pearce et al., 2007; 2011a).

Fire managers point to several factors that could increase wildfire risk and therefore expose New Zealand residents to more wildfires in the future (Jakes & Langer, 2012). The first factor is global climate change. Climate change studies predict that the hot, dry weather conditions that support wildfires could become more common in New Zealand, and as a result, more severe fire weather and fire danger are likely in the future (Pearce & Clifford, 2008; Pearce et al., 2011b). A second factor is changing fuel loads and fuel types within the landscape. Land Information New Zealand (LINZ) undertook a review of high-country grazing leases on government land (land tenure review), which at that time (May 2011) showed conversion of over 229,000 hectares of grazing land to conservation and recreation uses (M. Clark, LINZ, pers. comm., 27 May 2011). Some people fear that vegetation previously kept in check by grazing and burning will revert to tall grasses or woody shrubs, increasing fuel loads and fire risk. The area affected by the spread of wilding conifers is also increasing, and there are concerns that this will also see an increase in fire risk, especially following wilding control treatments (Clifford et al., 2013). Although fires caused by recreational users of rural land are not common (Doherty et al., 2008), concern exists that the designation of these lands for recreation is likely to encourage more visitors and increase opportunities for human-caused wildfires in these areas (Hart & Langer, 2011).

However, a third, more concerning factor is an expanding rural-urban interface (RUI). Demographers have suggested that, like many other parts of the world, population in the RUI is likely to grow significantly in New Zealand over the next decade, placing more people and property in high fire-risk areas. Projections suggest that population in rural areas with moderate urban influence (i.e. the RUI) is likely to increase by 21% between 2001 and 2021, compared with a national average of 16% (Bayley & Goodyear, 2005). Lifestyle block development is also growing steadily, with approximately 6,800 new lifestyle blocks registered annually between 1980 and 2002 (Sanson et al., 2004). This equates to just over 37,600 ha per year being converted to lifestyle blocks, adding to the nearly 140,000 lifestyle blocks documented in New Zealand in 2003 totalling more than 753,000 ha (Sanson et al., 2004).

Although house and life loss in the New Zealand RUI have thankfully been very low to date, there are numerous examples of significant fires occurring in these areas that had potential to cause much graver consequences (Fogarty, 1996; Pearce, 1994; 2000; Anderson, 2002; 2003; Graham & Langer, 2009; Jakes et al., 2010).

While a number of existing fire risk assessment and mitigation planning systems already exist in New Zealand, none of these specifically focus on the risk associated with wildfires in the RUI. Methods such as the NZWTAS (Cameron, 2002; Majorhazi & Hansford, 2011) and subsequent Strategic/Tactical Fire Management Plan (STFMP) process (Wakelin & Teeling, 2012), and the National Rural Fire Authority's (NRFA) 'Assessing Fire Hazards' Standard (NRFA, 2010) and draft 'Guideline for Development of Risk Management Plans' (NRFA, 2104), do not specifically address the threats to life and property as intended by the BPA/WFPA concept identified in the VBRC recommendations. Therefore there is a need for a new methodology to identify WFPAs in New Zealand.

1.2 Project scope

The aim of this Scion Rural Fire Research Group project was to develop a methodology for identifying WFPAs, that can be used by New Zealand RFAs to assist with the targeting and prioritisation of locations for fire mitigation activities. Fire mitigation activities include fire prevention, fuel reduction, development of FireSmart[2] communities and other wildfire risk planning.

The first objective was to conduct a workshop with New Zealand rural fire managers to aid in defining what constitutes a WFPA in the New Zealand context, and therefore what factors need to be considered when identifying and mapping WFPAs.

The second objective was to combine workshop feedback with the findings from a review of local and international literature on wildfire risk assessment. The aim of this component of the project was to produce a definition of what constitutes a WFPA in the New Zealand context, which could be used as the basis for developing a conceptual methodology for identifying WFPAs in New Zealand.

This methodology was then tested by undertaking case studies to map WFPAs for two areas of New Zealand. The methodology was then further evaluated through sensitivity testing and feedback from fire managers to determine how it could be improved and best implemented.

This final report provides recommendations on the need for further developments, as well as on operational implementation of the suggested methodology.

[2] 'FireSmart' is a programme to engage with communities in reducing the risk of fires in the rural-urban interface in New Zealand, which has been modelled on the US FireWise programme.

2. Advisory Group Workshop

To initiate discussion on what constitutes a 'Wildfire Prone Area' (WFPA) in the New Zealand context, an interactive workshop session was held during the annual Regional Rural Fire Committee Chairpersons' Conference held in Napier on 11-12 June 2013 (Pearce & Langer, 2013c). The objective of this workshop was to seek fire manager input into the definition of what constitutes a WFPA in New Zealand using 'knowledge café' group discussions to obtain answers to four questions. The questions focused on: how the WFPA concept should be used in NZ; its definition; factors that need to be considered and their data sources; and finally, how the definition fits with other existing wildfire risk assessment systems, such as the NZWTAS.

Chairpersons' Conference attendees included Principal Rural Fire Officers from RFAs across the country who are the Chairpersons (or a delegate) of the nine Regional Rural Fire Committees, Enlarged Rural Fire District Chairpersons, members of the National Rural Fire Advisory Committee (NRFAC) and other rural fire stakeholder representatives (i.e. Local Government NZ, Department of Conservation (DOC), NZ Forest Owners Association, Federated Farmers, NZ Defence, Ministry for Primary Industries), as well as NZ Fire Service (NZFS) and NRFA. A total of around 40 people participated in the 1-hour workshop session.

The workshop process, questions and results of the knowledge café group discussions are described in detail in Appendix A.

2.1 End-user discussion results summary

Q1. Assuming the WFPA concept is valid for NZ, how should it be used in NZ?

- Allocation of resources and determining priorities;
- Part of regional and fire planning, including FireSmart, and drawing on fire history;
- Tailored reduction planning to enhance community awareness in specific areas;
- Council building guidelines, defensible spaces, response/suppression, identifying reduction & readiness areas; and
- Creation of a national WFPA database.

Several participants also commented that caution is required, as there are risks associated with such a process for identifying WFPAs, including possible impacts on property values or insurance premiums.

Q2. Considering the possible uses, what should the definition of a WFPA be for the NZ context (i.e. for use in NZ)?

The conclusion was that the WFPA definition should apply to areas where communities are located in fire prone areas, particularly in the RUI, with:

- A history of fire events and/or known threats (e.g. prone to Extreme fire danger);
- Potential to endanger life / property;
- Areas with common values (life, property) / risks (weather, fuels, topography, population, access);
- Isolated / absentee owners / population swell;
- Utilities of regional /national significance; and
- A defined boundary or area description.

Q3. (a) What factors need to be considered in describing and mapping WFPAs in NZ? (e.g. physical/environmental, social, infrastructure)

(b) What data sources are available for describing these factors?

Physical/Environmental	Data sources
1. Weather / fire danger conditions	- EcoConnect FWSYS
2. Fuels / vegetation	- land cover database
3. Topography / aspect	- mapping
4. Fire history	- RFA fire records
5. Ecological values?	- DOC
6. Aesthetic values?	- District plan
Social	
1. Population - density & diversity	- Census data
- socio-economic status	
- transient / seasonal population	- TLAs
2. Cultural values / heritage?	- District Plan, HPT, iwi
3. Livestock / crop / other economic values?	- MPI databases
Infrastucture	
1. Access (roads, tracks, bridges)	- NZTA/TLAs
2. Provision of services / lifelines	- TLAs, CDEM, utilities
3. Risks (powerlines, rail, etc.)	- utilities
Political	
1. Policies & planning	- TLAs + RCs
2. Government intent	- Govt. depts.
3. International agreements	
4. Political trade-offs & associated risks	

Other

1. Unforseen events

Process issues

1. Commonality – use a standard nationwide definition for all wildfire prone area criteria/inputs;
2. Data sources – use existing databases rather than developing new and duplicate ones; and
3. FireSmart as the end-point – results need to be taken to communities.

Q4. How does the definition of WFPAs in NZ fit with the current NZ Wildfire Threat Analysis (WTA) methodology and data inputs?

- Some said WFPA does not fit with WTA, but the WTA may assist to identify general areas of concern
    - Use individual layers (e.g. risk / values / hazards) to identify areas
    - Mix / balance of values, interests and resources
    - Evaluate desired outcomes (e.g. WFPAs) when/if NZWTAS methodology is reviewed;
- Others said WFPA does fit – already have systems in place / flows out of existing systems
    - WTA – whole range of assets, large scale
    - STFMP – local/area level
    - But need to add fire history and population density considerations to WTA to define WFPAs and identify/prioritise FireSmart areas.

2.2 Additional end-user feedback

In addition to the Chairpersons' Conference workshop, a presentation on the WFPAs project was also made to a meeting of the Scion fire group's Rural Fire Research Advisory Committee (RFRAC) held on 27 August 2013. The RFRAC comprises rural fire stakeholder representatives from Local Government NZ, DOC, NZ Forest Owners Association, NZ Defence, Federated Farmers, NZFS and NRFA, as well as Scion management and research staff. The Committee was chaired by former National Rural Fire Officer, Murray Dudfield.

Scion fire scientist Grant Pearce gave a Powerpoint overview of the WFPA project, including the interim results from the Chairpersons Conference workshop (Pearce & Langer, 2013d). Additional feedback from RFRAC members included the following points:

- From the NRFA perspective, the emphasis should be on identifying areas for FireSmart planning through community engagement, etc.; i.e. the ambulance at the top of the cliff (and not other uses suggested at bottom of the cliff).
- Other non-fire planning issues will have an effect; for example, in peri-urban areas if someone is not allowed to cut down vegetation then other problems may arise (e.g. property access for firefighting, or increased risk of the house burning down).
- If we define WFPAs, are insurance companies going to alter premiums and hence some people may not insure if premiums become too high?
- In using previous fire history to define WFPAs, it is important not to overlook areas that haven't had fires (as they may still be fire prone environments but just lucky, or have a good FireSmart group and therefore have not had fires).
- The methodology should be a Geographical Information System (GIS) tool that can be used to filter high wildfire prone areas, for which individual properties can then be subsequently evaluated using a FireSmart checklist to indicate where work is required to make them safer (i.e. more FireSmart – through better defensible space, access, distance to safe zone, etc.).
- Properties could be given a green, orange or red category, or some other scoring system, to indicate how fire prone they are and how much work is needed to reduce this to a low risk level.
- Question – how much of this latter step (e.g. evaluating defensible space) for individual properties can be done remotely (using GIS data, aerial photography or remote sensing) versus on-ground property surveys? Are there other data sources (e.g. housing construction type)?
- Developing the checklist guidelines/tool should be an output from the project.
- Project findings should be disseminated to communities, as they are the true end-users.

Rural fire managers were also made aware of the WFPA project, and asked to provide input where possible, during a research presentation to the Forest and Rural Fire Association of New Zealand (FRFANZ) annual conference (Pearce et al., 2013b). This conference was attended by over 160 fire managers from across the country.

3. Literature Review and Definitions

A review of local and international literature was undertaken to further refine the definition, factors and methodology to be used to identify and map WFPAs for New Zealand. As the focus of WFPAs is the risk to human life and property, the starting point for any method is likely to be the RUI – or the wildland-urban interface (WUI) as it is referred to in North America and other parts of the world – where people and property intersect with flammable vegetation.

The literature review (Pearce et al., 2013a) included evaluation of over 60 references, including a number of international studies that have defined and mapped the RUI/WUI or other aspects of wildfire risk, as well as local literature on fire risk including the NZWTAS. All references have been stored in Endnote and in a Mendeley database to allow easy retrieval of more detailed information.

3.1 Literature review findings

Butler's 1974 description of the WUI as "any point where fuel feeding a wildfire changes from natural [wildland] fuel to man-made [urban] fuel" is considered to be the original interface definition (Hill, 2001, cited in Platt, 2010). More than a quarter of a century later, the US Federal Register (Federal Register, 2001) defined the WUI as an area "where humans and their development meet or intermix with wildland fuel", and published a set of characteristics to try to standardise the concept and to enable identification of at-risk communities in the vicinity of public lands. The term was imported into Europe, although WUI features are different, particularly since agriculture is a major landscape creator and component in many European countries (Herrero-Corral et al., 2012). Throughout the evolution of the term, three elements are always included: human presence, wildland vegetation, and a distance representing the potential for effects to extend beyond boundaries and impact neighbouring land.

The inadequacy of the Federal Register definition, even within the US alone, is attested to by the number of studies that have attempted to redefine and improve its parameters. As well as being open to different interpretations and within different contexts (Macie & Hermansen, 2003, cited by Herrero-Corral et al., 2012; Wilmer & Aplet, 2005 and Platt, 2006, both cited by Platt, 2010), the definition does not include a criteria for a measure of exposure or fire likelihood (Mell et al., 2010; Haas et al., 2013). This is problematic when trying to identify an at risk area (Wilmer and Aplet, 2005 and Platt, 2006, both cited in Platt, 2010) and therefore does not account for differences in fire risk (Radeloff et al., 2005).

The revolution in technology, including mapping and spatial analysis has greatly improved the opportunities for mapping WUI areas since the evolution of the term, and numerous studies have attempted to find a replicable and commonly acceptable method. However, a variety of datasets and mapping techniques are used at national, regional and local levels.

WUI maps at national or regional levels tend to combine population or housing data with satellite-based land type classifications (Stewart et al., 2007). Alongside vegetation data, population information is commonly derived from American census data or the European level Corine Land Cover (see for example, Radeloff et al., 2005; Theobald & Romme, 2007; Herrero-Corral et al., 2012). Radeloff et al. (2005) created the first consistent map of the WUI for the conterminous US using census-based data. This study identified WUI areas based on maximum distance (2.4 km) from heavily vegetated areas of at least 5 km^2 to produce a strategic level WUI map.

National and regional scale methods are useful to gauge the extent of WUI areas within regions and countries (Beverly et al., 2010) and offer a useful baseline to inform wildland fire and fuels management (Haas et al., 2013). However, this type of smaller scale mapping is limited by coarse source data (Platt et al., 2011) and is not detailed enough to allow for specific planning and fire management activities (Beverly et al., 2010; Lampin-Maillet et al., 2010; Haas et al., 2013). It can also oversimplify or omit spatial variation in wildfire potential (Platt et al., 2011) by assuming that flammable vegetation is automatically a wildfire hazard (Haas et al., 2013). Haas et al. (2013) make particular note of the exclusion of topographical information since a large proportion of the area burned within the US is due to the spread of large fires, rather than localised ignitions.

The importance of a commonly accepted definition of WUI areas is illustrated by Platt (2010), whose study compared five WUI models across four US counties using slightly different foci (vegetation or housing) and implementation (details of WUI definition). The results show how WUI maps differ according to definition and focus used. Stewart et al. (2007) completed a similar study, using GIS analysis to evaluate the national WUI in the US by altering the parameters of the definition. Their study found that each alteration created differences in WUI area, with the most sensitive parameter being housing density. However the resulting WUI changes were small, and the study concludes that the definition can generate stable results in most landscape types.

Studies that have used census-based ‘meshblocks’, commonly used for zonal mapping, are also impacted by the nature of the data itself. US census meshblock data are based on density of population, and are divided by physical features such as roads, or invisible features such as county boundaries (Bar-Massada et al., 2013). Therefore they offer limited spatial resolution in ‘extra-urban areas’, such as commuter communities on the outskirts of suburban areas (Lu et al., 2009; Bar-Massada et al., 2013), for example where rural lands are included within a census block in an area where housing density may be too low to be considered as WUI (Stewart et al., 2007). Factors such as fuels, topography, and zoning laws can all vary within a meshblock (Platt et al., 2011). Additionally, census data has limited temporal resolution due to its multi-year nature (decadal in the US) (Lu et al., 2009), and population datasets and landscape patterns can change dramatically in a short time (Galiana-Martin et al., 2011; Haas et al., 2013). Therefore New Zealand’s five-yearly census datasets (e.g. Statistics NZ, 2006, 2013) offer advantages to some of these limitations.

The main disadvantage of the European Corine land cover system is again the spatial resolution, with a cartographic scale of 1:100,000, and a minimum mapping unit of 25 ha and minimum width of linear elements of 100 m (Herrero-Corral et al., 2012; Chas-Amil et al., 2013). Therefore, like US census data, it is recognised as not supplying enough detail to study WUIs at the local spatial level and, in particular, underestimates areas with highly dispersed human settlements.

A variety of methods have been used to provide more detailed WUI mapping. There is wide agreement that there is no mapping technique that satisfactorily produces a true representation of the WUI area over a region or country, while providing the level of detail and accuracy to overcome issues associated with using small-scale data sets that will provide local communities and fire managers with the tools needed to plan for and mitigate against wildfire.

Overlay mapping has been employed in an attempt to overcome the limitations of census-derived data. For example, studies have used other geographic boundaries such as uninhabitable water bodies, national parks and steep slopes (Theobald & Romme, 2007; Haas et al., 2013). In the US, Haas et al. (2013) attempted to create a risk-based WUI identification by using wildfire simulation models to produce estimates of likely fire occurrence near and within populated areas. Similarly Haight et al.’s (2004) study overlaid current vegetation types classified into flammability, and subsequently combined a map of fire risk with a WUI map to identify high-risk WUI areas.

Mapping at the local scale allows the WUI to be mapped more accurately, with detail possible to the area around individual homes. Since the detail is so much higher, such methods can include information about the elemental characteristics of the WUI, allowing fire risk to neighbouring built-up areas to be assessed (Lampin-Maillet et al., 2010). The finer detail around buildings and forestland is particularly advantageous in providing information about complex rural areas where the population is highly dispersed (Chas-Amil et al., 2013). It also offers improved understanding of how human settlement patterns affect fire risk which in turn can inform urban planning in terms of fire prevention (Lampin-Maillet et al., 2010).

Other studies have developed non-zonal mapping methods based on individual building footprint or point data (Lampin-Maillet et al., 2009, 2010; Silva et al., 2010, cited in Bar-Massada et al., 2013). Buffering, using set distances from points or objects, has been used in various ways to derive WUI maps from housing location data (Wilmer and Aplet, 2005, cited by Bar-Massada et al., 2013; Lampin-Maillet et al., 2010; Platt, 2010). Beverly et al. (2010) combined information about fire behaviour processes with buffer mapping in GIS to map the extent of the WUI and associated degree of ignition exposure for four communities in Alberta, Canada. Bar-Massada et al. (2013) aimed to develop a consistent point-based method to map the WUI in four distinct US states by manually digitizing individual structures using aerial photographs. The study used fully scalable circular buffers to generate ‘neighbourhoods’, which were then applied using a moving window approach, with the same zonal densities of housing and vegetation as set out in the Federal Register (2001). The study generated more precise results than zonal mapping, but such a method can lead to inaccurate results especially in densely populated areas (Haas et al., 2013).

Such studies also allow WUIs to be further categorised into different types. For example, Herrero-Corral et al. (2012) identify seven ‘situations’, and Lampin-Maillet et al. (2010) recognise twelve interface types based on a matrix of four kinds of building configuration and three types of vegetation structure. Galiana-Martin et al. (2011) use a similar methodology to produce nine WUI characterisations.

A simpler method that has been employed uses features of both zonal and point-based methods, based on digital cadastral data (Calkin et al., 2005, cited in Bar-Massada et al., 2013; Platt, 2010). Although advantageous in that such a method does not require the digitisation of structure location, its main weakness is that its centroid may in fact not be the actual structure location, since factors such as landscape features, infrastructure and parcel size also determine this. This limitation can be overcome using multivariate modelling, but this is highly time-intensive (Bar-Massada et al., 2013).

Since not all vegetation is equally at risk of suffering wildfire, simulated likelihood of wildfire has been incorporated into human development data in an effort to develop more risk-based mapping (Ager et al., 2013; Atkinson et al. 2010; Haas et al., 2013). However, these do not give enough detail or consistency to allow expansion to the national scale (Haas et al., 2013). Fire history data sets have been used to attempt to produce more risk-based measures. For example, Lu et al. (2009) combined data sets illustrating historic wildfires, ignition potential and vacant lands with raster data sets containing information about elevation, slope, aspect and vegetation.

This review of literature highlights the importance of finding a suitable and precise definition of the RUI for New Zealand, and a methodology for mapping it, as the basis for identifying WFPAs where the focus is risk to people and property.

3.2 Definition of a Wildfire Prone Area

The objective of the second phase of the project (Pearce & Langer, 2013b) was to develop an initial definition of what constitutes a WFPA in the New Zealand context, and to determine the factors that then need to be used to apply this definition to the spatial identification (i.e. mapping) of WFPAs in New Zealand.

While it is comparatively easy to define the term 'Wildfire Prone Area' in a qualitative sense (i.e. in words) – for example, as "an area where wildfire poses a high risk to people and property" – it is much more difficult to define this in quantitative terms that enable such areas to be identified spatially. This requires identification of the factors that define an area and its elevated fire risk, plus any additional factors that contribute to the vulnerability of the people and buildings within it, in quantitative terms that enable mapping of all these contributing factors using GIS.

From the original VBRC recommendation, it is clear that a WFPA refers to an area which poses an increased risk from wildfire to human life and property (primarily houses). This implies particular emphasis on the RUI, where flammable vegetation coincides with people and buildings, and this is the context in which the WFPA concept been applied here. The focus on risk to human life and residential dwellings also differentiates this analysis from other wildfire risk assessment tools such as the NZWTAS, which aims to describe threat to all values-at-risk (i.e. including economic, biodiversity, cultural, recreation values, etc.). In effect, identification of WFPAs represents a subset of the NZWTAS focusing on the threat to lives and built assets only. However, not all the important factors in defining a WFPA are captured within the NZWTAS – for example, social factors, such as community vulnerability – so a separate methodology is required.

In addition, a criticism of the NZWTAS is that it only goes part way to addressing the need to describe both the likelihood and consequence components associated with wildfire risk. This was recommended to meet international best-practice for risk management (i.e. AS/NZS ISO 31000: 2009). The WFPA methodology proposed here could be considered a better means of meeting this requirement, with mapping of the RUI describing the consequences associated with potential loss of life and property. Added to this are overlays of contributing risk factors (fuels, climate and fire occurrence statistics, etc.) addressing the likelihood component. Therefore, if deemed appropriate for further implementation, the WFPA methodology outlined here should be included within the NRFA's 'Guideline for Development of Risk Management Plans' (currently in draft format), which aims to provide guidance to RFAs on how they can meet the national Standard for 'Assessing Fire Hazards'. However, caution should be applied in not providing too many alternative approaches to meeting the Standard, with it likely that the number of methods will need to be rationalised at some point to include only a limited number of preferred methods.

Defining the Rural-Urban Interface (RUI)

The basic distinction between rural lands and urban interface areas is the presence of buildings (structures) (Mell et al., 2010), especial residential housing. The presence of buildings also implies a greater number of people and increased risk to human life. However, despite recognised formal definitions for RUI/WUI terminology (e.g. Federal Register, 2001; NFPA 2008), and a number of studies attempting to map the RUI/WUI (e.g. in the US: Stewart et al., 2003, 2007; Theobald & Romme, 2007), a universal definition of RUI/WUI land areas is still not available. Mell et al. (2010) note that, in the US, *"a standard definition is [still] needed in order to consistently track the extent of the WUI, measure the cost of the WUI problem, implement risk assessment methods, and prioritise risk-reduction activities at local, regional, and national scales"*.

The lack of a conclusive definition is in part due to the fact that the RUI/WUI typically includes several categories, including ‘interface’, ‘intermix’ and ‘occluded’ zones (e.g. Federal Register, 2001; NFPA, 2008). Interface communities exist where structures directly abut rural lands containing vegetation fuels (i.e. on the boundary of urban areas), whereas intermix communities exist where structures are scattered throughout vegetated rural areas (Federal Register, 2001). The less used ‘occluded’ term refers to islands of vegetation surrounded by structures (such as parks in urban areas). Any quantitative, spatially-applicable, definition therefore needs to be able capture these different interface categories.

Despite these issues, common factors were apparent from the literature that can be used to map the extent of the RUI in New Zealand as the first step in defining WFPAs. These typically include housing density (number of houses/ha) and/or population density (number of people/ha), vegetation type, distance from rural vegetation (km) and vegetation cover (%). For example, Stewart et al. (2007) provided a method for distinguishing between interface and intermix areas that uses housing density, vegetation cover and distance from vegetation (see Fig. 1). Similarly, Mell et al. (2010) included a comparison of different criteria that have been used to define the WUI in the US (see Table 1). It also highlights the impact of differences in the criteria used, as well as of use of differing values for the same criteria, on the resulting estimate of the extent of the WUI area. While New Zealand data sets exist for some of these factors (e.g. population density and possibly buildings), others may need to be derived.

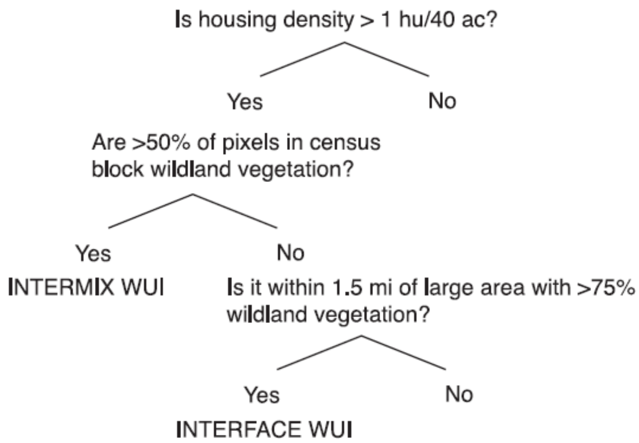

Figure 1. Decision tree methodology used by Stewart et al. (2007) to define Wildland-Urban Interface (WUI) areas in the US, including distinguishing between interface and intermix zones. (Non-metric units are shown; ‘hu’ = housing unit; 1 hu/40 acre = 1 hu/16.2 ha (0.06 hu/ha); 1.5 mile = 2.4 km).

Table 1. Definitions of interface, intermix, and occluded Wildland-Urban Interface (WUI) communities and resulting land area in the US from different studies (adapted from Mell et al. 2010). (For reference, the land area of the contiguous US is 808 M ha; 'hu' = housing unit).

	Federal Register (2001)	**Stewart et al. (2003)**	**Theobald & Romme (2007)**
Interface	>7.5 hu/ha or >1 person/ha	>0.06 hu/ha and <50% vegetation	>0.5 hu/ha and >10 ha patch
Intermix	>0.06 hu/ha or 0.1 - 1 person/ha	>0.06 hu/ha and >50% vegetation	0.06 - 0.5 hu/ha
Occluded	<400 ha wildlands	not considered	not considered
Distance to untreated fuels[A]	not specified	2.4 km	0.8, 1.6 and 3.2 km[B]
Extent of WUI		70 M ha	47 M ha

[A] Untreated fuels mean wildlands where no fuel treatments have been implemented to mitigate wildland fire risk to the community.
[B] Based on buffer distances typically treated to create Community Protection Zones for structure protection, crown fires and flying embers, respectively.

Defining Wildfire Prone Areas

Given the focus on risk of wildfire to life and residential property (houses), WFPAs therefore represent areas of the RUI that are more prone to wildfires than others. These could be in particular parts of the country where the fire climate is more severe and fires are more likely to occur. Conversely, they could be areas of the RUI in regions with the same fire climate severity, but with a greater risk of wildfires due to ignition risk, or areas with more severe fire behaviour potential resulting from more flammable fuel types or the effects of slope on potential fire spread. However, inherent in all of these situations is the influence of the fire environment factors (topography, fuels and weather) on increasing the risk of wildfires occurring, as well as the severity of fire behaviour.

Therefore important 'physical/environmental' factors that could be included in defining WFPAs, on top of those used to identify RUI areas, include:

- vegetation/fuel types;
- fire climate severity;
- slope steepness;
- other topographic factors (e.g. slope position, aspect);
- fuel loads and fire spread potential; and/or
- fire history.

In the majority of cases, data associated with these physical/environmental factors are quantitative, so that they can be readily included in a GIS-based method for mapping WFPAs. In addition, data sets for many of these factors are readily available (including from the existing NZWTAS), so that they can be used directly, or updated, or otherwise easily modified. The exception is likely around fire history, where there is no single, accurate, national database of fire causes, locations and sizes.

However, these physical/environmental factors in themselves do not enable identification of 'at risk' WFPAs, where one community is more 'vulnerable' than another. This could be due to social factors, such as socio-economic status or age groupings (e.g. families with young children, or the elderly), or to the presence (or lack of) social networks within a community that make it more (or less) resilient. These social factors can in some cases be subjective and, on the whole are much more difficult to describe quantitatively. Therefore data are unlikely to be available in a spatial format suitable for use directly in GIS mapping, with the exception of existing Census-derived data sets on socio-economic status (e.g. social deprivation indices) and population age class data.

Vulnerability could also be the result of other 'infrastructure' factors, such as fire suppression resource availability (e.g. proximity to fire station), water supplies (reticulated vs static), or potentially even risk to lifelines (e.g. evacuation routes/transport access, power supply, domestic water supplies, etc.). These are more likely to be available in a spatial format (e.g. through CDEM sources), at least at the local level required for the WFPA analyses.

Glossary of terms

To aid understanding of the terminology, a set of definitions for relevant terms are provided here. The definitions considered most appropriate for use on New Zealand are highlighted in italics in the text that follows, and then re-worded in the break-out box at the end of this section. Discussion and agreement is required by the NRFA to confirm these definitions. It is recommended that once these have been accepted as standard definitions applicable for use in New Zealand, they are added to applicable glossaries if they are not already included (e.g. NRFA, 1998; AFAC, 2012).

Rural-urban interface (RUI) = Wildland-urban interface

Areas where homes are built near or among lands prone to wildland fire. It is usually described as the line, area or zone where structures and other human development meet or intermingle with undeveloped wildland or vegetative fuels (McPherson et al., 1990). The area where humans and their development meet or intermix with wildland fuel (Federal Register, 2001). The zone of transition between unoccupied land and human development; these lands and communities adjacent to and surrounded by wildlands are at risk of wildfires (Wikipedia).

The line, area or zone where structures (houses) and other human development adjoin or overlap with undeveloped (wildland) vegetation (after AFAC, 2012).

The RUI is often defined from a spatial or geographical perspective, and can include several different categories of interface.

Interface

The classic interface is where urban sprawl presses up against public and private natural areas, in the form of a distinct line between urban and rural areas (Hermansen-Báez et al., 2009).

Where structures directly abut wildland (vegetation) fuels (i.e. on the boundary of urban areas) (Federal Register, 2001).

Intermix

The intermix is an area undergoing a transition from agricultural and forest uses to urban land uses. As its name implies, this type of interface involves a mixing of rural and urban land uses in the same area (Hermansen- Báez et al., 2009).

Where structures are scattered throughout a wildland (vegetated) area (Federal Register, 2001).

Occluded interface

These are islands of undeveloped land within predominantly urban areas that are left as urban areas expand (Hermansen-Báez et al., 2009), creating remnant patches of vegetation such as along river corridors or in steep gullies.

Where structures abut an island of wildland (vegetation) fuels (e.g. a park or open space within an urban area) (Federal Register, 2001).

Isolated interface

The isolated interface is a remote area interspersed with structures such as summer and recreation homes, ranches, and farms, all surrounded by large areas of wildland vegetation (Hermansen-Báez et al., 2009).

Bushfire Prone Area (BPA) – Australia

A bushfire prone area is an area of land that can support a bushfire or is likely to be subject to bushfire attack (NSW RFS 2006; Standards Australia, 2009; DTPLI, 2014; Leonard et al., 2014). Bushfire prone areas are mapped for a local government area and identify the vegetation types and associated buffer zones for building development due to bushfire risk (NSW RFS 2014) or where specific bushfire constructions standards apply (DTPLI, 2014).

In general, a bushfire prone area is an area occurring within 100 m of a high or medium bushfire hazard (NSW RFS 2006). In Tasmania (TPC, 2012), the definition has been further refined to identify any area of land subject to bushfires within 100 m of a contiguous area of vegetation of greater than 1 ha (10,000 m^2):

> *Bushfire Prone Area* means an area of land which is subject, or likely to be subject to bushfires being any area of land that is within 100 m of an area of bushfire-prone vegetation equal to or greater than 1 hectare (10,000 m^2);
>
> where *bushfire-prone vegetation* means contiguous vegetation including grasses and shrubs but not including maintained lawns, parks and gardens, nature strips, plant nurseries, golf courses, vineyards, orchards or vegetation on land that is used for horticultural purposes;
>
> and *contiguous* means separated by less than 20 m (TPC, 2012).

Wildfire Prone Area (WFPA) – New Zealand

In a qualitative sense, an area where wildfire poses a high or increased risk to human life and property (primarily houses). Areas of the RUI that are more prone to wildfires than others due to high vegetation fuel hazard and fire spread potential.

An area of the rural-urban interface (RUI) where wildfire poses an increased risk to people and buildings due to high vegetation fuel hazard and fire spread potential.

Recommended definitions for use in New Zealand

Rural-urban interface (RUI)
The area or zone where structures (houses) and other human development adjoin or overlap with flammable vegetation.

Interface
An area of the rural-urban interface (RUI) where structures (houses and associated outbuildings) directly abut vegetation fuels to form a distinct line between urban and adjacent rural areas.

Intermix
An area of the rural-urban interface (RUI) where structures (houses and associated outbuildings) are scattered throughout a vegetated area.

Occluded interface
Areas of the rural-urban interface (RUI) where structures (houses and associated outbuildings) abut an island of vegetation fuels (e.g. a park or open space) within an urban area.

Wildfire Prone Area (WFPA)
An area of the rural-urban interface (RUI) where wildfire poses an increased risk to people and buildings due to high vegetation fuel hazard and fire spread potential.

4. Methodology

4.1 Conceptual methodology

Despite the problems noted above with varying definitions for identifying RUI/WUI areas, sufficient common factors were apparent from the various methods described in the literature to formulate a conceptual methodology for defining WFPAs in New Zealand.

This methodology comprises two principal steps for mapping of WFPAs, which were subsequently tested using the pilot case studies undertaken as part of the project (Pearce et al., 2014a):

1) Mapping the extent of RUI areas based on population density, building density and/or locations, and proximity to vegetation; and
2) Overlaying other fire risk factors to identify high wildfire prone areas and to enable prioritisation of WFPAs for mitigation.

Data required

Step 1 of the conceptual methodology requires access to data on population density, housing density or location, and land cover from which vegetation cover and proximity can be derived. New Zealand data sets already exist for these factors in a format that was able to be utilised directly (or relatively easily derived) for use in testing the various methods for defining the RUI/WUI outlined below. These data included:

- Population density – describing the number of people/ha, available as population mesh blocks from LINZ based on the latest Statistics NZ Census data;
- Housing density – describing the number of residential buildings/ha), which is available from Statistics NZ;
- Building locations - as either point data or building footprints, which are available from some District Councils;
- Vegetation type – describing the presence of vegetation or specific fuel types, obtained the Land Cover Database (LCDB) classification; and
- Distance from rural vegetation (km) – obtained within GIS from land cover data (i.e. LCDB).

The study commenced using 2006 Census (Statistics NZ, 2006) data sets, but was updated when 2013 Census data (Statistics NZ, 2013) was released. Similarly, the study utilised LCDB3.3 land cover data, but version 4 has since been released (http://www.lcdb.scinfo.org.nz/).

Step 2 of the conceptual methodology involves the overlaying of spatial data for other fire risk factors over identified RUI areas, potentially including:

- Fuel type maps derived from the LCDB (either from the existing NZWTAS data based on LCDB2, or more recent work, e.g. by Scion to update to LCDB3.3);
- Slope steepness and/or aspect derived from topographic data (DEM);
- Fire climate severity, particularly the Seasonal Severity Rating component, based on maps from Pearce et al. (2011a);
- Fuel 'flammability' maps, including fuel loads and fire behaviour potential (rate of fire spread and/or fire intensity) based on fuel type, slope and fire climate, either from the NZWTAS or derived from updated information;
- Data on infrastructure coverage and vulnerability, potentially including fire suppression resource availability (proximity to fire station), water supplies (reticulated vs static), and/or lifelines (e.g. evacuation routes/transport access, power supply (e.g. from RFAs, Councils &/or CDEM agencies; and

- Data on social vulnerability, including socio-economic status, social deprivation indices, or community demographics from existing national data sets (e.g. Statistics NZ) and, if possible, community networks or other community resilience measures where available (e.g. Scion social case studies).

Wherever possible, it is recommended that existing data sets should be utilised in the analyses; however, in some cases, new purpose-derived data layers will need to be developed, Similarly, depending on the number and types of additional risk factors to be overlayed over RUI areas, threshold values or rating scales for each of these additional risk factors will need to be defined. Where this is the case, a simple rating (e.g. 3 or 5 class) for high, medium and low risk contributions could provide the most efficient solution for combining multiple, often complex, risk factors. This rating could then be used in highly wildfire prone areas as well as regions of the country considered to have lower fire risk.

4.2 Mapping of RUI areas

As noted from the literature review (see Section 3 above), the international studies that have attempted to define and/or map the RUI/WUI largely all included use of factors such as population density and/or housing density or building locations, combined with vegetation type and distance from rural vegetation. Use of different threshold values for these factors enables distinction to be made between interface and intermix areas (see, for example, the comparison between the methods of Federal Register (2001), Stewart et al. (2003) and Theobald & Romme (2007) included in Table 1).

The complexity of the RUI/WUI mapping analyses from the literature depends on how many of the WUI categories are recognised, the number of variables used to define these, and the need to define land cover types (see Appendix B). The use of building density or locations, in particular, adds considerable complexity, with additional software such as the WUImap ARC GIS tool (Lampin-Maillet et al., 2010) required to integrate housing data and vegetation continuity.

Step 1 of the conceptual methodology for identifying WFPAs first involved mapping the extent of the RUI. From the international literature, four methods for spatially identifying RUI/WUI areas were initially tested, of which two were selected for further investigation of their use in mapping WFPAs. The four methods initially tested for identifying RUI/WUI areas in the two case study areas included:

Method 1) Zhang et al – assessed as a low complexity method (see Appendix B), this method developed by Zhang et al. (2008) only defines interface areas (and not the intermix) based on census meshblock data for a single housing density class plus vegetation cover. This method defines the WUI as those meshblocks with 60% or more wildland vegetation cover and a housing density of between 0.06 units/ha and 1.55 units/ha.

Method 2) Haight, Radeloff & Stewart – another of the low complexity approaches, this method has been widely used in the US to define the WUI (e.g. Haight et al., 2004; Radeloff et al., 2005; Stewart, 2007). It uses census meshblock data for either a single housing or population density threshold, together with proximity to wildland vegetation for two different cover categories, to define both interface (<50% vegetation) and intermix (>50% vegetation) areas. In this case, housing density data ≥ 0.06 units/ha) was utilised, initially along with the standard distance from vegetation used in the US of 2.4 km.[3]

Method 3) Theobald & Romme – another low complexity method that is similar to the two methods above, this method of Theobald & Romme (2007) also utilises two classes of either housing or population density, but in this instance does not consider vegetation cover or proximity to wildland fuels. The distinction between interface (>0.5 units/ha) and intermix (0.06-0.5 units/ha) areas is simply made on the basis of density which, for our purposes here, was again done using meshblock housing density. Denser urban areas are excluded through use of a lower density threshold (0.5 units/ha) compared to the previous methods, which considered housing densities up to and even greater than 1.55 units/ha (see Table 2 below).

All three of these methods distinguish between RUI/WUI areas using the same housing density threshold of 0.06 units/ha (Table 2). However, the first two methods define 'wildland' as areas of vegetation greater than a particular size – in these cases, both 500 ha – so as a result, smaller areas of vegetation less than this threshold are excluded. In the Haight, Radeloff & Stewart method, they also impose an additional requirement for the area of wildland vegetation to have high vegetation cover (>75%). The Haight, Radeloff & Stewart method has a further potential advantage in that it also considers the distance to this adjacent wildland vegetation. For the purposes of the initial case study testing undertaken here, the vegetation classes from LCDB version 3.3 for forest (LCBD3-classes 71,64,68,69) and scrub/shrubland (LCDB3-classes 51,52,58,54,56) were used to define 'wildland' areas.

Table 2. Summary of thresholds used to define interface and intermix areas in the first three methods tested.

Method	WUI categories	House density	Vegetation cover
1) Zhang et al.	Interface only	0.06-1.55 units/ha	≥ 60%
2) Haight, Radeloff & Stewart	Interface & Intermix	≥ 0.06 units/ha	≤ 50% >50%
3) Theobald & Romme	Interface & Intermix	>0.5 units/ha 0.06-0.5 units/ha	n/a

The Zhang et al. method could be considered the simplest of the methods tested (see Appendix B), in that it only considers a single housing density class and vegetation cover requirement. However, it has the disadvantage that it does not distinguish between interface and intermix areas, although it could be assumed from the high vegetation cover requirement (≥ 60%) that this captures both interface and intermix areas. In the authors view, they consider their method includes all intermix areas and a large portion of the interface (Zhang et al., 2008).

The Theobald & Romme method could be considered the next simplest because it only considers housing density, but does still distinguish between interface and intermix areas. This method does not consider vegetation cover within these interface and intermix areas on the assumption that vegetation cover will be higher where housing density is lower, and vice versa. However, the unrestricted housing density at the upper end (>0.5 units/ha), combined with the lack of a vegetation cover threshold, means that the interface category

[3] Subsequent trialling suggested that a distance of 500 m may be more appropriate in New Zealand; however, the sensitivity testing of this and other threshold values used in the different methods is discussed as part of the later section on case study evaluation and in Appendix D.

could capture some high density areas that might otherwise be classed as urban (e.g. at densities greater than the 1.55 units/ha threshold used by Zhang et al.).

The Haight, Radeloff & Stewart method distinguishes between interface and intermix areas, but on the basis of vegetation cover within the built-up area for a single housing density class (which is only limited at the low end to separate areas with sufficient density of houses from lower density wildland). This could be seen as taking the reciprocal assumption to Theobald & Romme that housing density will be higher where vegetation cover is lower, and vice versa. However the unrestricted housing density at the upper end of their single housing density class (≥ 0.06 units/ha) means that interface areas with low vegetation cover (≪ 50%) could again capture some high density areas that might otherwise be classed as urban (e.g. at densities >1.55 units/ha, after Zhang et al.).

Method 4) Lampin-Maillet – a more complex approach (categorised as medium complexity in Appendix B), this method developed by Lampin-Maillet et al. (2010) separates RUI/WUI areas into a greater number of classes based on the distance between individual houses, the size of clusters of houses and housing density, as well as distance to vegetation. As such, it requires point data for individual buildings, either as locations or footprints, as opposed to meshblock-based building density (as in the previous three methods). A 50 m radius around each house is used to discriminate between isolated, scattered and clustered housing, and a 15 m radius around each house belonging to the clustered category used to discriminate between dense and very dense (i.e. urban) clustered housing. This results in four categories, which can be further separated based on vegetation cover (no, low and high 'aggregation').

'Isolated dwellings' (ID) refer to houses (or clusters of 2-3 houses) located >100 m apart, 'Scattered dwellings' (SD) to clusters of 4-50 houses <100 m apart, 'Dense clustered dwellings' (DCD) to clusters of <10 houses located <30 m apart, and 'Very dense clustered' (VDCD) to urban areas with >10 houses located <30 m apart. The very dense and dense clustered dwellings categories are likely to fall outside of the interface classifications of the three meshblock-based methods due to the high building density, and also are likely to have low vegetation cover (low or no aggregation). However, it is possible some of the dense clustered category may be captured as interface where vegetation aggregation is high. The scattered dwellings class potentially includes both interface and intermix as classified by the other methods, with high aggregation lending more to intermix and low/no aggregation to interface. The isolated dwellings category is less likely to be captured by the intermix class of either the Haight, Radeloff & Stewart or Theobald & Romme methods, especially where vegetation aggregation is high. The number of dwellings in these areas probably falls below the 0.06 units/ha housing density threshold used in these methods and therefore would be considered as wildland.

Other more complex methods were also considered (see Appendix B), but were discounted due to their complexity, additional software requirements, problems with availability of required data, or time needed to develop required data sets (e.g. building data from aerial photography and reclassification of fuel types to suit overseas software). Hence the assessment of methods was limited to the four approaches described above, which are compared below.

Sensitivity testing

The sensitivity to use of the threshold values used to define the RUI/WUI (see Table 1) was investigated as part of the case study component of the project. The Haight, Radeloff & Stewart methodology (method 2) was used to test the effect of changing values for distance to vegetation and housing density. In this way it was hoped to determine values appropriate for defining RUI areas in New Zealand. The results from this are reported as part of the case study evaluation discussion and in Appendix D).

4.3 Overlaying of social and other wildfire risk factors

The more complex, and potentially more useful, fire risk mapping methods in the literature go beyond just identifying RUI/WUI areas. They also quantify wildfire-prone areas by typically incorporating data for either wildfire occurrence or other factors that are known to increase wildfire risk (e.g. slope and other environmental factors; e.g. Chuvieco et al., 2012; Herrero-Corral et al., 2012).

As a demonstration of the value of overlaying wildfire risk factors, several environmental and social risk factors were mapped onto the RUI areas identified for the two case study areas. These factors included:

- Fire climate severity, based on the Seasonal Severity Rating component (from Pearce et al., 2011a);
- Community vulnerability, using the Deprivation Index and population demographics for age of vulnerable residents; and
- Community resilience, based around presence of community networks such as schools and marae, and number of people who undertake volunteering.

With updating and further research, there are a number of additional environmental, social and, potentially, also infrastructure fire risk factors that could mapped at national scale for overlaying over the RUI extent to aid in identifying WFPAs.

Environmental risk factors

Key data sets describing environmental factors that contribute to wildfire risk are, for the most part, readily available. These include existing data sets for slope steepness, fire climate, fuel types and fire behaviour potential, which are available from the NZWTAS (Majorhazi & Hansford, 2011). However, in some cases, these data are now out-of-date and would therefore benefit from updating using the latest data. Examples of this include:

- Updated data for slope steepness and aspect obtained from the topographic data contained within up-to-date Digital Elevation Models (DEMs);
- Updated ArcGIS maps describing fire climate severity across New Zealand available from the study by Pearce et al. (2011a), which includes long-term averages for weather inputs (temperature, rainfall, relative humidity and wind speed) as well as fire danger ratings (Fire Weather Index System codes and indices, plus seasonal severity measures); and
- Updated fuel type maps currently being developed by Scion's Rural Fire Research Group, using a more recent version of the Land Cover Database (LCDB3.3, 2013) and other sources.

The combination of these (slope, fire climate and fuel type) would allow the production of updated maps for fuel loads and fire spread potential, and for a range of scenarios as opposed to the single 'worst case' scenario currently used in the NZWTAS. However, as a first simplification, existing (e.g. from the NZWTAS based on LCDB2) or improved (recently updated for LCDB3.3 by Scion) fuel type classifications could be used to derive a simple fuel flammability rating that could be used as an overlay layer to highlight the additional risk posed by fuels.

For the purposes of this study, it was not possible to consider the value of utilising fire occurrence data. Despite spatially-based wildfire occurrence data being available for some areas of New Zealand (e.g. DOC jurisdictions, and from the NZFS incident reporting system, SMS), there is no single, accurate national data set of wildfire incidents that is currently available in a format suitable for use in the conceptual methodology. This is in part because the NZFS SMS system typically attributes fire incidents to property street addresses, which do not always reflect their true locations, especially for rural fires (W. Tyson, DOC, pers. comm.). Additionally, the NRFA only requires RFAs to report the total number of fires and area burned for major fuel types for each jurisdiction each year (via the Annual Return of Fires), and not individual fires or their locations. Even so, at the local scale at which WFPA mapping is likely to be best undertaken, there are likely to be local RFA spatial fire occurrence data sets that could be utilised in such analyses.

Social fire risk factors

As noted above and in many of the international studies, these physical/environmental factors in themselves do not enable identification of ‘at risk’ WFPAs, where one community is more ‘vulnerable’ than another. This is because social factors, such as socio-economic status (Román et al., 2013), age or land-ownership groupings (Jakes et al., 2010), or the presence (or lack of) social networks within a community (Jakes & Langer, 2012), can make it more or less resilient to wildfire impacts (Poudyal et al., 2012).

These social factors can in some cases be subjective and, on the whole are much more difficult to describe quantitatively. Therefore data are less likely to be available in a spatial format suitable for direct use in GIS mapping without considerable additional work to derive them for case study areas. However, the exceptions to this are existing data sets (e.g. those derived from Census data) on socio-economic status (such as social deprivation indices) and population age class data or where other Scion case studies have collected adequate spatial data.

The most up-to-date indexes of socioeconomic deprivation in New Zealand are represented by the New Zealand Deprivation Index (NZDep2013) which combines nine variables from the 2013 Census (Statistics NZ, 2013; Atkinson et al., 2014). It reflects eight dimensions of deprivation and provides a deprivation score for each meshblock in New Zealand, and divides New Zealand into tenths of the distribution of the first principal component scores. The attained scale ranges from 1 to 10, where 1 represents the areas with the least deprived scores and 10 the areas with the most deprived scores. For example, a value of 10 indicates that the meshblock is in the most deprived 10% of areas in New Zealand, according the NZDep2013 scores. NZDep2013 is derived by combining the following census data (calculated as proportions for each small area in order of decreasing weight in the index):

- Communication – people aged <65 with no access to the Internet at home;
- Income – people aged 18 - 64 receiving a means tested benefit;
- Income – people living in equivalised* households with income below an income threshold;
- Employment – people aged 18 - 64 unemployed;
- Qualifications – people aged 18 - 64 without any qualifications;
- Owned home – people not living in own home;
- Support – people aged <65 living in a single parent family;
- Living space – people living in equivalised* households below a bedroom occupancy threshold; and
- Transport – people with no access to a car.

* Equivalisation includes using methods to control for household composition.

Although the social deprivation index is a useful tool to evaluate the characteristics of a community and its capabilities (e.g. to afford insurance, or to pay for contractors to assist with fire prevention measures such as defensible space around their homes), it does not necessarily mean that an area with a high index value is less resilient. In fact, the opposite maybe the case, as communities with high social deprivation may have strong family and community networks and be more likely to assist one another, whereas communities in areas with a low social deprivation index may not be as well connected, networks maybe sparse and the community may be more vulnerable to wildfire risks.

Vulnerability can also be the result of other ‘infrastructure’ factors, such as fire suppression resource availability (e.g. proximity to fire stations) or water supplies (reticulated vs static), or potentially even risk to lifelines (e.g. evacuation routes/transport access, power supply, domestic water supplies, etc.) (Britton & Clark, 2000). Data for these are likely to be available in a spatial format (e.g. from NZFS datasets, STFMP analyses, or through Council or CDEM sources), at least at the regional level required for the proposed case study analyses. However, due to time and data availability constraints, no mapping of infrastructure factors was included in the case studies or methodology evaluation undertaken.

5. Case Studies

As a test of the conceptual methodology proposed for identifying WFPAs, a pilot study-type trial was undertaken to map WFPAs for two case study areas of New Zealand (Pearce et al., 2014a).

Initial areas considered for these case studies included the Rotorua region, the Port Hills area on the outskirts of Christchurch city, and the Nelson region, based on the availability of the required data (especially for building density and locations). Ultimately, it was decided to proceed with two case studies in different parts of the country – Nelson and Rotorua.

5.1 Case study locations

The Nelson region was chosen as one case study location due to it being a recognised area of the country with relatively high fire risk, based on both fire climate severity and knowledge of past wildfire events. The region covers a wide range of potential RUI types, from the city of Nelson (population 43,000; Statistics NZ, 2013) to small rural communities, and sparsely populated rural areas to densely populated seasonal holiday settlements. In addition, some work has been undertaken in this region by the RFA (Waimea Rural Fire Authority) to begin FireSmart planning to mitigate wildfire risk in high-risk communities (e.g. Sandy Bay, near Kaiteriteri to the west of Nelson).

Population and building density data sets were available for the Nelson region from the 2013 Census (Statistics NZ, 2013), and individual building footprints were also available for the Nelson City Council area (unfortunately, individual building data was not available for the neighbouring Tasman District Council). Knowledge of social factors, including community networks, was also available for the suburb of Atawhai, on the urban fringe about 5 km north-east of Nelson city, as it was one of the case study areas for research into effective communication of wildfire risks (undertaken as part of the Bushfire CRC Effective Communication project; Hart & Langer, 2014). This study provided useful information, including that Atawhai and many other suburbs of Nelson are made up of small, disjointed communities located in steep, unconnected valleys. Most of the properties are suburban houses, but can include larger (‘lifestyle’) properties bordering grazed farmland, scrub and pine plantations. For most community services, the residents of Atawhai use Nelson city; however, the suburb has a primary school, two early childhood centres, a local store, a hairdresser, a takeaway outlet and two churches that provide hubs for community networks.

Rural Fire Network Ltd., based in Richmond (14 km south west of Nelson), provides fire management services for the Waimea RFA area, and manages a voluntary rural fire force at Hira (10 km north-west of Atawhai) as one of several across the district. Nelson has also experienced numerous RUI fire events (Pearce, 1994), including several in the Atawhai area (Anderson, 2002). A larger fire necessitated the evacuation of over 200 properties in Atawhai in February 2009.

In contrast, the Rotorua region was selected as the second case study location because it is an area of the country generally not perceived as having a high wildfire risk, due to its less severe fire climate. However, it also encompasses a range of RUI types, including major urban areas, small settlements and sparsely populated rural areas, plus more densely populated lakeside communities that include a mix of both permanent and seasonal holiday accommodation. Population and building density information was again available from Census data (Statistics NZ, 2013), together with a well-detailed spatial data set of individual building point locations and types for the entire region from the Rotorua District Council.

5.2 Case study results for RUI extent

Figures 2 and 3, respectively, illustrate the extent of the RUI identified using the four different methods for each of the two case study areas. Examples in each case are shown for both the wider region as well as more localised close-up areas to better illustrate the detail of each method. Of the four methods tested, two contrasting methods – the meshblock approach of Haight, Radeloff and Stewart, versus the individual building data approach of Lampin-Maillet – appear to produce the best spatial descriptions of the RUI.

The Zhang et al. method identifies much smaller areas than the other two meshblock-based methods, identifying similar areas to those classed as intermix by Haight, Radeloff & Stewart, and only a very small proportion of the areas classed as either intermix or interface by the Theobald & Romme method. The Haight, Radeloff & Stewart and Theobald & Romme methods identify very similar extents for the combined RUI, with Theobald & Romme classifying a greater proportion as intermix, whereas Haight, Radeloff & Stewart class more as interface. Therefore either could provide a suitable meshblock-based method. However, the Haight, Radeloff & Stewart approach has the added advantage of considering distance to adjacent wildland vegetation, which can also be adjusted to further refine the RUI extent identified. In the examples above, the US standard (of 2.4 km) for distance to vegetation was initially reduced to 500 m for the purposes of comparing different methods, but was subsequently investigated further as part of the sensitivity testing undertaken as part of the conceptual methodology evaluation.

Because it is based on actual data for building locations, the Lampin-Maillet method potentially provides the best description of the actual RUI area compared to the meshblock approaches based on building density. However, building data, either as point locations or building footprints (e.g. obtained from aerial photography), is believed to be available in only a few regions of the country. The Nelson case study (see Figure 3b, method 4) is a good example of this, where building data is available for the Nelson City Council area but not in the neighbouring Tasman District. In some instances, it is also unclear whether the point locations reflect actual building locations (i.e. as taken from aerial photography) or are based around address points (e.g. Rural Address Property Identification (RAPID) numbers). It is also unclear how complete these building data sets are, especially for rural parts of districts compared with more urban areas, and whether some data sets capture just residential and other urban buildings or also include outbuildings (again, especially in rural areas). There is likely to be significant variability in how and what is collected across the country.

However, it is important to recognise that there is no ‘right or wrong’ approach to mapping of the RUI, as this is highly dependent on the intended application (Stewart et al., 2009). By comparing two WUI mapping approaches, Stewart et al. (2009) showed that WUI maps derived from the same data sets can differ significantly depending on the purpose for which they were developed. They emphasised that no single map is ‘best’ because users' needs vary. They also cautioned against the use of ancillary data to modify census meshblock data to ‘improve’ WUI maps[4]. Stewart et al. (2009) further suggested that analysts who create maps are responsible for ensuring that users understand their purpose, data and methods used. Map users are in turn responsible for paying attention to these features and using each map accordingly.

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[4] Note this specifically applies to the modification of meshblock data for mapping of the RUI, as opposed to overlaying of data for identifying WFPAs.

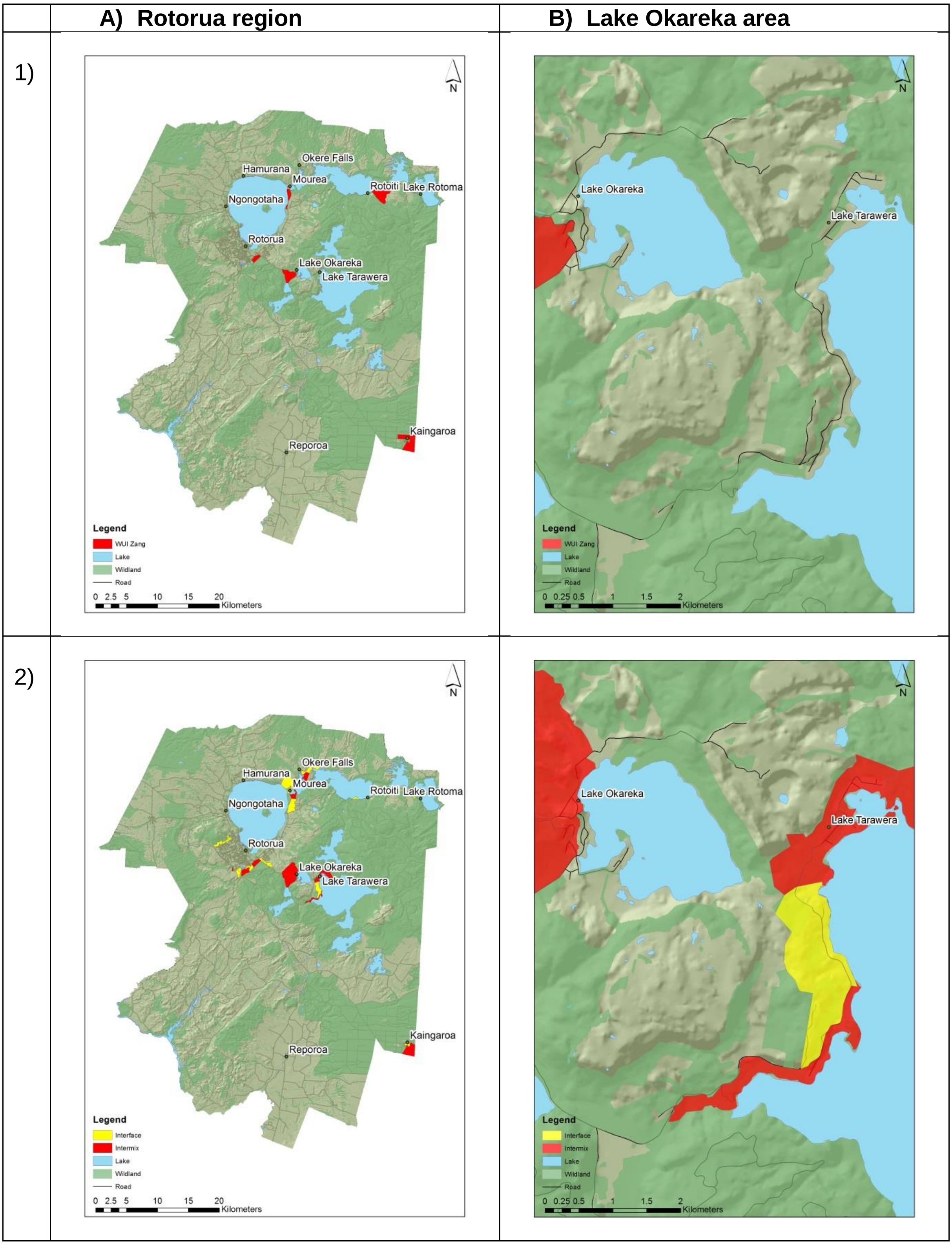


Figure 2a. GIS maps for the Rotorua case study region for both A) the wider Rotorua region, and B) more detailed local close-ups for the Lake Okareka area, produced using each of the four different methods tested, including: 1) Zhang et al.; and 2) Haight, Radeloff & Stewart. [Methods 3 & 4 are shown on the following page].

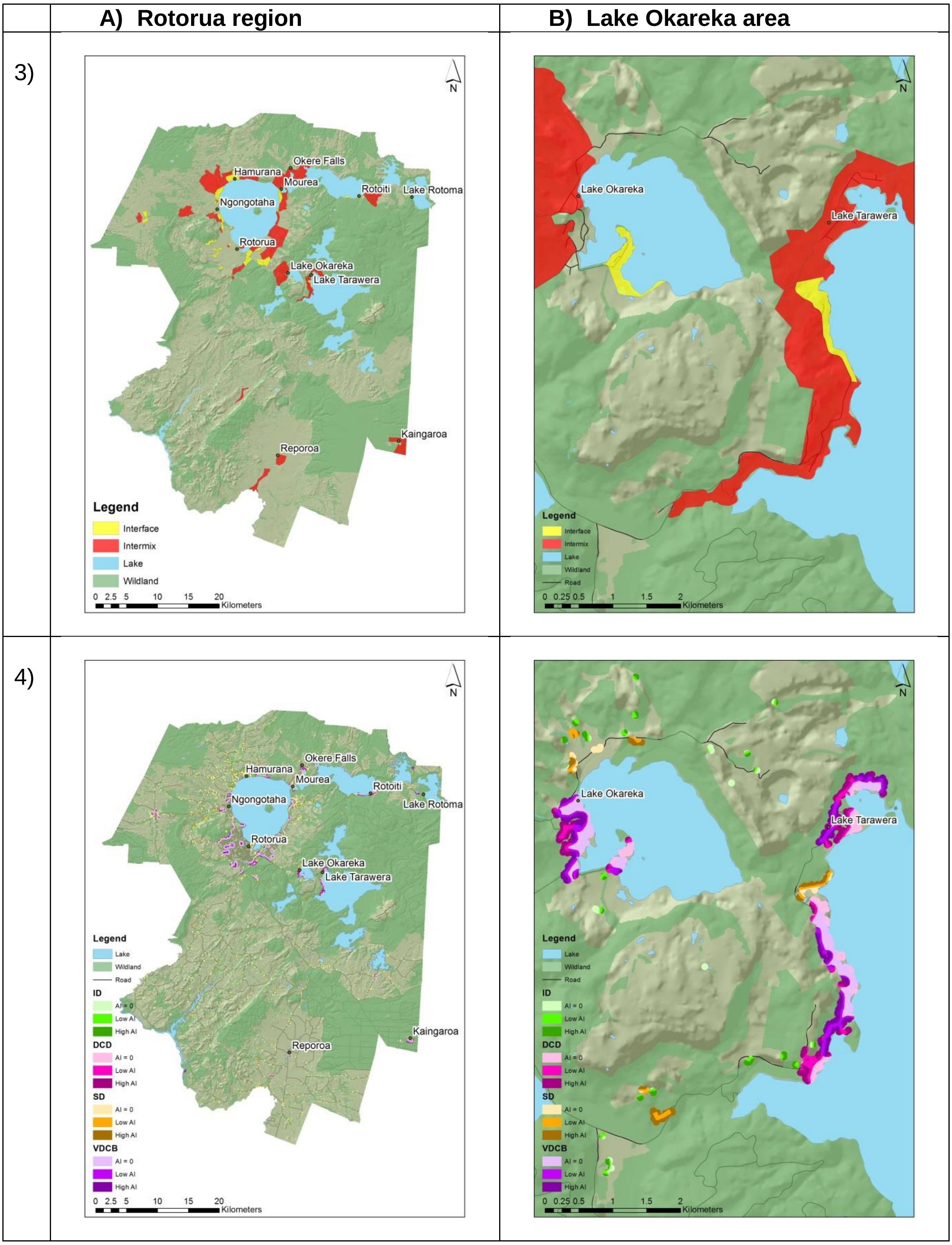


Figure 2b. GIS maps for the Rotorua case study region for both A) the wider Rotorua region, and B) more detailed local close-ups for the Lake Okareka area, produced using each of the four different methods tested, including: 3) Theobald & Romme; and 4) Lampin-Maillet. Within the Lampin-Maillet method 4), ID = Isolated dwellings, SD = Scattered dwellings, DCD = Dense clustered dwellings, and VDCD = Very dense clustered dwellings (urban). [Methods 1 & 2 are shown on the preceding page].

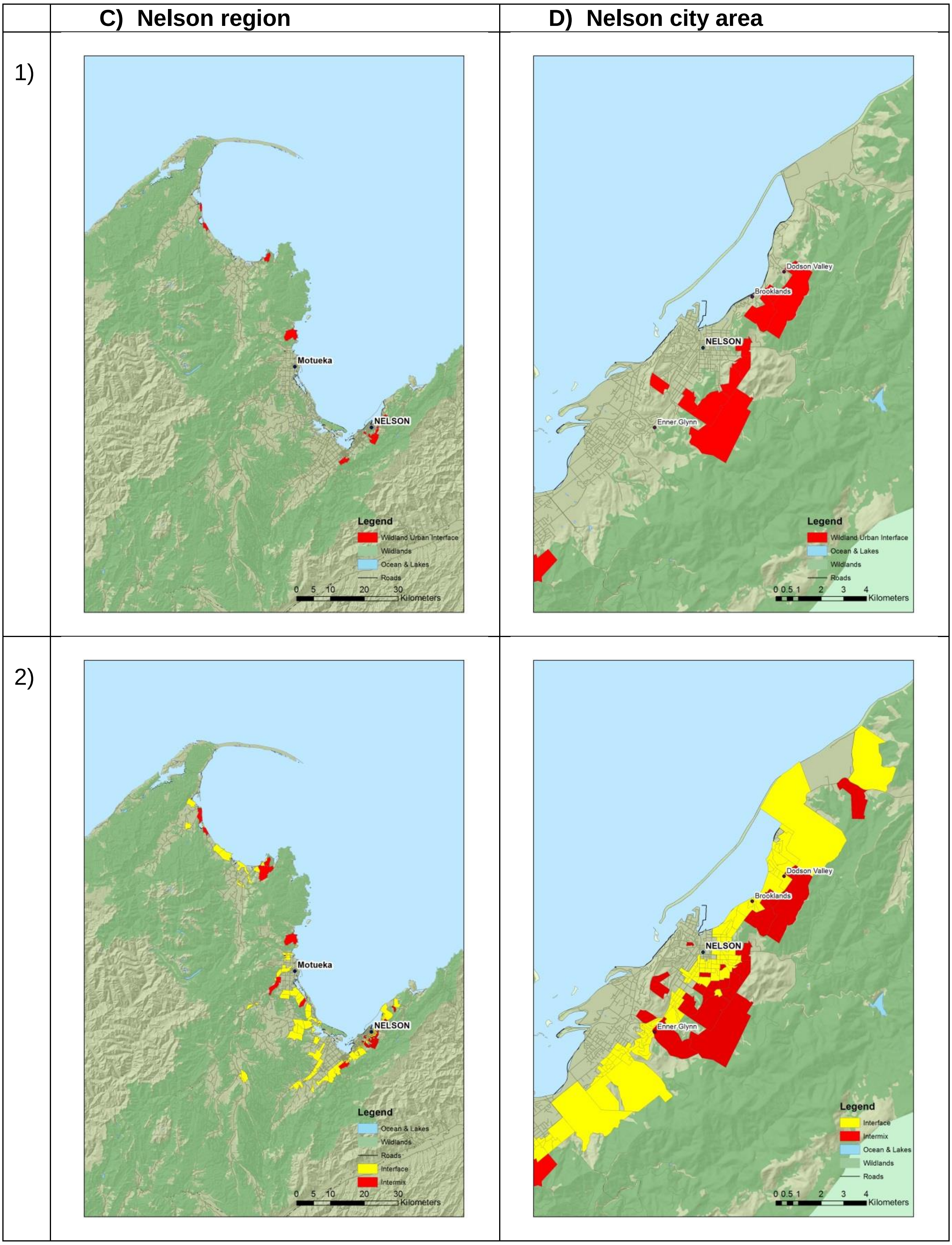


Figure 3a. GIS maps for the Nelson case study region for both C) the wider Nelson region, and D) more detailed local close-ups for the Nelson city area, produced using each of the four different methods tested, including: 1) Zhang et al.; and 2) Haight, Radeloff & Stewart. [Methods 3 & 4 are shown on the following page].

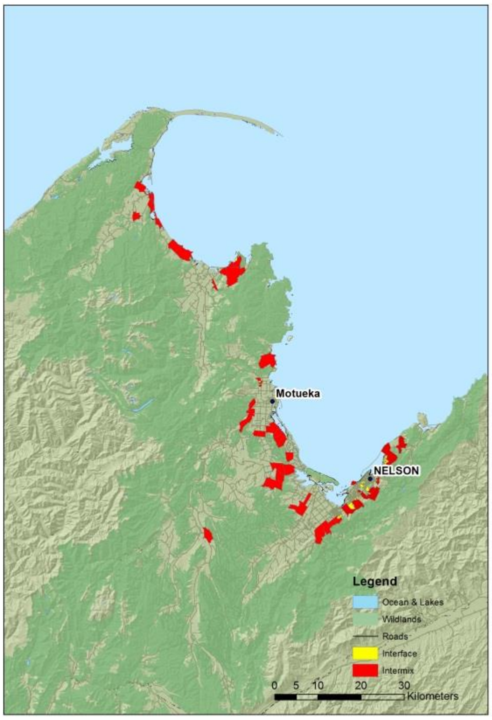
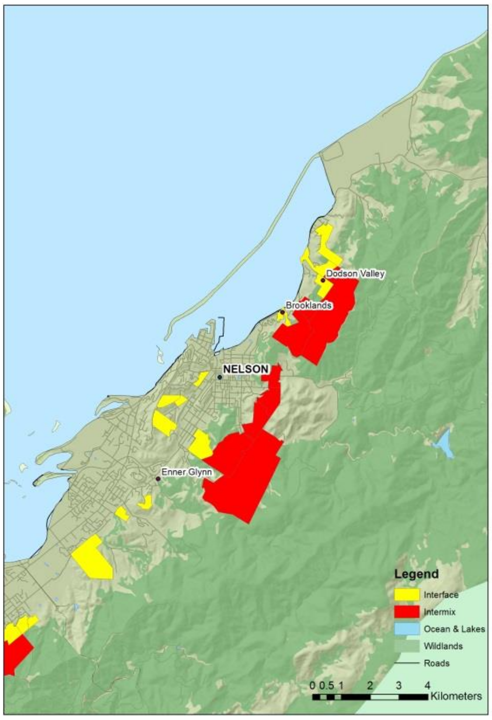
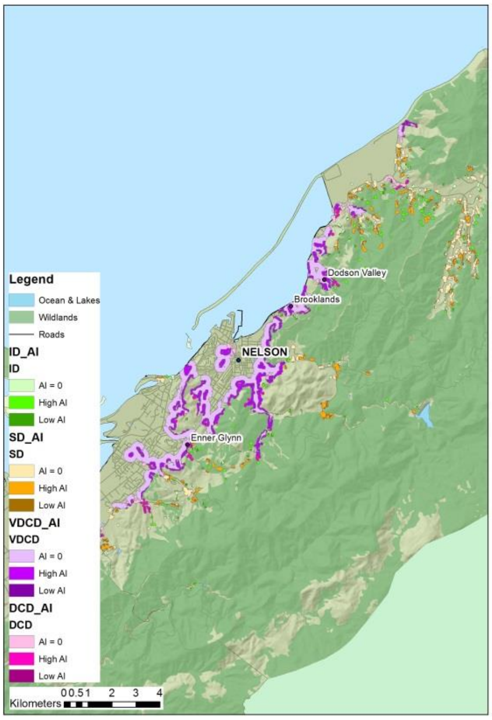
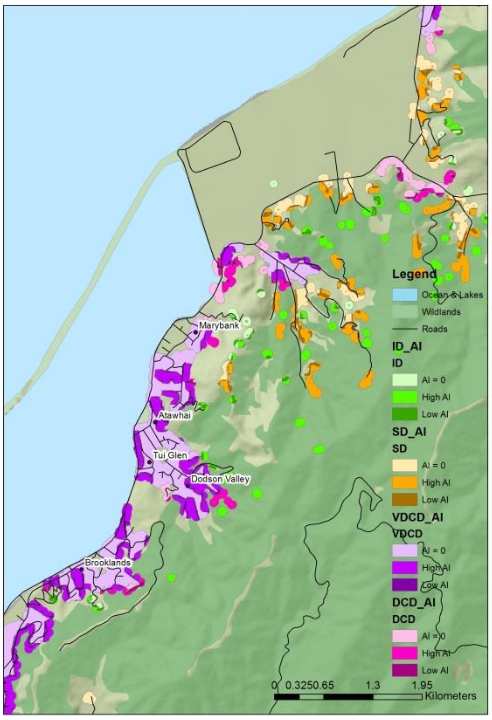
	C) Nelson region	D) Nelson city area
3)		
4)		

Figure 3b. GIS maps for the Nelson case study region for both C) the wider Nelson region, and D) more detailed local close-ups for the Nelson city area, produced using each of the four different methods tested, including: 3) Theobald & Romme; and 4) Lampin-Maillet. Within the Lampin-Maillet method 4), ID = Isolated dwellings, SD = Scattered dwellings, DCD = Dense clustered dwellings, and VDCD = Very dense clustered dwellings (urban). [Methods 1 & 2 are shown on the preceding page].

5.3 Results from overlaying of fire risk factors

Step 2 of the conceptual methodology involved the overlaying of wildfire risk factors on to the mapped RUI extents to identify the more wildfire prone areas to enable prioritisation of fire mitigation activities. Within each of the environmental and social wildfire risk components, several factors were used to illustrate how overlaying of these helps to identify the WFPAs. These were based on the ready availability of data from existing sources although, in the majority of cases, the factors considered were also seen as major contributors to wildfire risk within each component.

Within the environmental component, fire climate severity is a key indicator of wildfire risk. The average fire season Daily Severity Rating (DSR) from Pearce et al. (2011a) was therefore overlain onto the RUI extents from the Haight, Radeloff & Stewart methodology (Figure 4). Due to the spatial scale at which the DSR was mapped (and the resulting lack of variation in DSR across the study areas), this was only somewhat useful in its current form for identifying higher risk WFPAs. For both the Rotorua and Nelson case study areas, DSR values ranged over only 2-3 of the existing classes. Mapping of DSR at a finer resolution, and/or reclassification of values into more DSR classes, would provide a broader risk range to better support prioritisation. However, it is important to note that such classes could vary significantly depending on the scale of the analysis, and whether it is local, regional or national.

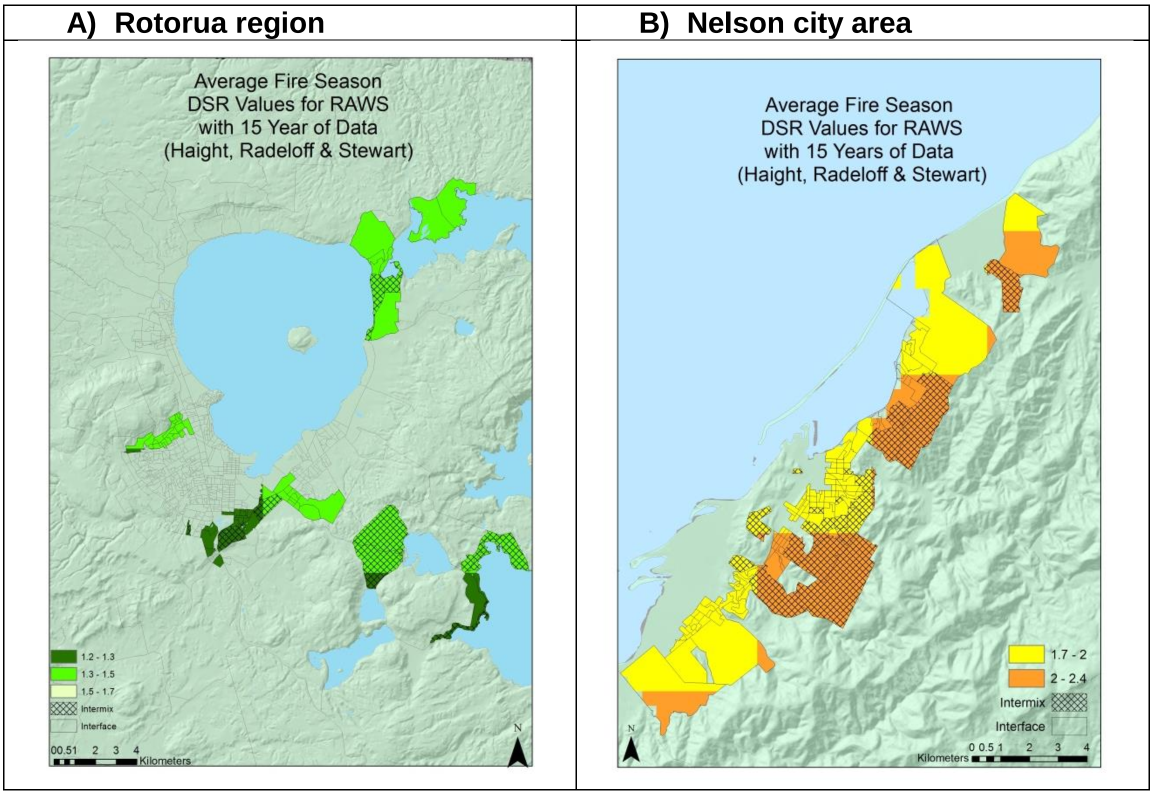


Figure 4. Fire season severity (as measured by the average fire season Daily Severity Rating, DSR) overlayed on RUI extents for A) the Rotorua region, and B) Nelson city, as mapped using the Haight, Radeloff & Stewart method.

Within the social fire risk component, a number of potential data overlays were considered from both 2006 and 2013 Census meshblock data (Statistics NZ, 2006, 2013). These included population demographics, average household income, education, how long people had resided in the area and in New Zealand, household tenure and social deprivation index. Of these, the NZ Deprivation Index (Figure 5) and population demographics (under 5 years, and over 65 years of age) (Figure 6) were selected for overlaying, as these are seen as potential indicators of community vulnerability; i.e. negative factors that increase wildfire risk. The Deprivation Index (Atkinson, 2014) already combines a number of the other factors, such as household income and tenure, employment status, qualifications, and access to a telephone and transport (see Section 4.3 above). However, local knowledge is also required as meshblocks with a high Deprivation Index may in fact be less vulnerable and have stronger networks and support mechanisms than those with a low Deprivation Index.

Young families and the elderly are also considered more vulnerable parts of the population, so the combination of number of people under 5 years and over 65 years of age was used (Figure 6). However, the actual number of people of these ages within a meshblock in itself is not a particularly useful measure, as this can vary significantly between meshblocks depending on the total number of people in each meshblock. A percentage indicating the relative proportion of vulnerable people of these ages within each meshblock could therefore be considered a more useful indicator (see Figure D8 and associated discussion in Appendix D). How long people have resided in an area is also known to be a useful vulnerability measure, as this influences their local knowledge including awareness of wildfire risk (Jakes et al., 2010); hence this could also be considered if compiling national data sets for future WFPA method implementation.

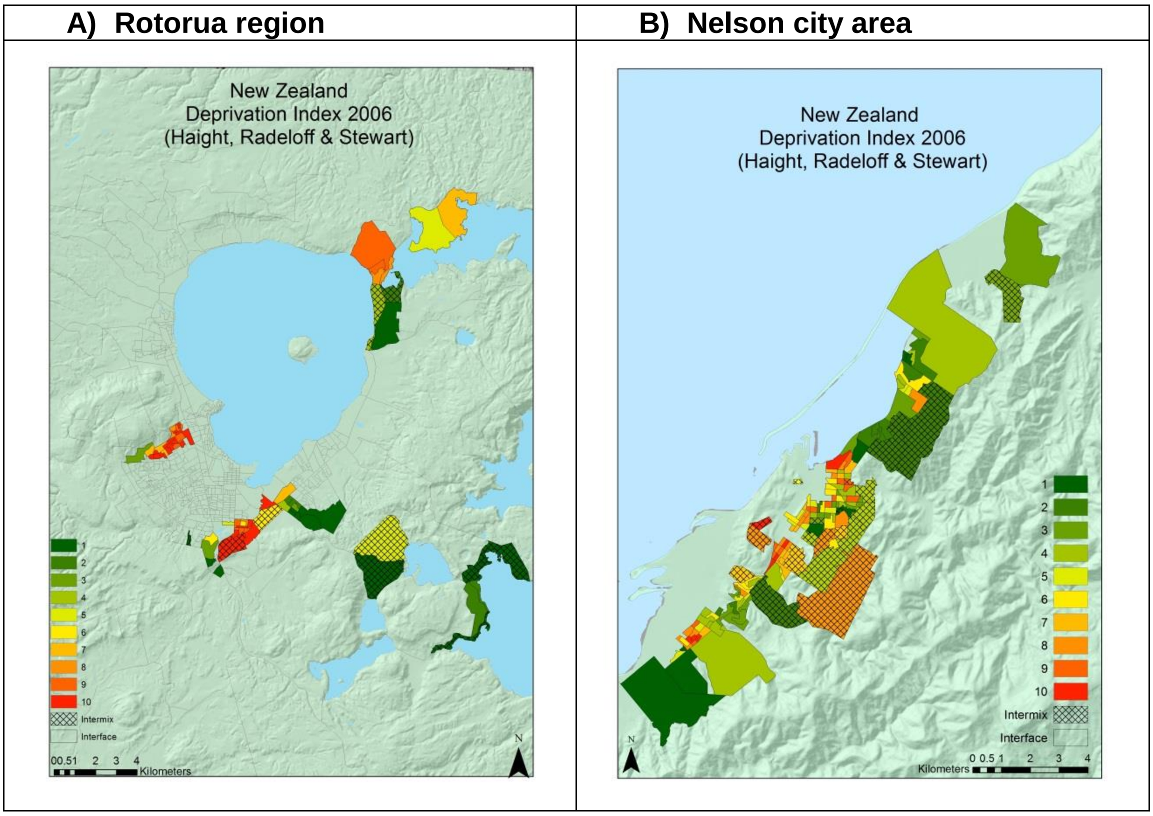


Figure 5. NZ Deprivation Index overlayed on RUI extents for A) the Rotorua region, and B) Nelson city, as mapped using the Haight, Radeloff & Stewart method (where 1 represents areas with least deprived scores and 10 areas with most deprived scores).

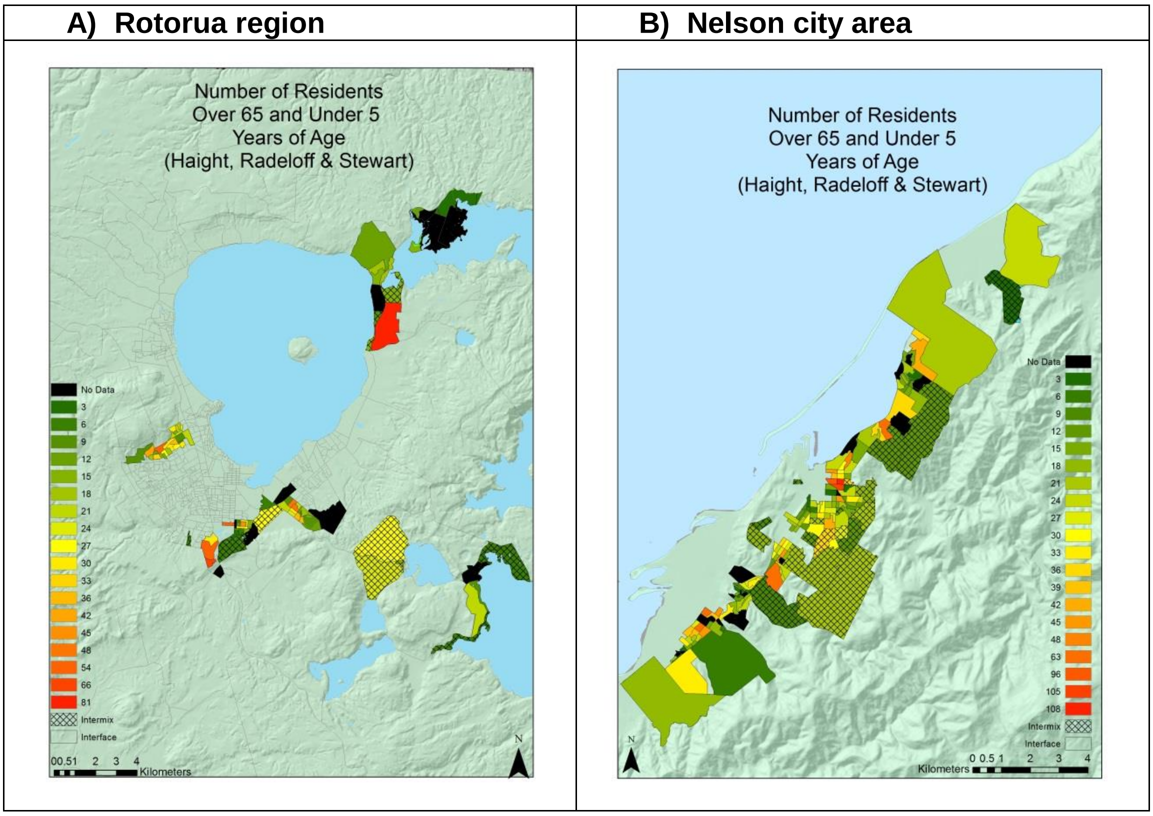


Figure 6. Combined number of people per meshblock aged under 5 years and over 65 years overlayed on RUI extents for A) the Rotorua region, and B) Nelson city, as mapped using the Haight, Radeloff & Stewart method. (A higher number indicates greater vulnerability, i.e. more old and young people at risk).

The number of people who reported participation in volunteering activities (defined as activities performed without payment, for people living either in the same household or outside it in the four weeks before the Census) was also chosen as a measure of community resilience and adaptive capacity, which are positive factors important in reducing risk (Jakes & Langer 2012). Volunteering was overlain over the RUI extent determined by the Haight, Radeloff & Stewart meshblock method (Figure 7). The presence of schools, early childhood centres and marae are also recognised as important centres for community networks that strengthen community resilience (Hart & Langer, 2014). Therefore information on the location of schools[5] and marae within the Rotorua District Council buildings database was utilised to illustrate how this might be used, either with other meshblock-based data (such as in the Haight, Radeloff & Stewart method; see Figure 7) and individual building information (such as in the Lampin-Maillet method; Figure 8). Again a relative proportion of people volunteering within each meshblock may be a more useful measure as the size of meshblocks and population within them is not consistent (see Figure D9). This is again discussed further in Appendix D.

[5] Data on presence of schools was derived from the 'Zenbu find everything' website (http://www.zenbu.co.nz/). This is incomplete data and it is unlikely to capture all primary, secondary and pre-schools; however it is updated regularly.

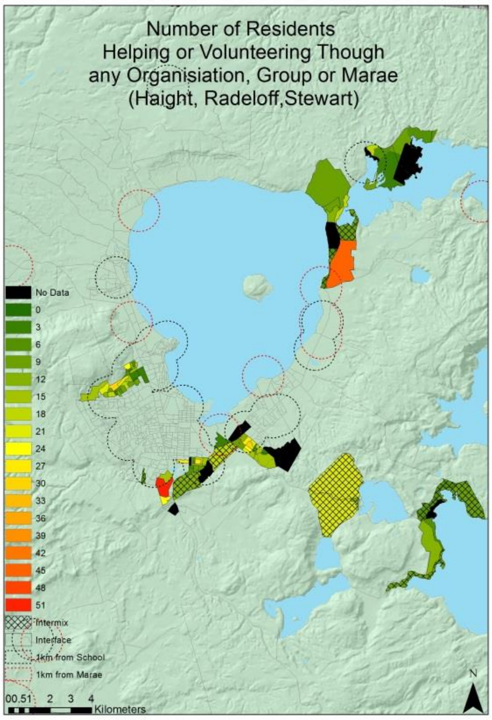
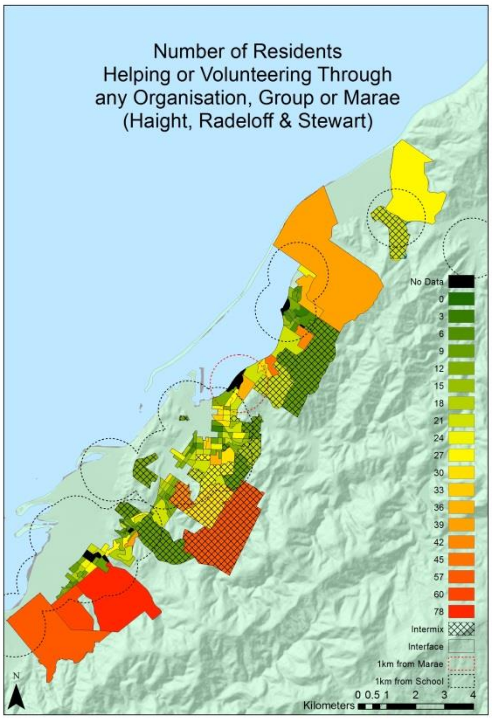
A) Rotorua region	B) Nelson city area
	

Figure 7. Number of volunteers overlayed on RUI extents for A) the Rotorua region, and B) Nelson city, as mapped using the Haight, Radeloff & Stewart method. Areas within 1 km of schools or marae are also shown (by dotted circles) as a second measure of community network strength.

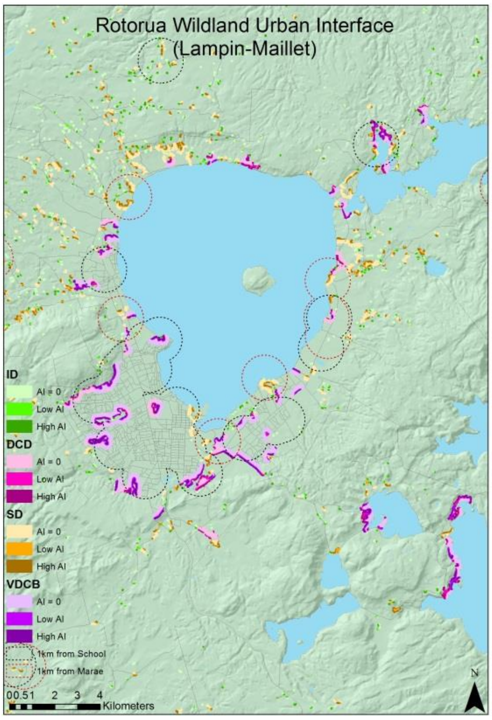
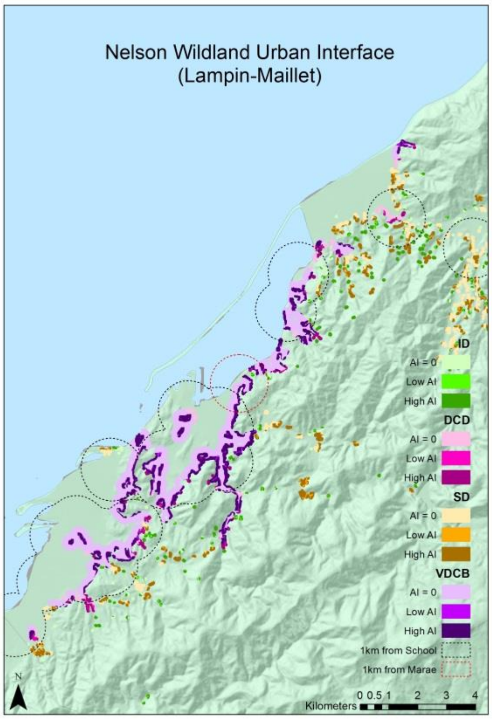
A) Rotorua region	B) Nelson city area
	

Figure 8. Areas within 1 km of schools or marae (shown by dotted circles) as a measure of community network strength overlayed on RUI extents for A) the Rotorua region, and B) Nelson city, as mapped using the Lampin-Maillet method.

5.4 Case study evaluation

RUI method sensitivity testing

The sensitivity of the area identified as RUI using the criteria from the literature for defining interface and intermix components was evaluated by trialling a range of alternative values. The aim of this analysis was determine whether these standard values are appropriate for defining RUI areas in New Zealand, or if use of different values can produce better (more representative) results.

The appropriateness of different values for these criteria (see Table 1) was assessed through subjective visual evaluation of the mapped RUI extents for the two case study areas. For the Haight, Radeloff & Stewart meshblock-based methodology, the distance to vegetation, housing density and vegetation cover thresholds were tested. Within the Lampin-Maillet point method, thresholds for distances from vegetation and vegetation aggregation index were investigated.

More detailed results from this sensitivity testing are included in Appendix D. However, for the Haight, Radeloff & Stewart meshblock method:

- Distance to vegetation – trialled 1 km, 500 m, 200 m, 100 m and 50 m; found 500 m was better than the standard 2.4 km distance;
- Housing density – tested 0.03, 0.05, 0.06, 0.08 and 0.10 units/ha (cf. ≥ 6.17 units per km² or 0.06 units/ha); use of the standard 0.06 units/ha is recommended;
- Vegetation cover – tried ≥ 30% and ≥ 75% of the meshblock as wildland vegetation (cf. default 50%); found little difference between extents mapped using 75%, but using 30% produced changes to the areas identified as interface vs. intermix, including areas of urban parkland not previously identified; therefore it is recommended remaining with the standard 50% cover;

The use of population density as an alternative to building density data was also tested. This showed that population density can provide a suitable substitute if building density data is not available. However, the analysis only used standard values (from Theobald & Romme, 2007), so sensitivity to these population density criteria should also be investigated further.

For the Lampin-Maillet method:

- Distance to vegetation – trialled 50 m, 100 m, 200 m and 500 m, and found distance used had a dramatic effect on the number of buildings selected within the RUI; however the standard 200 m distance subjectively produced the best results;
- Distance between buildings – although not tested specifically, the standard values (100 m for isolated, scattered & clustered, and 30 m for dense & very dense) appeared to identify urban and peri-urban densities well, so are recommended for use as currently prescribed;
- Aggregation Index (for vegetation) – trialled 20 m, 80 m, 100 m moving window for grouping of areas of vegetation, with no discernible difference; use of the standard 80 m is therefore recommended.

Although not specifically tested, the minimum size of wildland area used also warrants further investigation. Here we used any area greater than or equal to 1 ha in size, as the standard (500 ha) assumed from the US would exclude the many smaller vegetated areas found on the boundaries of and within urban areas in New Zealand. This (1 ha) is the minimum area recognised from satellite imagery within LCDB, and is also used in the Emissions Trading Scheme (ETS) description of a forested area, so is well captured by existing New Zealand vegetation mapping data sources. Further discussion on whether the LCDB adequately captures vegetation on the RUI boundaries and within built-up areas (occluded interfaces) is included in Appendix D.

End-user feedback on case study testing

During the period covered by case study testing, the research team was asked to provide an update on the project to rural fire end-users participating in the NRFA's *FireSmart Strategic Workshop* (held in Wellington on 12-13 March 2014). The aim of this workshop was to share information and experiences on 'FireSmart-type' community wildfire risk mitigation projects being conducted around the country by RFAs, and to determine what national resources were required to support this. The methodology for identifying WFPAs being developed through this project is seen as one potential tool to assist in identifying and prioritising at-risk communities for FireSmart activities.

A presentation on the project, including results to date was made to the Workshop (Pearce et al., 2014b)[6]. Detailed notes from the end-user discussion which followed this presentation were recorded. This proved extremely valuable in gaining useful feedback on the proposed methodology, as well as how it might be implemented operationally, and potential issues and implications associated with implementation.[7]

The WFPA method was seen as ultimately only a decision support tool, not a decision-making tool, which should also incorporate local knowledge and expert judgement. In particular, workshop participants noted that they did not want a rigid methodology that was to be applied nationally. They considered that the highest priority identified in one area will be different from the number one priority somewhere else. They strongly indicated that what they needed was a tool to assist local assessment and prioritisation of WFPAs, which utilised the huge amount of information known locally that is not (and cannot be readily) captured in national data sets (e.g. seasonal communities or high recreational use areas). However, they also noted that significant resources would be required to put this local information together, and to keep it maintained and up-to-date.

The ability to use up-to-date data was also seen as a key limitation, as the WFPA would be based on existing data which in many cases is already out of date. Therefore participants considered that data would require constant updating to be accurate, and all available data sources (e.g. council data) should be used. Data sets were also considered to be lacking for fire history information. Participants also highlighted that the proposed method currently only identifies existing WFPAs, and not future area. The assumption is also made that underlying risk factors won't change over time, e.g. demographics, but it is known that significant immigration changes are occurring in some areas.

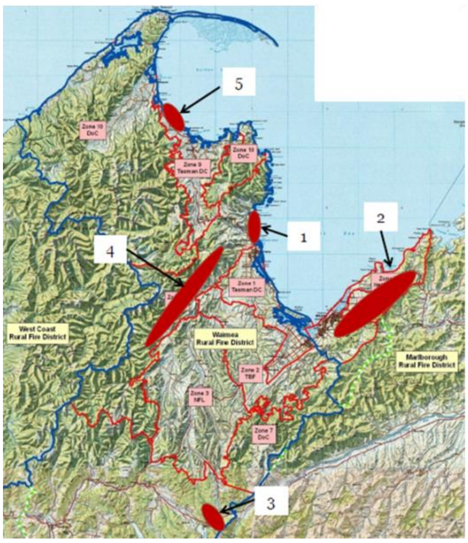
Regarding prioritisation of at-risk communities, it was pointed out that there were often other factors that determined which communities should be addressed first and where mitigation activities were most likely to be successful, such as the presence of a local community champion to engage other community members and drive FireSmart-type activities. Participants also voiced concerns about fire agencies potentially being held accountable by both the public and political masters (including the NRFA) to mitigate wildfire risk in all WFPAs identified as high risk. They suggested that this would not be possible due to lack of resources (i.e. funding). Successful risk mitigation may also not be possible for other reasons, such as the lack of a local champion (as mentioned above) or conflict with other resource management requirements or community values.

[6] A presentation was also made on the NZ Effective Communication case studies, which included the Atawhai, Nelson case study (Langer & Hart, 2014).
[7] Results from the project were also included as part of a presentation to the 2014 RRFC Chairpersons Conference (Pearce, 2014).

Overlap with other systems was identified as another issue. Hence the need for another system was questioned as New Zealand already has WTA, STFMP and ISO 31000-based risk management planning as parts of the NRFA's 'Assessing Fire Hazard' national Standard (NRFA, 2010). Some participants suggested that this suite of systems together with expert assessment/local knowledge should already be capable of identifying communities where FireSmart activities are or are not required. They considered that it is essential to balance the need for another system with community expectations for greater information and warnings. Simplicity was also seen as important, so the community can comprehend it and understand when an individual property is vulnerable. However, some participants foresaw potential difficulties if information on wildfire risk is tagged to a property. Conversely, it was also seen as important not to infer to communities that their area isn't fire prone just because it has not been identified as a WFPA. Final comments re-emphasised the need for consultation and peer review by the fire sector ahead of any proposed implementation of a new system/tool.

The Workshop also included presentations from fire managers on existing FireSmart community risk reduction activities being undertaken around the country. This included one on the Nelson region (Reade, 2014) which included a map of areas identified using local expert knowledge of where it was considered FireSmart efforts were required (Figure 9a). This provides a useful qualitative test of the capability and accuracy of the WFPA mapping methodology proposed here (Figure 9b). This comparison shows that the suggested methodology for mapping RUI areas can identify the correct areas, but through overlaying of additional wildfire risk factors also enables these areas to be more easily prioritised. The proposed WFPA method does therefore provide a useful new tool to support the identification of areas where wildfire risk mitigation activities should be undertaken. However, further comparisons of outputs from application of the WFPA methodology with known high-risk wildfire areas should be undertaken for other areas of the country to more properly 'ground truth' the method.

A) From local knowledge



Areas identified where life/property are at risk from wildfire:
1. Split Apple Rock/Kaiteriteri/Marahau
2. Valleys east of Nelson
3. Lake Rotoiti
4. Motueka valley
5. Milnethorp/Parapara

B) Using the WFPA method

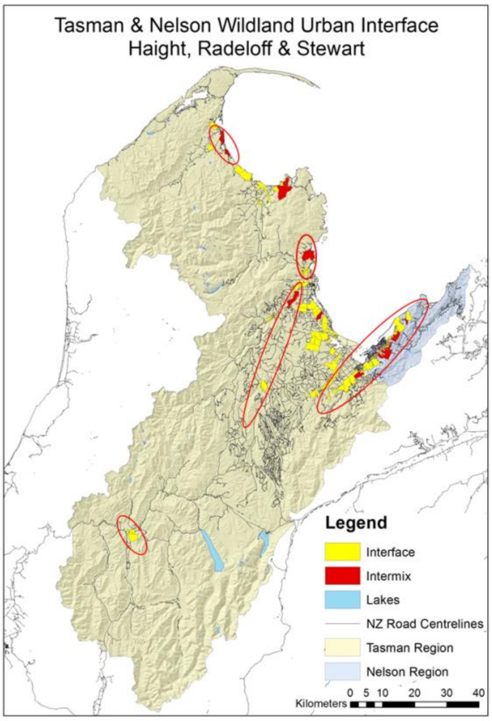


Figure 9. Comparison of identification of Wildfire Prone Areas for the Nelson region based on A) local expert knowledge, and B) the proposed RUI methodology (of Haight, Radeloff & Stewart).

5.5 Regional versus individual property wildfire risk

Beverly et al. (2010) noted that mapping of RUI/WUI areas should ideally only be part of a suite of wildfire risk assessments conducted at multiple scales. Identification of WFPAs only maps the potential for wildfires to enter into populated built environments (i.e. the RUI) (and, conversely, in some regards, the possibility of fires spreading from built-up areas to adjacent wildland vegetation). Therefore, it does not directly consider the probability of house ignition or house-to-house ignitions as affected by individual property characteristics (building construction, defensible space, building separation distances, vegetation flammability including ember production, etc.). Similarly, it doesn't reflect the influence of other factors on the probability of house survival (e.g. homeowner attendance, or storage of flammable materials) and firefighting response capability (e.g. emergency vehicle access, or water supplies).

Therefore, the identification of WFPAs needs to be considered in combination with investigations conducted at other spatial scales as part of a comprehensive RUI risk assessment. Landscape-level assessments such as WFPA (and WTA) can provide information about the likelihood of wildfires occurring in fuel types of concern around a community, including consideration of fire suppression capability (such as access, water supplies and resources) and community coping capacity (socio-economic status, networks, etc.). However, these mapping exercises should be undertaken alongside site-level assessments that evaluate the likelihood that locations within the built environment will be threatened by and be receptive to ignitions should fires occur (Beverly et al., 2010).

Therefore consideration should also be given to the development of an individual property assessment tool that can be used to support and validate the WFPA identification and mapping method by providing checklists of fire risk factors at the individual property level (e.g. defensible space, access, construction materials). This could be similar to those already available in paper form as part of the FireSmart package (NRFA, 2009), but in electronic format (e.g. a spreadsheet or smart app). These property level risk factors should also be able to be 'grouped up' at the community level (e.g. by 'averaging' of assessments for individual properties). In addition, they should be combined with information on suppression capability and community vulnerability to determine an overall suburb or community level rating of wildfire risk. This would enable WFPAs, and communities within WFPAs, to be compared and prioritised for risk mitigation activities such as FireSmart planning. The development of such a tool would therefore enable WFPAs to be identified from a 'bottom-up' approach, or using the more 'top-down' method outlined here.

6. Conclusions and Recommendations

6.1 Conclusions

New Zealand has a history of significant wildfire events that have impacted on people and property. However, the number and scale of wildfires is considered low compared to many other countries. Residents in rural and semi-urban areas, and those visiting rural areas, therefore do not expect wildfires to occur, and are unprepared for a major fire event when one does happen. Wildfire risk is also expected to get worse in future, due to changing land use, increasing population and an expanding RUI, and climate change.

The NZ Fire Service Commission, NRFA and rural fire agencies therefore seek a method for identifying high risk areas prone to wildfires that can be used to assist in targeting of fire mitigation activities, such as development of FireSmart communities, fuel reduction planning and creation of defensible space.

This project has developed methods for mapping New Zealand's RUI, the high fire risk area where flammable vegetation fuels meet people and property. Alternative methods for RUI mapping were developed based on the availability of individual building data versus broader census mesh-block information. Data layers for a range of environmental and social fire risk factors were identified for overlaying onto maps of the RUI, for use in aiding the prioritisation of areas for fire mitigation activities. Two of these methods were successfully tested for two case study areas (Nelson and Rotorua).

Results from various stages of the research were presented to fire managers for feedback on a number of occasions during the project in an effort to ensure that the project delivered useful and practical outcomes. As well as the initial workshop to gain feedback on the WFPA definition and perceived uses, this included participation by Scion project team members in a national FireSmart planning workshop led by the NRFA. This progressed development of a nationally coordinated FireSmart programme for community-led reduction of wildfire risk. It also provided very useful feedback and validation on the conceptual WFPA methodology that has been integrated into this report's conclusions and recommendations.

The methodology proposes two steps in the identification of WFPAs: 1) the mapping of the RUI, and then 2) overlaying of relevant wildfire risk factors on to this RUI extent. Two alternative methods were identified for completing the first step of mapping the RUI – the meshblock based approach of Haight, Radeloff & Stewart, and the building point-based method of Lampin-Maillet. The latter is considered to be the better method if the required building location data are available. However, careful consideration is required in adopting and implementing a prescribed approach as international studies have highlighted that no single map is 'best' because users' needs vary. Study authors also place the onus on the analysts who create the maps to ensure that users understand their purpose, data, and methods. Map users are in turn responsible for paying attention to these features and using each map accordingly.

The case study testing illustrated that while both original methodologies are suitable for identifying the RUI in New Zealand, and assumptions around applicability of the standard definition criteria used within each of these are reasonable, results can be improved by making a few minor changes to these values. In particular, the sensitivity analysis of these criteria showed that a reduction of the distance of buildings (or meshblocks containing buildings of appropriate density) from wildfire vegetation (from the 2.4 km used in the Haight, Radeloff and Stewart method) to 200-500 m produced more reasonable representations of the RUI extent for the New Zealand case studies. However, these sensitivity analyses were based on subjective visual judgements for only the two case study locations. Hence caution should be exercised before definitively applying these modified criteria to other areas of the country.

A number of existing fire risk assessment and mitigation planning systems already exist in New Zealand (such as the NZWTAS and STFMP), so the need for an additional method can be questioned. However, none of these existing systems specifically focus on the risk of wildfires in the RUI, and associated threats to life and property, as intended by the BPA/WFPA concept identified in the VBRC recommendations. Neither do they adequately address the likelihood and consequence components recognised in formal risk assessment (i.e. AS/NZ ISO 31000). Therefore there is a need for a new methodology to identify WFPAs in New Zealand. The WFPA methodology outlined here should form part of the NRFA's 'Guideline for Development of Risk Management Plans' (currently in draft format), which aims to provide guidance to Rural Fire Authorities on how they can meet the national Standard for 'Assessing Fire Hazards'.

This project has improved information and understanding of rural fires by enabling better mapping of wildfire risk. Identification of wildfire-prone areas will result in increased protection of public safety, as well as reduced risk to property exposure. Identification of the highest risk areas will also enable authorities to more effectively target fire risk mitigation activities, such as fire prevention, fuel reduction and promotion of FireSmart communities. Use of the information by local government and fire agencies will also enable strengthening of planning and building controls in high fire risk areas (e.g. through building guidelines and regulations), including restriction of development in areas of highest wildfire risk.

6.2 Recommendations

The study has highlighted the need for a number of further developments and testing of the proposed methodology, as well recommendations around potential operational implementation of the methodology developed.

Operational implementation

- Standard definitions relevant to the use of Rural-Urban Interface (RUI) and Wildfire Prone Areas (WFPAs) terminology in New Zealand (see pages 12-14) should be included in applicable glossaries, such as the NRFA's *Glossary of New Zealand Fire Management Terminology* (NRFA, 1998).
- As developed, the suggested methodology for mapping WFPAs should be applied at the local or regional scale, rather than nationally.
- The two methods (Lampin-Maillet and Haight, Radeloff & Stewart) recommended for identifying the extent of the RUI can be applied nationally, and the meshblock-based method (of Haight, Radeloff & Stewart) in particular could be produced as a standard national data layer.
- Where point building data is available, it should be used (via the Lampin-Maillet method) as the first preference. However in the absence of this data, census meshblock data can be used (in the Haight, Radeloff & Stewart method).
- For use in identifying WFPAs, the RUI methods should be supplemented by overlaying wildfire risk factors. These should include a range of environmental, social and infrastructure factors.
- Where possible, national data sets for as many of these wildfire risk factors should be compiled and made available through a 'data warehouse' storage website.

- To produce best results for identification of WFPAs, these national wildfire risk data overlays should be further supplemented with available local knowledge and data (e.g. wildfire occurrence data and information on community networks).
- The WFPA method suggested here must only be considered a tool to assist, rather than as a definitive method for identifying and prioritising WFPAs for mitigation activities. There will be other factors not included in the method that determine where mitigation might be most effective, such as the presence of local champions and funding sources.
- If deemed suitable, the WFPA methodology should be included in the NRFA's proposed 'Guideline for Development of Risk Management Plans' as an alternative approach to meeting the national Standard for 'Assessing Fire Hazards'.

Further methodology developments

- Further evaluation of the results from the sensitivity testing of threshold values for defining the RUI should be undertaken for other areas of the country.
- Comparisons of outputs (from both recommended methods) with known high-risk wildfire areas should also be undertaken for other case study areas, along the lines of the example shown for the Waimea/Nelson region, to 'ground truth' the methods.
- National data sets of environmental risk factors, such as fire behaviour potential (fire hazard layers from the NZWTAS), should be updated using more recent data on fuel types and fire climate, and for a greater range of scenarios (especially for fire climate).
- Research should be undertaken to develop a simple fuel type flammability ranking based on land cover types and modelled fire behaviour potential that can be used to provide a national fuel flammability risk layer.
- Efforts should be made to improve national spatial data sets on wildfire occurrence, as a key input into identification of WFPAs.
- Further research should be undertaken into the mapping of social factors such as community resilience (e.g. networks, and adaptive capacity), which are currently difficult to describe spatially.
- Local knowledge of social factors should be captured to prepare localised data sets and create a more robust implementation.
- Support should be given to developing a model to spatially measure social and financial capital for use in indicating a community's resilience to fire.
- Availability of national and local data sets for infrastructure risk factors should be investigated and appropriate national data layers made available for use in overlaying.
- More consideration should also be given to how to combine 'negative' and 'positive' risk factors that offset each other.
- Methods for combining the results from overlaying of multiple risk factors should be investigated. This could include investigating the use of simple rankings (e.g. Low/Moderate/High) for all wildfire risk factors to simplify the combination of multiple overlays.
- Consideration should be given to the development of an electronic tool for assessing individual property risk (e.g. based on the FireSmart property checklist). This should also include the capability to 'group up' individual property assessments to provide community ratings.

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Appendix A

Advisory Group Workshop

To initiate discussion on what constitutes a ‘Wildfire Prone Area’ (WFPA) in the New Zealand context, an interactive workshop session was held during the annual Regional Rural Fire Committee Chairpersons’ Conference held in Napier on 11-12 June 2013 (Pearce & Langer, 2013a). The objective of this workshop was to seek fire manager input into the definition of what constitutes a WFPA in New Zealand using ‘knowledge café’ group discussions to obtain answers to the following series of questions.

Questions discussed

1. Assuming the WFPA concept is valid for NZ, how should it be used in NZ?

2. Considering the possible uses, what should the definition of a WFPA be for the NZ context (i.e. for use in NZ)?

3. (a) What factors need to be considered in describing and mapping Wildfire Prone Areas in NZ? (e.g. physical/environmental, social, infrastructure)

   (b) What data sources are available for describing these factors?

An additional question was also asked regarding how WFPAs, as they are to be defined and used in New Zealand based on the above questions, relate to other existing wildfire risk assessment systems, such as WTA:

4. How does the definition of WFPAs in NZ fit with the current NZWTAS methodology and data inputs?

Prior to attending the Chairpersons’ Conference, the attendees were notified that the Workshop was to be held, and provided with background information on the project and the workshop questions to allow them to consider their responses in advance of the workshop and to seek wider input.

Chairpersons’ Conference attendees include Principal Rural Fire Officers RFAs across the country who are the Chairpersons (or a delegate) of the 9 Regional Rural Fire Committees, Enlarged Rural Fire District Chairpersons, members of the National Rural Fire Advisory Committee and other rural fire stakeholder representatives (i.e. Local Government NZ, DOC, NZ Forest Owners Association, Federated Farmers, NZ Defence, Ministry for Primary Industries), as well as NZFS and NRFA. A total of around 40 people participated in the 1-hour workshop session.

Workshop process

Background/introduction (5 mins), Grant Pearce

- ‘Bushfire Prone Areas’ - 2009 Victorian Bushfires Royal Commission recommendation
- NZ Fire Service Commission adopted identification of BPAs recommendation
- Renamed BPAs as ‘Wildfire Prone Areas’
- Not clear what constitutes a WFPA in NZ context
- Not clear relationship with existing risk assessment methods e.g. Wildfire Threat Analysis

- Scion NZFSC project to develop a methodology for identifying WFPAs.
    - workshop with NZ rural fire managers to aid in defining what constitutes a WFPA in the NZ context, and factors needed to identify and map WFPAs
    - international literature review on wildfire risk assessment
    - developing a methodology for identifying WFPA in NZ
    - case study to map WFPAs for at least one area of NZ to test methodology
    - final report, including recommendations for further developments and/or operational implementation
    - project due to be completed by 30 June 2014.

Knowledge café group discussions (60 mins)

Materials

- Seats grouped around 4 tables
- Large sheets of paper provided with one of 4 questions written at top of page, with subsequent pages numbered (e.g. Q1. How should it be used in NZ? Group 1. Sheet 1)
- Permanent marker pens in 3 different colours provided for recording of responses.

Method

- 4 'question coordinators' were appointed to remain at each table, to keep discussion on track and ensure continuity of discussions between groups – NRFA staff (Rob Goldring, John Rasmussen, Paul Baker & Geoff Cameron)
- Attendees were divided into 4 random groups, by numbering people 1-4 and moving all 'number 1s' to table 1, etc.
- Each group nominated a scribe to record responses – in some instances this was the NRFA question coordinator, in others a member of the group
- Workshop chair (Scion researcher, Grant Pearce) circulated and checked discussion going in right direction, and kept eye on time.
- 15 minutes given per question, with a 2 minute warning given for groups to wrap up discussions
- At 15 minutes, bell rung for change over.
- Half of table 1 moved to table 2, and other half to table 3, etc. (to ensure people do not move as a group)
- At start of second (and third and fourth) rounds, the question coordinator summarised previous discussion(s)
- Second (as well as third and fourth) group responses added to discussion comments from previous groups, highlighting agreements and any disagreement
- Process repeated for third and fourth rounds, with a different group moving on to the other 3 tables to answer remaining questions (i.e. mixing encouraged each time)
- Question coordinators led discussion if focus got off track and brought anyone into discussion who had not contributed.

Conclusion and follow-on steps (5 mins), Grant Pearce

- Group brought together again
- Informed of next steps in project
    - feedback will be combined and summarised with input from other sources (e.g. NRFAC/RFRAC, NZWTAS project team)
    - Plus input will be used with literature review
        - to develop draft definition for what constitutes a WFPA in NZ
    - draft definition will be circulated for feedback and consensus (e.g. via RRFCs)

- determine whether data is currently available for input factors
- develop a methodology for mapping WFPAs in NZ
- case study for at least one area of NZ to test definition
- evaluate need for further refinement and/or implementation.

- Group thanked for contribution
- Asked to contact Grant Pearce if want more information or further input.

Discussion results (based on notes recorded on question sheets by participants)

Q1. Assuming the WFPA concept is valid for NZ, how should it be used in NZ?

Sheet one

- Who to take the $$$ from and who to give to
- How to allocate the resources
- Influence regional & fire planning
- Lessons learned from history → (i.e. no. & size of fires) to develop future plans.

Sheet two

- *Already have systems in place – flows out of existing systems, i.e. WTA - whole range of assets, large scale; also STFMP – at more local/area level* [NB. this applies more to Q4]
- How to identify/prioritise FireSmart areas – for community engagement; also based on fire history
- Risks associated with process – could impact on property values or insurance premiums.

Sheet three

- Require higher building codes
- Need to implement asset protection
- Influence subdivision design
- Identification of FireSmart communities → sieve process to map/identify test areas
- Resource allocation (part of process)
- Uses dependent on size of Wildfire Prone Areas?
- Could make a game – most wildfire prone loses!

Sheet four

- National database of WFPAs
- Pre-determined response
- Allows for tailored Reduction planning → focus reduction, education, etc., enhance community awareness in specific areas which don't fit general pattern
- Used in association with FireSmart
- Sourcing funding
- Setting priorities.

Q2. Considering the possible uses, what should the definition of a WFPA be for the NZ context (i.e. for use in NZ)?

Sheet one

Communities residing in fire prone areas:

- Known threats – area prone to Extreme fire danger / intensity
- Fire history
- Potential to endanger life / property
- Areas with common values / risks

- Isolated / absentee owners / population swell
- Utilities of regional /national significance.

Sheet two

- Area of extreme risk from wildfire
- Protection of life & property exposure
- Fire environment
- Pre-emptive
- *Uses – councils for building guidelines, defensible spaces, response/suppression, identifying reduction & readiness areas* [NB. this relates more to Q1]
- History of fire, or fireprone/flammable fuel type
- Combination of people, fuel, structures.

Sheet three

- Risk – population, access, fire history
- Values – life, property (dwelling)
- Hazard – fuel type & loading, topography, weather
- Has a boundary.

Sheet four

- Area description
- High risk – weather, fuels, topography
- Urban / rural interface (RUI)
- Life & buildings
- Potential based on extreme potential or average values?

Q3. (a) What factors need to be considered in describing and mapping WFPAs in NZ? (e.g. physical/environmental, social, infrastructure)

(b) What data sources are available for describing these factors?

<u>Physical/Environmental</u>	<u>Data sources</u>
7. Weather / fire danger conditions	- EcoConnect FWSYS
8. Fuels / vegetation	- land cover database
9. Topography / aspect	- mapping
10. Fire history	- RFA fire records
11. Ecological values?	- DOC
12. Aesthetic values?	- District plan
<u>Social</u>	
2. Population - density & diversity	- Census data
- socio-economic status	
- transient / seasonal population	- TLAs
2. Cultural values / heritage?	- District Plan, HPT, iwi
3. Livestock / crop / other economic values?	- MPI databases
<u>Infrastucture</u>	
4. Access (roads, tracks, bridges)	- NZTA/TLAs
5. Provision of services / lifelines	- TLAs, CDEM, utilities
6. Risks (powerlines, rail, etc.)	- utilities

Political

5. Policies & planning - TLAs + RCs
6. Government intent - Govt. depts
7. International agreements
8. Political trade-offs & associated risks

Other

2. Unforseen events.

Process Issues

1. Commonality – need to use a standard nationwide definition for all wildfire prone area criteria/inputs
2. Data source – use existing databases rather than developing new and duplicate ones
3. End point – this should be FireSmart; the program / results should be taken to communities

Q4. How does the definition of WFPAs in NZ fit with the current NZWTAS methodology and data inputs?

Sheet one

- Doesn't, but WTA may assist to identify general areas of concern, e.g. application of ISO 31000 (DOC Canterbury)
  - Use individual layers e.g. risk / values / hazards to identify areas
  - Should be a mix / balance of values, interests & resources
  - Desired outcomes such as Wildfire Prone Areas need to be evaluated when/if WTA methodology is reviewed
- WFPA definition needs to be determined, e.g. is it a Queenstown?
- Add population density consideration to WTA
- Will give Wildfire Prone Areas.

Sheet two (taken from Q1, sheet two)

- Does – already have systems in place, flows out of existing systems
  - WTA - whole range of assets, large scale
  - STFMP – local/area level
- Add fire history (*instead of existing WTA Risk layers?)*
- Use to identify/prioritise FireSmart areas.

Appendix B

Table B1. Summary of key studies that have mapped Wildland-Urban Interface (WUI areas, including a brief description of the methodology and variables used, and subjective assessments of the complexity of applying each method in New Zealand and the availability of the required data sets. Note units have been converted to enable comparison (from Pearce et al., 2013a).

Study/Source	Methodology	Complexity of method	Available data in NZ?
(Theobald and Romme, 2007)	• Interface = >1 housing unit per 2.4 acre (>0.5 house/ha), based on 250 people/mi^2 (1 person/ha) and >25 acre (>10 ha) patch. • Intermix = 1 house per 2.4–40 acre (0.06-0.5 house/ha). • Wildland vegetation as being composed of the following National Land Cover Dataset (NLCD; Vogelmann et al., 2001) classes: forested, shrubland, grassland (except tundra), and wetlands types (excluding agricultural, transitional, water, and urban/built-up lands). • Based solely on housing density in the areas of wildland vegetation.	Low	**Yes** Vegetation cover – LCDB Household density (number by area) or building density meshblocks – Stats NZ
(Haight et al., 2004; Radeloff et al., 2005; Stewart, 2007)	• Define WUI as >0.06 housing units/ha. Data is defined by US census blocks. • Vegetation information then used to classify areas as intermix or interface. • Intermix = WUI area with >50% wild land vegetation. • Interface = <50% wildland vegetation. Also must be within 2.4 km of a >500 ha heavily vegetated area (census block with >75% wildland vegetation).	Low	**Yes** Vegetation cover – LCDB, Household numbers by area – Stats NZ, Building density meshblocks – LINZ
(Zhang et al., 2008)	• Housing density defined by census data employed at the census block group (CGB). • Land use based on 30m Landsat data. • Urban density = 1.55 houses/ha. Wildland = 0.06 houses/ha. WUI = densities between those values. • Wildland vegetation must cover ≥60% of a CGB. • To qualify as a WUI both density of housing and vegetation must be met.	Low	**Yes** Land use – LUC/NZLRI, Vegetation cover – LCDB, Household numbers by area – Stats NZ, Building density meshblocks – LINZ

Table B1. continued.

(Bar-Massada et al., 2013)	• Used moving window (ArcMap Neighbourhood tools) to identify WUI. • WUI = housing density >0.06 units/ha, and either (1) at least 50% wildland vegetation, or (2) less than 50% wildland vegetation but within 2.4 km of an area >500 ha with at least 75% wildland vegetation. • 1 = Intermix WUI; 2 = Interface WUI. • Only 2 surfaces needed – building/structure point file and vegetation cover map (https://lris.scinfo.org.nz/layer/404-lcdb-v33-change/).	Medium	**Yes?** Land cover map – LCDB, Point data for buildings – possibly available from District or regional councils (CERA/CCC for Christchurch, Rotorua DC)
(Lampin et al., 2008; Lampin-Maillet et al., 2009; 2010; 2011)	• Housing density categorised by isolated, scattered, dense clustered and very dense clustered, based on distance between houses, the size of clusters of houses and housing density. • Isolated dwellings refer to houses (or clusters of 2-3 houses) located >100 m apart, scattered is clusters of 4–50 houses <100 m apart, dense clustered is clusters <10 houses located <30 m apart, and very dense clustered (urban) is >10 houses located <30 m apart. • Used a 50-m radius around each house to discriminate between isolated, scattered and clustered, and a 15-m radius around each house belonging to clustered dwellings to discriminate dense and very dense clustered dwellings. • Vegetation classed into no vegetation, sparse, and continuous (using LFT tools, http://clear.uconn.edu/tools/lft/lft2/index.htm), based on degree of fragmentation (by urban areas) within vegetation cover types. • Uses WUImap tool (http://fireintuition.efi.int/products/wuimap.fire) to integrate housing density and vegetation continuity classes.	Medium	**Some** Vegetation cover – LCDB, requires Land Fragmentation Tool (LFT), requires housing point data or density, uses WUImap ARC GIS tool
(Chas-Amil et al., 2013)	• Human presence – housing density by Spanish parish (the smallest administrative unit) using Lampin-Maillet et al. (2010) classes = isolated, scattered, dense clustered and very dense clustered. • Identified housing from aerial photographs. • Vegetation classed into no vegetation, sparse, and continuous using (LFT tool to input land cover grid of 1=non forest 2=forest). • All above surfaces combined to create a WUI risk map.	Medium	**Some** (similar to Lampin-Maillet et al.) Land use/vegetation – LCDB, requires Land Fragmentation Tool (LFT), requires housing point data/footprints or density – Councils may have detailed building GIS layers (e.g. CERA/CCC for Christchurch, Rotorua DC)

Table B1. continued.

(Haas et al., 2013)	• Federal (US) WUI community definition (Federal Register, 2001): 1. Interface ≥3 structures/acre (7.5 houses/ha) or population ≥250/mi^2 (≥1 person/ha) 2. Intermix ≥1 structure/40 acres (≥0.06 houses/ha) or population 28-250/mi^2 (0.1-1 person/ha) 3. Occluded same as interface but in wildland areas smaller than 1000 acres (<400 ha) in size. • Uses LandScan USA population dataset (Bhaduri et al., 2007) to identify population density nationally (US). • Employs probabilistic exposure analysis to identify the likelihood of populated places interacting with wildfire, and classify at-risk areas according to a risk matrix comprised of population density and burn probability categories.	High	**No** requires LandScan to map population density (US only) - could use LINZ meshblock data instead?, also requires burn probablility mapping using a large fire simulation model (e.g. US FSim model) – could possibly be done using Prometheus
(Madrigal et al., 2013)	• WUI – residential houses that are either inhabited permanently or temporally. Houses located 200m from forest or shrubland. A radius of 100 m around each house. This distance has been proposed for EU countries but may be changed to suit local conditions. • Houses were configured - isolated, scattered, dense or very dense using the method set out by Lampin-Maillet et al. (2009). • Vegetation characterized to emphasize its horizontal continuity. This produced three types of aggregation – high (forest vegetation), low (transition forest/agricultural land) and zero (without forest). • WUImap tool produces intersections between the four types of housing and three types of aggregation to produce 12 WUI types. • Partial least square (PLS) multiply regression model was used to correlate between wildfire occurrence and areas occupied by WUI typologies.	High	**Little, if any** (similar to Lampin-Maillet et al., 2009) Land use/vegetation – LCDB, requires Land Fragmentation Tool (LFT), requires point data for buildings, uses WUImap ARC GIS tool, requires wildfire occurrence data
(Herrero-Corral et al., 2012)	• Uses a landscape approach to account for the spatial connected-ness of physical, ecological and social components to understand wildfire risk in WUI areas. • Hypothesize that fire risk not only depends on the presence of WUI, but characteristics of territorial context in which the WUI is located.	Very high	**Little, if any** Land cover/vegetation – LCDB, requires detailed point data for buildings,

(Herrero-Corral et al., 2012) - continued	• WUI - refers to all building located less than 400m from wildland vegetation and includes the surrounding area within a 100 m radius. • Uses modified WUImap specific for the research area (Western Madrid, Spain). • Housing density – 5 classes: Isolated structures - individual or cluster of <4 houses located >90 m apart and not part of an urban structure. Group of buildings – cluster of 5-15 houses located >90 m apart. Residential housing estate – a development organised around single houses with a repetitive pattern, or emerging spontaneously from existing rural structures; >16 houses located >20 m apart. Isolated residential housing estates – as above but located >200 m away from the urban core. Towns – traditional urban areas of >75 plus houses located <20 m apart or with a ratio of between 50 and 70. • Horizontal continuity of vegetation was measured within the limits of the WUI. The aggregation index (AI) was used for this. This was mapped using FRAGSTATS (http://www.umass.edu/landeco/research/fragstats/downloads/fragstats_downloads.html), results = very low or no aggregation (AI=0), sparse vegetation (0<AI>60) and continuous vegetation (>60). • Wildfire incidences in the WUI were calculated based on spatial analysis of previous wildfires. Provide number of fire contacts and burned area in the WUI. • Wildfire risk was based upon Landscape Character Assessment (LCA). Areas are grouped based upon distinct and recognizable combinations of elements (geology, soils, topography, vegetation, historical land use and human settlement patterns). • Risk = Hazard * Vulnerability, where Hazard includes slope, forest vegetation (combustibility of fuel & flammability of species), and fire occurrence (fire density). • WUI's are then placed into their correct /corresponding landscape context. This produces WUI situations. This can indicate all information needed about these fire prone areas.		uses WUImap tool, also requires FRAGSTATS tool to determine Aggregation Index, requires wildfire incidence data, slope – DEM, also uses Landscape Character Assessment to group areas based on geology, soils, topography, vegetation, historical land use and human settlement patterns

Appendix C

GIS Step-by-Step Guide for the Various Methods

Haight et al., 2004; Radeloff et al., 2005; and Stewart 2007

1. Download data for required area from Statistics NZ (building density meshblocks).
2. Copy required data from downloaded Statistics NZ data to new Excel sheet.
3. In ArcMap join Excel data to spatial meshblock data, using join tool and save new spatial layer.
4. Add new columns in meshblock spatial layer data table for housing density and calculate.
5. From LCDB3.3 select forest (LCBD3-class 71,64,68,69) and scrub and shrubland (LCDB3-class 51,52,58,54,56). This is the 'wildland areas'.
6. Convert wildland areas shape file to raster with a value of 1 for wildland areas, 0 for other..
7. Then convert wildland raster back to shape and remove all areas that are smaller than 500 ha and save shape file as 'wildland greater than 500 ha'.
8. Convert meshblock shape file to raster using meshblock column as the descriptor.
9. Use ArcMap tool Zonal stats with the meshblock raster to describe the zones and the wildland input value raster with statistic type set to mean. The resulting table will show for each zone the area of wildland vegetation within it.
10. Join the zonal stats table to the meshblock shape file and save as a new shape file. Add a new column and calculate the % of wildland per meshblock.
11. From the meshblock shape file use the select by attributes tool to select the WUI area (housing density ≥ 6.17 units/km² = 0.06 units/ha). Then from the WUI areas select those which match intermix (> 50% wildland veg) and interface (≤ 50% wildland veg). Save both intermix data and interface as new shape files.
12. From the meshblock shapefile use the select by attribute tool to select all meshblocks that are greater than 75% wildland vegetation. From these meshblocks select those which also fall within the 'wildland greater than 500 ha'. Save as '75%_vege'
13. Using select by location tool, use the '75%_vege' file to select areas of the interface and intermix meshblocks that are within 500 m (as opposed to the standard 2.4 km) of the '75%_vege' shape file areas. Save results as the final intermix and interface areas.

Zang et al., 2008

1. Download data for required area from Stats NZ (building density meshblocks).
2. Copy required data from downloaded Stats NZ data to new Excel sheet.
3. In ArcMap join Excel data to spatial meshblock data, using join tool and save new spatial layer.
4. Add new columns in meshblock spatial layer data table for housing density and calculate.
5. From LCDB3.3 select forest (LCBD3-class 71,64,68,69) and scrub and shrubland (LCDB3-class 51,52,58,54,56). This is the 'wildland areas'.
6. Convert wildland areas shape file to raster with a value of 1 for wildland areas, 0 for other.
7. Convert meshblock shape file to raster using meshblock column as the descriptor.
8. Use ArcMap tool Zonal stats with the meshblock raster to describe the zones and the wildland input value raster with statistic type set to mean. The resulting table will show for each zone the area of wildland vegetation within it.
9. Join the zonal stats table to the meshblock shape file and save as a new shape file. Add a new column and calculate the % of wildland per meshblock.
10. Using select by attribute, identify all meshblocks that have 60% or more wildland vegetation cover.
11. Then from that selection, identify the meshblocks that have a housing density of between 0.06 units/ha and 1.55 units/ha. These will be the interface (combined interface and intermix, with no distinction between). Save as a new shape file.

Theobald and Romme, 2007

1. Download data for required area from Stats NZ (building or population density meshblocks).
2. Copy required data from downloaded Stats NZ data to new Excel sheet.
3. In ArcMap join Excel data to spatial Meshblock data, using join tool and save new spatial layer.
4. Add new columns in meshblock spatial layer data table for housing density and calculate.
5. Select all meshblocks that have an area greater than 10 ha. Save selected data.
6. From the greater than 10 ha meshblocks select areas of interface (>0.5 units/ha) and intermix (0.06 – 0.5 units/ha).

Note - WUI are not selected using wildland greater than 500 ha shapefile in this method.

Data used and source

1- Meshblocks

Meshblocks are the smallest geographic area used by Statistics New Zealand in the collection and/or processing of data. It is the building block for aggregation into larger areas such as area units and urban areas.
Spatial data available from koordinates.com

Meshblock data collected from Stats NZ at time of analysis initially only included available 2006 data, since this time the 2013 census data has become available. Initial maps were created using the 2006 census data; however these were later updated using the 2013 census data.
Data available from stats.govt.nz/census

2- Land Cover Data Base version 3.3 (LCDB3.3)

The New Zealand Land Cover Database (LCDB) is a thematic classification of land cover. The current version LCDB3.3 contains 33 classes designed to be compatible with earlier LCDB versions. The polygon features contain a code and boundary representing the land cover type at each of three periods; summer 1996/97, summer 2001/02, and summer 2008/09. Data for LCDB4 may now also be available.
Data available from lris.scinfo.org.nz

Lampin-Maillet et al., 2009; Lampin-Maillet et al., 2010

1. Create a point file or shapefile of roof area for each building in the research area. (This can be created from digitising aerial photography or alternatively some District Councils may have this data available).
2. From LCDB3.3 select forest (LCBD3-class 71,64,68,69) and scrub and shrubland (LCDB3-class 51,52,58,54,56). This is the ‘wildland areas’.
3. Convert wildland areas shape file to raster with a value of 2 and all other areas with a value of 1. Save as a tiff file.
4. Import the tiff file into the ‘Fragstats’ programme. Within the analysis Parameters select a Moving window sampling strategy. Select Class metrics within the Moving window and set to round with a radius of 80 m (the radius was set at 8 times the cell size, to correspond to that set by Lampin-Maillet et al., 2010). Select the “use 8 cell neighbourhood rule”. Within the Class metrics select Aggregation and then select Aggregation index (AI). Then run the programme. The results will be saved automatically in a tiff file.
5. Convert the AI tiff file to an ESRI grid raster and save.

6. Classify the data in the AI raster file (-999 = no data, 0 = Zero aggregation). The remaining data will be split equally using the natural breaks method in the classify tool within layer properties. This will give 2 more categories (Low aggregation and High aggregation).
7. Create a 200 m buffer around wildland areas and then select all buildings within the buffer and the wildland areas. These houses are within the WUI.
8. For all houses within the WUI create a 50 m buffer. Dissolve the buffer to create a single shapefile.
9. Use the 'multipart to singlepart' tool to split the single shapefile into separate areas.
10. Spatially join the building data to the split shapefile.
11. Classify and save each area shapefile by the classification from Lampin-Maillet:
    - Isolated dwellings (ID) = <3houses located 100 m apart;
    - Scattered dwellings (SD) = 4 – 50 houses located 100 m apart;
    - Clustered dwellings (CD) = 50 houses located 100 m apart.
12. Select all dwellings within the Clustered dwellings (CD) and create a new file.
13. Buffer all dwellings in the CD by 15 m. Dissolve the buffer to create a single shape file.
14. Use the 'multipart to singlepart' tool to split the 15 m buffer shapefile into separate areas.
15. Spatially join the 15 m buffer building data to the split 15 m buffer shapefile.
16. From the 15 m spatially joined data, classify and save each area shapefile by the classification from Lampin-Maillet:
    - Dense clustered dwellings (DCD) = <10 buildings located 30 m apart;
    - Very densely clustered dwellings (VDCD) = more than 10 buildings located 30 m apart.
17. From the original 100 m buffer file select and save the buffers that intersect with DCD file. Dissolve to create a single shape file. Use the 'multipart to singlepart' tool to split the single shapefile into separate areas. Save as DCD.
18. From the original 100 m buffer file select and save the buffers that intersect with VDCD file. Dissolve to create a single shape file. Use the 'multipart to singlepart' tool to split the single shapefile into separate areas. Save as VDCD.
19. Four shape files should now exist for housing density (the CD category has been split into DCD and VDCD, so no longer exists). Merge these to create one housing density layer. Convert to raster.*
20. Intersect the housing density layer with the AI layer to create the final WUI layer. Now there are 12 categories with each housing density now split into 3:
    - Isolated housing & no aggregation
    - Isolated housing & low aggregation
    - Isolated housing & high aggregation
    - Scattered housing & no aggregation
    - Scattered housing & low aggregation
    - Scattered housing & high aggregation
    - Dense clustered housing & no aggregation
    - Dense clustered housing & low aggregation
    - Dense clustered housing & high aggregation
    - Very dense clustered housing & no aggregation
    - Very dense clustered housing & low aggregation
    - Very dense clustered housing & high aggregation

*alternatively the AI raster can be converted to a shape file and then intersected with the combined housing density to create the final WUI layer.

1- **Data for local schools and marae added to the final maps**

Data for locations of schools and marae (as hubs for social networks) was sourced from koordinates. Each point location was buffered by 1000 m. It should be noted that these data may not be complete and some schools and marae may be missing.
Data: https://koordinates.com/layer/170-nz-building-locations/data/ for marae,
and https://koordinates.com/layer/243-nz-schools/ for schools

Appendix D

Case Study Evaluation – Sensitivity Testing

The sensitivity of the methods for mapping RUI extent to use of the threshold values for inputs from the literature was evaluated by trialling a range of alternative values. The aim of this analysis was determine whether these standard values are appropriate for defining RUI areas in New Zealand, or if use of different values can produced better (more representative) results. The appropriateness of different input values (see Table 1) was assessed through subjective visual evaluation of the mapped RUI extents for the two case study areas. For the Haight, Radeloff & Stewart meshblock-based methodology, the distance to vegetation, housing density and vegetation cover thresholds were tested. Within the Lampin-Maillet point method, thresholds for distances between buildings, and from vegetation, were investigated.

Haight, Radeloff & Stewart method

With data from the 2013 Census becoming available during the study period, the analysis was updated to include this more recent data. Figure D1 compares the area of WUI identified for the Rotorua case study area (with the standard distance from vegetation of 2.4 km) using the 2006 data (Fig. D1a) versus the more recent 2013 Census data (Fig. D1b). This shows very little change in the identified RUI/WUI extent from 2006 to 2013, with only a small reduction around the townships of Kaingaroa and Rotoiti.

A) 2006 Census data	B) 2013 Census data

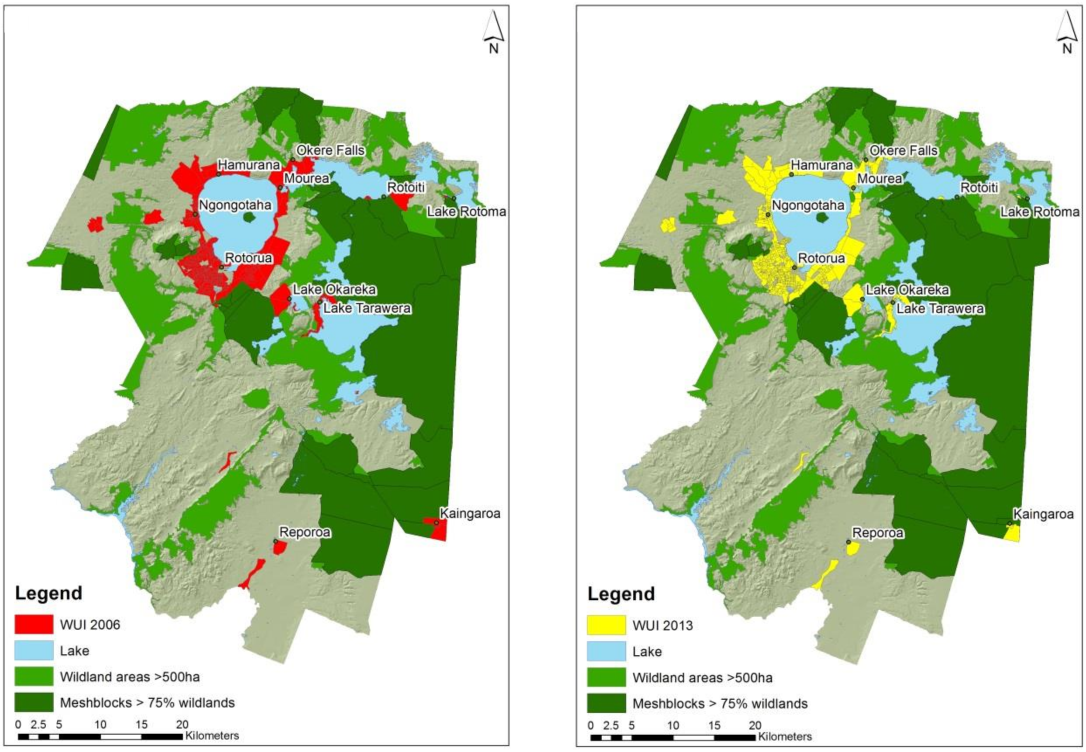

Figure D1. Area of Wildland Urban Interface (WUI) identified by the Haight, Radeloff & Stewart method for the Rotorua case study area derived using **(A)** 2006 versus **(B)** 2013 Census meshblock data.

Figure D2 below shows the process by which the WUI is defined using the Haight, Radeloff and Stewart method. The original methodology calls for a distance of 2.4 km from vegetation to be used to identify WUI areas (step 3). This distance was trialled and found to be problematic, as in the New Zealand context this results in practically all of the urban areas in the two case studies being classed as WUI (see Fig. D1).

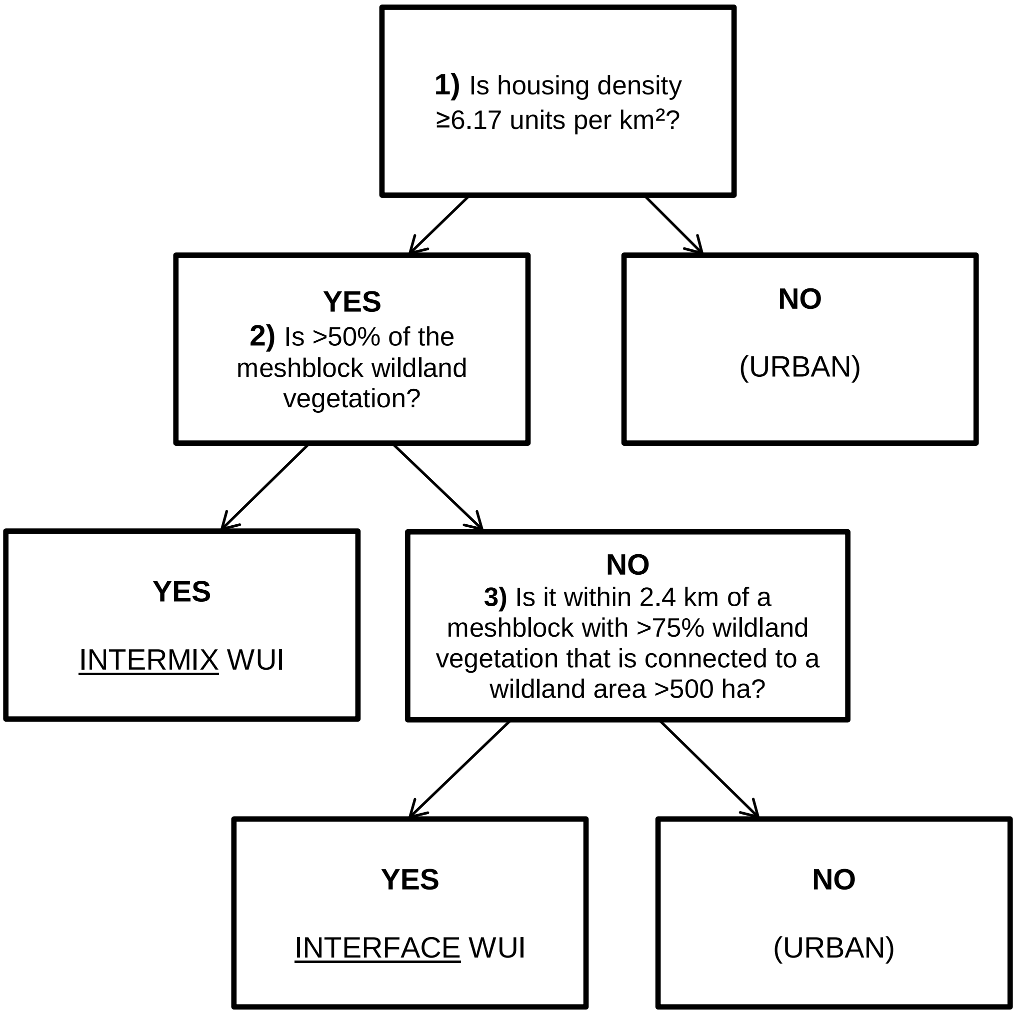

Figure D2. The method used by Haight, Radeloff & Stewart to define the Wildland Urban Interface (WUI) (from Stewart et al., 2007).

Distance from vegetation

A range of alternative distances from vegetation to the standard 2.4 km used by Haight, Radeloff & Stewart were therefore tested, including 1 km, 500 m, 200 m, 100 m and 50 m (Fig. D3). The effect of decreasing the threshold for distance from meshblocks containing vegetation (with >75% wildland vegetation and >500 ha in size) is to reduce the area of WUI identified. Figure D3a again shows that for the Rotorua case study area, use of a distance of 2.4 km classifies virtually all of the built-up area of Rotorua city as interface, with only a comparatively small amount of intermix identified. This is impractical for the purposes of assisting identification of WFPAs. In terms of shorter distances, there is little difference between using 200 m (Fig. D3b) and 50 m (Fig. D3c), with only a few additional meshblocks identified as interface at Mourea for the 200 m distance that are not identified using 50 m. A few less of the urban meshblocks on the northern edge of Rotorua are also classified as interface using 200 m compared with 50 m.

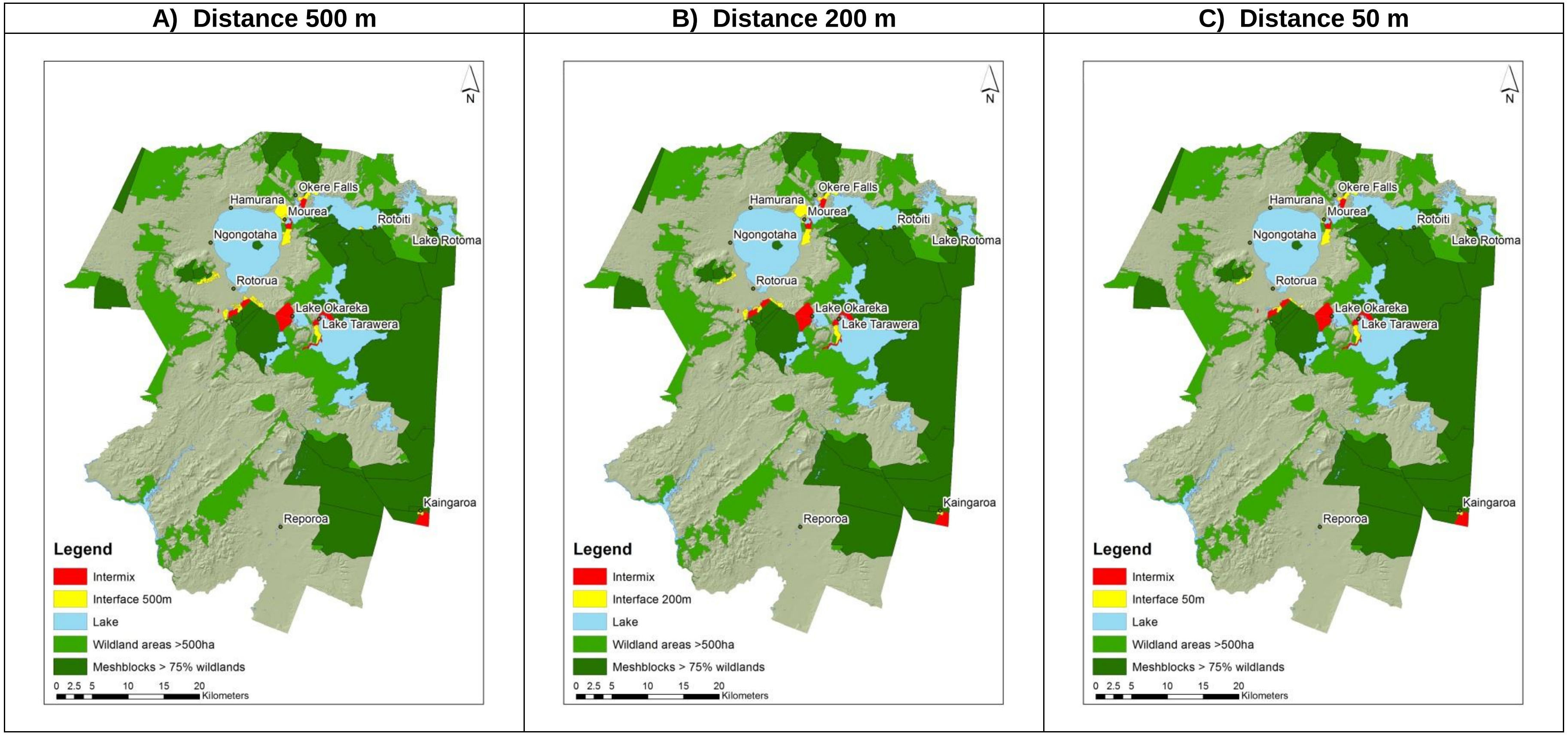

Figure D3. Effect of varying distance from vegetation on the areas classified as Wildland Urban Interface (WUI for the Rotorua case study using the method of Haight, Radeloff & Stewart: **(A)** for a distance of 500 m, **(B)** 200 m, and **(C)** 50 m from vegetated meshblocks. Note meshblocks with areas of >500 ha and with >75% wildland vegetation that do not meet the building density criteria for WUI are also shown.

A distance of 500 m setback from vegetation (Fig. D3b) was selected as a more representative value for New Zealand, and is used in subsequent analyses. Distances in this order (100-500 m) also represent more likely spotting distances for the New Zealand plant species typically found in RUI areas, such as gorse and/or manuka scrub or pine trees, compared with much longer distances that might be expected for eucalypt tree species, for example.

Wildland vegetation cover percentage

The effect of changing the vegetation cover threshold for meshblocks to be selected as wildland vegetation was also tested (see step 2 of Figure D2). The standard vegetation cover value assumed for 'wildland' in the Haight, Radeloff & Stewart method is 50%. The effects of both decreasing (to >30%) and increasing (to >75%) this were investigated (Figure D4). [Note that step 3 in Figure D2 also includes a vegetation cover requirement (>75%) for identification of interface meshblocks; however, the effect of also changing this was not tested].

Using a lower cover threshold (>30%) increased the likelihood of meshblocks containing vegetation being identified as intermix, so that the number of meshblocks and area classed as intermix increased (Figure D4a). For the Rotorua case study area, this included addition of small park or reserve areas within more urban parts of Rotorua city. The use of a higher vegetation cover threshold (>75%) also resulted in an increase in the number of meshblocks identified as intermix (Figure D4c). However, unlike the decrease in cover threshold which identified new areas of intermix, increasing the required vegetation cover resulted in a reclassification of existing RUI meshblocks identified using the default cover (>50%; see Figure D4b) from interface to intermix.

Setting the threshold vegetation cover value below the recommended >50% therefore appears to identify areas that may not be considered a significant wildfire risk., whereas using a higher threshold appears to reduce the areas classed as higher fire risk in many places. While this provides an opportunity to possibly change the cover threshold to fit the wildfire risk of a region (e.g. by using a lower vegetation threshold value in a low fire risk area such as Rotorua, but a higher value in a higher risk area such Canterbury) for most analyses use of the default >50% vegetation cover is recommended. This is especially the case where regional or national comparisons are required, where a standard value should be used across the entire country.

Housing density

The effect of changing the housing density threshold used to define WUI areas (Step 1 in Figure D2) was also tested using a range of values less than and greater than the default value of ≥ 6.17 units per km² (0.06 units/ha) (Figure D5). Values tested included ≥ 0.03, 0.05, 0.08 and 0.10 units/ha. The purpose of this threshold is to distinguish between higher density built-up (and therefore populated) areas from lower density rural areas. The previous vegetation cover requirement is then used to distinguish between moderate density WUI areas with some vegetation and very high density urban areas with little or no vegetation.

Use of housing density values below the standard 0.06 units/ha (e.g. 0.03 units/ha; Figure D5a) identified areas that are more rural, whereas using higher values (e.g. 0.10 units/ha; Figure D4c) appeared to produce similar results to the default density of 0.06 units/ha (Figure D5b). However on closer inspection, some areas are no longer classified as WUI areas with this higher building density threshold (for example, areas around Okere Falls) northeast of Lake Rotorua). Therefore, due to the potential removal of areas that should otherwise be classified as WUI, use of a higher threshold is not recommended and the standard density criteria (of 0.06 units/ha) should be used.

A) >30% vegetation cover	B) >30% vegetation cover	C) >30% vegetation cover

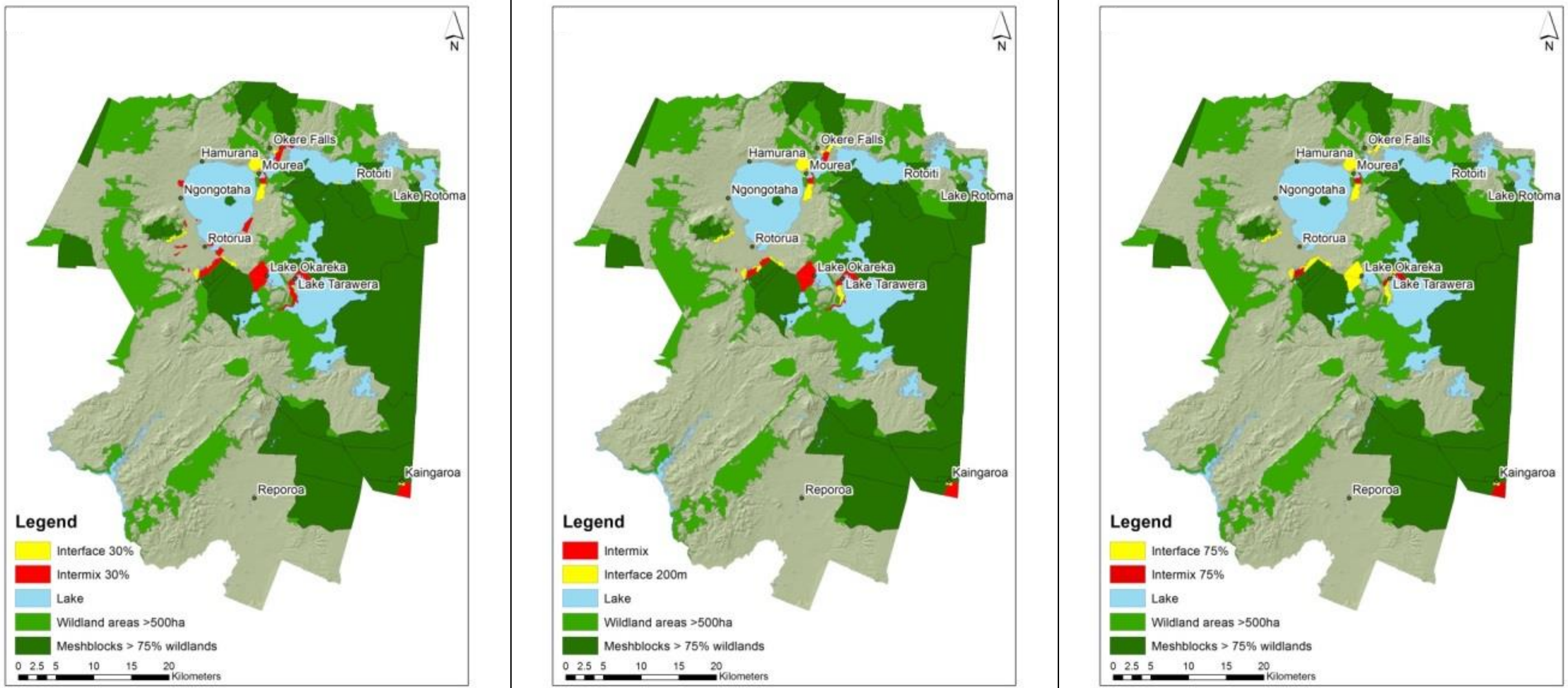

Figure D4. Effect of changing the meshblock vegetation cover threshold on the areas classified as Wildland Urban Interface (WUI for the Rotorua case study using the method of Haight, Radeloff & Stewart: **(A)** for vegetation cover of >30%, **(B)** the default >50%, and **(C)** >75%. Note meshblocks with areas of >500 ha and with >75% wildland vegetation that do not meet the building density criteria for WUI are also shown.

A) Housing density 0.03 units/ha	B) Housing density 0.03 units/ha	C) Housing density 0.03 units/ha

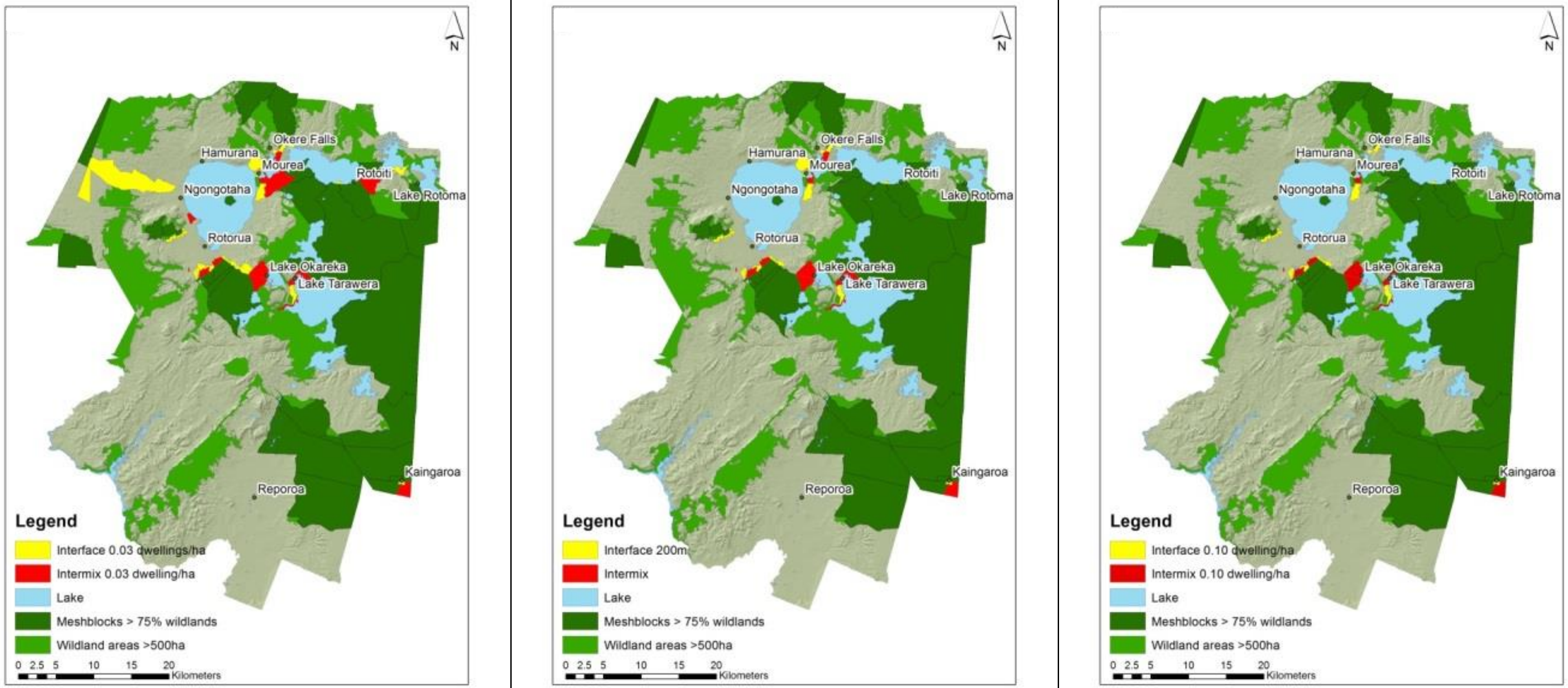

Figure D5. Effect of varying the meshblock housing density threshold on the areas classified as Wildland Urban Interface (WUI for the Rotorua case study using the method of Haight, Radeloff & Stewart: **(A)** for housing density of 0.03 units/ha, **(B)** the default 0.06 units/ha, and **(C)** 0.10 units/ha. Note meshblocks with areas of >500 ha and with >75% wildland vegetation that do not meet the building density criteria for WUI are also shown.

Using population density instead of housing density

Replacement of the housing density criteria for identification of WUI areas with a criteria based on population density instead was also tested. Theobald and Romme (2007) suggested that a population density of between 11-96 people/km² would constitute a WUI area. Therefore the requirement for building density to be ≥ 6.17 units per km² (0.06 units/ha) in step 1 of Figure D2 was replaced with "Is population density ≥ 11 people per km²?"

Using this population density criteria (Figure D6a) resulted in identification of a similar WUI extent to that from building density (Figure D6b), although there were some minor differences. For example, extra meshblocks were identified just south of Mourea (as intermix) and around Rotoiti (of both interface and intermix) using population density as opposed to building density. These differences suggest that despite having low housing density, these newly identified areas have a higher number of residents per household. As the number of people likely to be present in an area is an important component of wildfire risk, the preferential use of population density over building density warrants further investigation. It may provide a more accurate measure since building density may capture outbuildings which are not lived in. However, use of population data is also not without problems, as it does not take in to account people being away during work hours or seasonal population changes (e.g. in holiday communities). Overall results though do indicate that population data can provide a suitable substitute should building density data not be available.

A) Using population density	**B) Using building density**

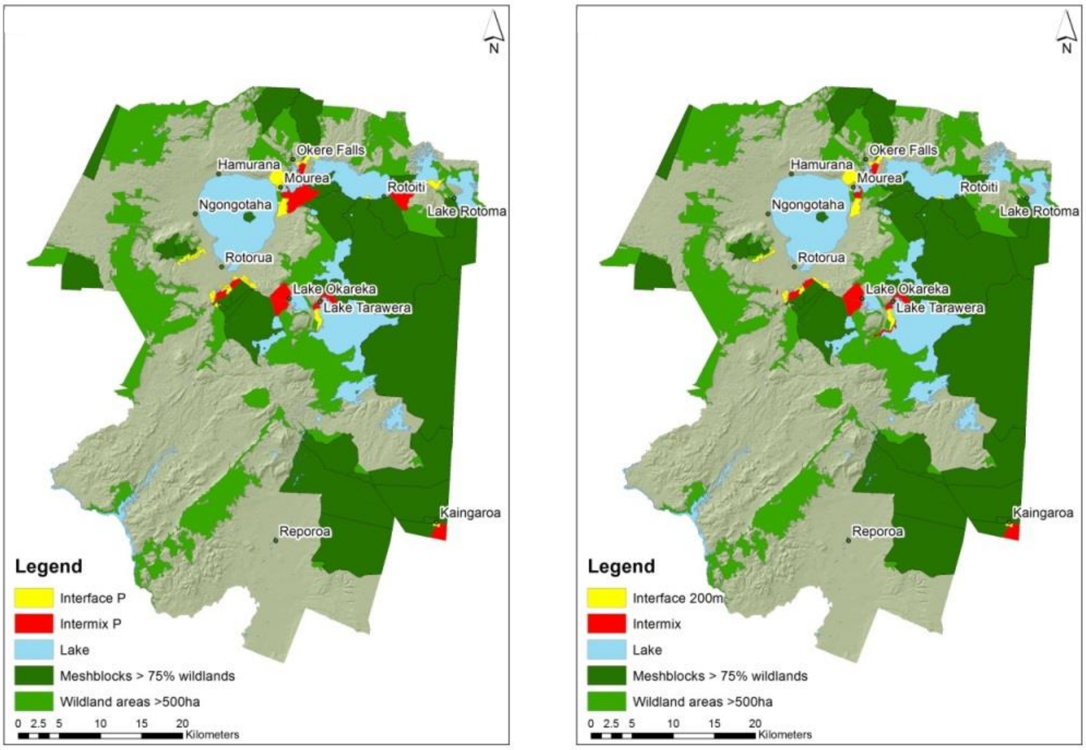

Figure D6. Area of Wildland Urban Interface (WUI) identified by the Haight, Radeloff & Stewart method for the Rotorua case study area derived using **(A)** population density, and **(B)** population density meshblock data.

Size of wildland area

Another of the criteria for identifying WUI areas tested was the effect of size of wildland areas. Step 3 of the method illustrated in Figure D2 includes the requirement that meshblocks identified as WUI must be adjacent to areas of wildland[8] vegetation with a size "greater than 500 ha". The effect of this size criteria was tested by investigating use of smaller areas, in this case of greater than 50 ha.

Changing the minimum size of vegetated areas adjacent to WUI areas from 500 ha to 50 ha did not result in any change to the areas identified as either interface or intermix for the Rotorua case study area. This is believed to because of the very consolidated nature of the landscape of the Rotorua district, where there are very few areas with sizes between 50 ha and 500 ha; vegetated areas where they are present tend to be more extensive, rather than intermediate in size. Vegetated areas smaller than 50 ha in size also tend to be isolated and therefore have no connection to other 'wildland' areas (to cumulatively reach a 50 ha threshold), or to built-up urban areas.

However, the effect of reducing this minimum size for vegetated areas does warrant further investigation. The use of the current US standard (500 ha) would exclude the many smaller vegetated areas found on the boundaries and within urban areas in New Zealand. In so doing, this would affect the extent of the RUI identified, including both boundary and occluded interface areas. The Lampin-Maillet method (see below) uses a lower wildland area criteria (1 ha), and current land cover mapping (see discussion on the New Zealand LCDB below) also recognises vegetated areas down to much smaller sizes. For example, both the LCDB and ETS use 1 ha as the minimum for vegetation area (although the LCDB does capture even finer-scale mapping where it is already present from previous classification).

Lampin–Maillet method

Distance from wildland vegetation

The first selection in this method, which involves selecting individual properties with buildings that are within a given distance of wildland vegetation, is the most influential step. This determines all properties that are classified as WUI. Lampin-Maillet (2010) designates all properties that are within 200 m of wildland areas as WUI. A range of possible alternative distances from vegetation were tested, including 50 m, 100 m, 200 m and 500 m (Figure D7).

This comparison showed that the distance of properties with buildings from wildland areas has a dramatic effect on the number of buildings selected. From the regional-level comparison in Figure D7, it appears that shorter distances of 50 m or 100 m would appear to be more sensible as the larger distances (200 m and 500 m) appear to capture too many buildings. However, when zoomed in to particular areas, the 200 m distance (Figure D7c) still appears more reasonable. As discussed above distances in this order (100-200 m) also represent more likely spotting distances for the New Zealand plant species typically found in RUI areas. We therefore recommend the standard 200 m to be used for analyses using the Lampin-Maillet method.

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[8] 'Wildland' areas were identified during the testing outlined above using LCDB3.3. There has since been an update and LCDB4 has now been released (see below). When carrying out such analyses, the most up–to-date data sets should be used. 'Wildland' vegetation was also selected using LCBD3-classes for Forest, Scrub and shrublands. Grassland areas were not used because of the difficulty in distinguishing between high and low risk grass types, especially those where seasonal effects (i.e. curing) are important. However, certain grassland types do play an important part in wildfire risk, and appropriate grassland areas should be incorporated into any future analysis.

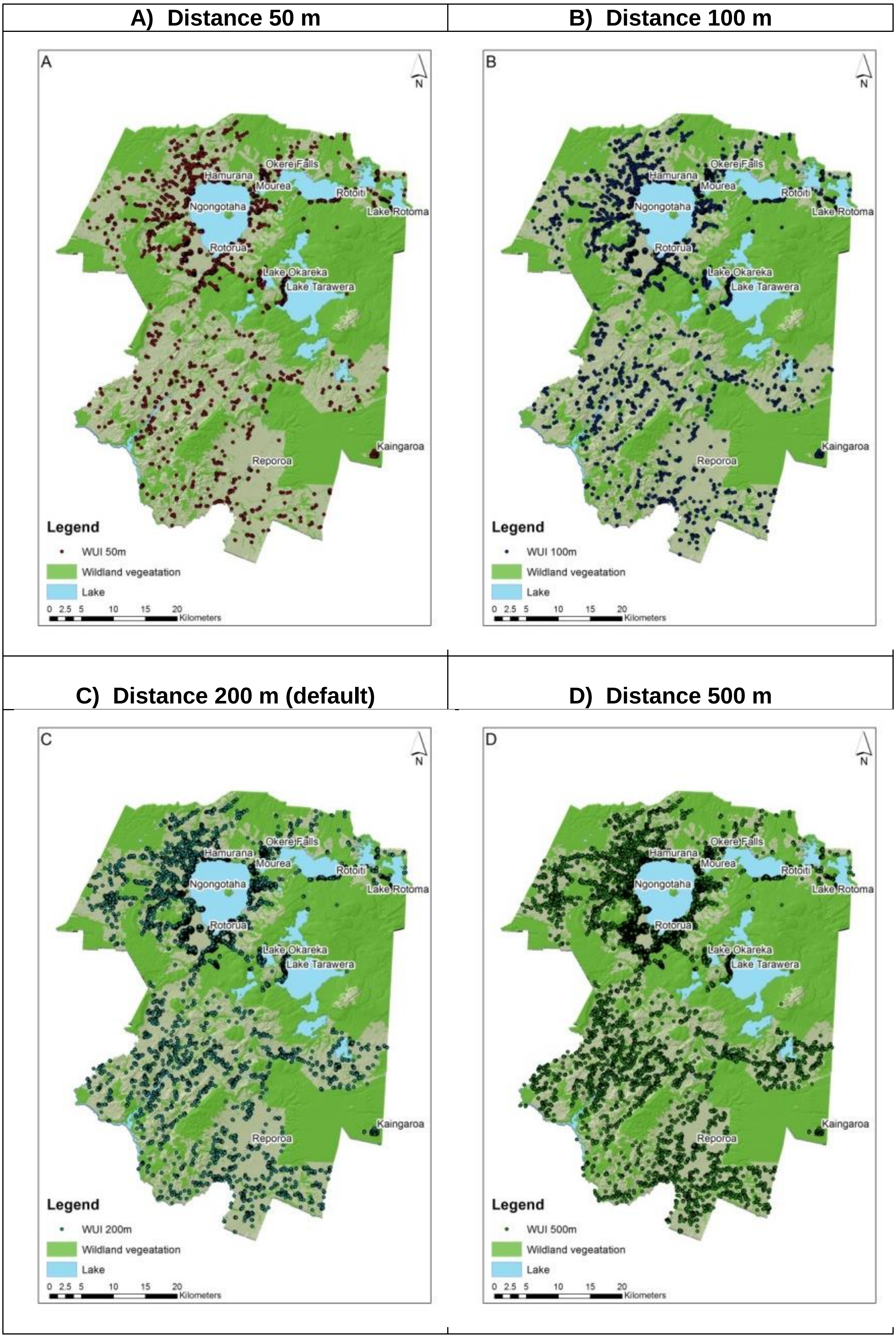

Figure D7. Effect of varying the distance of buildings from vegetation on the area of Wildland Urban Interface (WUI) identified by the Lampin-Maillet method for the Rotorua case study area: **(A)** buildings 50 m, **(B)** 100 m, **(C)** 200 m, and **(D)** 500 m from wildland vegetation.

Other variables

Aggradation Index – The Lampin-Maillet method characterises and maps vegetation continuity but without trying to accurately map vegetation fuel. The Aggradation Index (AI) is used to do this, with all areas classified as either no vegetation, sparse vegetation or continuous vegetation. The Fragstats software package is used to create this layer spatially. Fragstats using a moving window to categorise individual pixels form a value of 0-100. The results are then classified into three final categories, where zero values = zero aggradation (no vegetation), and remaining figures are split equally into two groups, low (sparse cover) and high (continuous cover). Within the Lampin-Maillet method, a moving window size of 80 m is recommended. Several alternative moving window sizes were tested, including 20, 80 m and 150 m. No discernible differences in the final results for WUI extent were found, so for consistency with the original method, we would recommend continuing to use the default 80 m moving window.

Housing density – Consideration was also given to varying the density configuration of housing identified within the WUI. Unlike the meshblock methods which use a threshold value for building density directly, Lampin-Maillet's building point-location method clusters houses together based on the distance between them and the number of houses within the cluster. Without knowing more about the rationale for selecting the classification thresholds for either distance or housing numbers/cluster size for France, and whether these are at all applicable in New Zealand, it was not deemed appropriate to change these.

Size of wildland area **–** In the Lampin-Maillet method, the WUI is defined according to the French Forest Orientation law of July 2002. For New Zealand, we used all buildings within 200 m of a wildland area greater than 1 ha. Areas larger than 1 ha were considered for the Lampin-Maillet method, as larger areas are usually used in the meshblock methods (e.g. 500 ha in Haight, Radeloff & Stewart; see above). Areas smaller than 1 ha are also available in some cases within the LCDB where vegetation remnants remain from previous mapping versions; however the spatial accuracy of these cannot be guaranteed. A minimum size of 1 ha is therefore recommended, due to 1 ha being the minimum pixel size for the satellite imagery used to classify vegetation cover classes in the Land Cover Database and ETS.

Land cover data

Availability of accurate, up-to-date land cover and fuel type data is likely to be one of the most important inputs affecting the overall accuracy of the WUI/RUI (and subsequent WFPA) mapping methods described here. As noted above, the New Zealand LCDB has recently undergone a number of updates, with the release of new versions using updated satellite imagery and improved cover classifications. LCDB2 used satellite imagery collected in 2001/02, and contained 42 cover classes plus shelterbelts as line features. At the time it was produced (July 2004), it represented a significant improvement over the earlier version (LCDB1, produced in 2000) which included only 16 classes based on imagery collected between 1994 and 1997. Released in July 2012, LCDB3.0 used imagery collected in 2008/09, but comprised only 33 cover classes resulting from amalgamation of several classes, and no longer included shelterbelts. A further version, LCDB3.3 was released in August 2013 based on the same 2008/09 imagery and cover classes, but corrected errors reported for earlier time periods, improved line-work, and included improvements to mapping of grassland and croplands. LCDB4, released in June 2014, also included 33 cover classes but utilised updated imagery collected during 2013/14. Metadata details and datasets for download for the various versions can be obtained from Landcare Research's Land Resource Information Systems (LRIS) portal, https://lris.scinfo.org.nz/ . Cover class correlation tables, change maps and area change summaries are also available.

In terms of influences on the WFPA methodology developed here, the key issue from the resulting changes in the LCDB is the reduction in the number of cover classes in the later versions. This results in a reduced ability to distinguish fire behaviour for different fuel types (e.g. between different exotic forest types from LCDB2 to LCDB3). Scion is attempting to overcome this problem in a separate project that aims to 'break' classes back out into individual vegetation types, based on the previous LCDB versions and other vegetation map sources (such as the Land Use Carbon Analysis System (LUCAS), National Indigenous Vegetation Survey (NIVS) and NZ Land Resource Inventory (NZLRI)). A key limitation of all LCDB datasets is the scale at which they map vegetation areas, which typically is restricted to areas greater than 1 ha in size. This is particularly problematic for the identification of RUI areas on the boundaries of built-up areas, where areas of flammable vegetation intermixed with houses are often less than 1 ha. Similarly, while recognised as a stand-alone cover class, areas of urban parkland and vegetated open space wholly within built-up areas are often less than 1 ha in size but, so may not be adequately captured by this LCDB class. If left unmanaged, or cured at the peak of the summer, these small vegetated areas can still present a significant fire risk, and their lack of identification will result in an underestimation of the extent of the RUI on the boundaries of these areas. This highlights the need for local knowledge to be added to the mapping process.

Conclusions from methods testing

Testing of methods using data for the Rotorua and Nelson case study areas indicates that both the original methodologies of Haight, Radeloff & Stewart and Lampin-Maillet are broadly suitable for use in New Zealand, and that assumptions made within the criteria for defining interface and intermix areas within these are reasonable. The case studies showed that little or no change should be required to either method to identify general RUI areas in New Zealand.

However, improvements can be made in distinguishing between interface and intermix areas by modifying some criteria slightly. This includes reducing the distance from wildland vegetation (to 500 m) for the Haight, Radeloff & Stewart method, and the setting of a lower size limit for wildland areas (1 ha) for the Lampin-Maillet methodology. While these changes and standard assumptions worked for the Rotorua and Nelson case study areas, it is recommended that results for other parts of the country are checked using expert local knowledge to ensure the areas identified are reasonable. Each of these methods were developed in other countries for environmental conditions (Lampin-Maillet: Mediterranean Europe) and scale (Haight, Radeloff and Stewart: US national or state level) that are different from those to which it is proposed they be applied in New Zealand.

Of the two methodologies recommended for use in New Zealand, the Lampin-Maillet methodology is preferable to that of Haight, Radeloff & Stewart. This building point location method was specifically designed to work at any scale (local – national) and is able to identify specific properties that are at most risk. This remains the case when other risk factors are overlain, such as fire climate severity, distance from schools, marae, or any other data that can be spatially defined. While the Haight, Radeloff & Stewart census meshblock method can also easily incorporate other spatial data, it can only identify meshblocks that are at risk rather than specific properties. However, application of the Lampin-Maillet method is currently restricted to those few Council jurisdictions for which building point or footprint data are available.

Effect of using actual versus relative data

As noted in Section 5.3, the use of actual number of people within a meshblock in itself may not a particularly useful measure for overlaying of risk factors, such as number of people volunteering or of vulnerable ages. This is because the size and total population for each meshblock varies greatly. Therefore use of the relative proportion of people within the meshblock may provide a more useful measure, and allow better comparison between meshblocks. Figure D8 illustrates the different results obtained using the two measures for the number of people of vulnerable ages (taken to be either >65 or <5 years of age). Perhaps the most obvious differences are apparent for the area on the northwestern edge of Rotorua, where the actual numbers (Figure D8a) show a much greater range of values (from close to zero, to in excess of 50 people per meshblock) involved in volunteering. The relative proportion (Figure D8b) shows that as a percentage of the total number of people per meshblock, the proportion of people varies much less (from 0% up to 30%).

The number of people volunteering (Figure D9) provides another example of the issues encountered in using actual numbers versus relative proportions. Although at slightly different scales, and with and without the RUI extent and school/marae networks shown, similar issues are apparent. The comparison again shows that what might be considered significant numbers of people volunteering (up to 50 people per meshblock; Figure D9a) are in fact only relatively low proportions of the total meshblock population (<40%; Figure D9b). Differences become most apparent at either end of spectrum, where high actual numbers correspond to only a low relative proportion, or low actual numbers to a high relative proportion of the total meshblock population. Hence caution should be exercised no matter which measure is utilised – actual numbers or relative percentages.

A) Actual number	B) Relative proportion

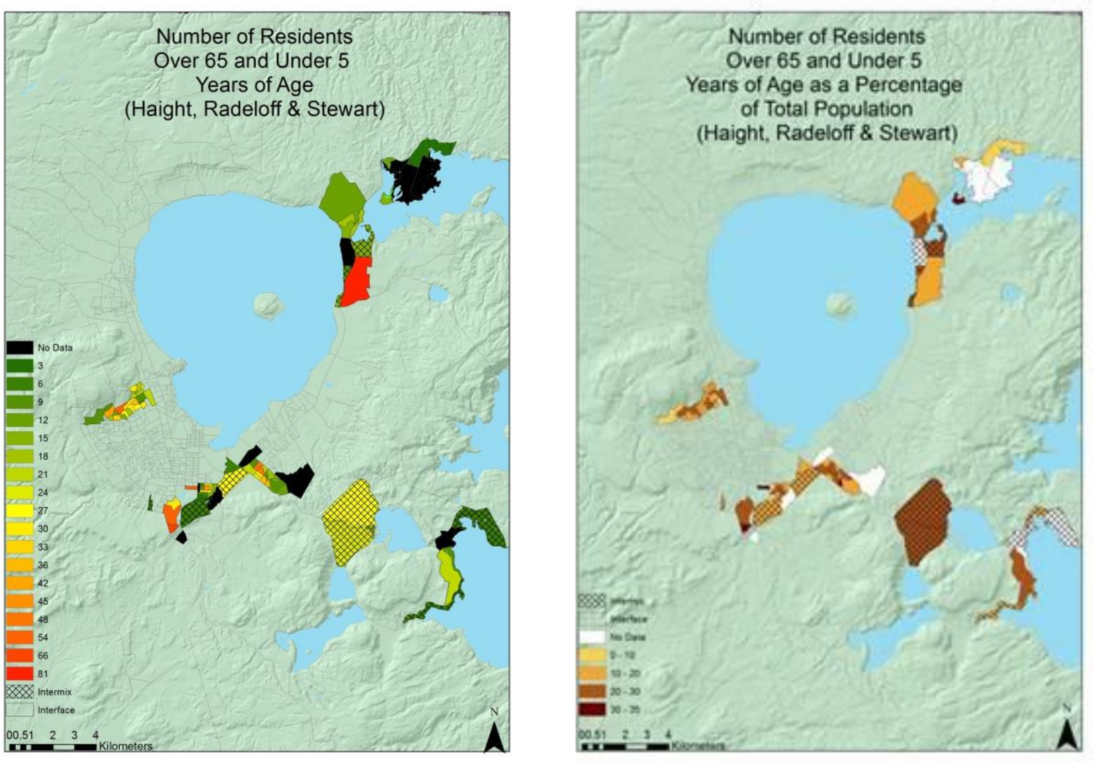

Figure D8. Differences resulting from the use of A) actual numbers versus B) relative proportion for Census meshblock data, in this case for people of vulnerable ages (<5 and >65 years old) overlain onto RUI extent identified using the Haight, Radeloff & Stewart method for the Rotorua case study area.

A) Actual number	B) Relative proportion

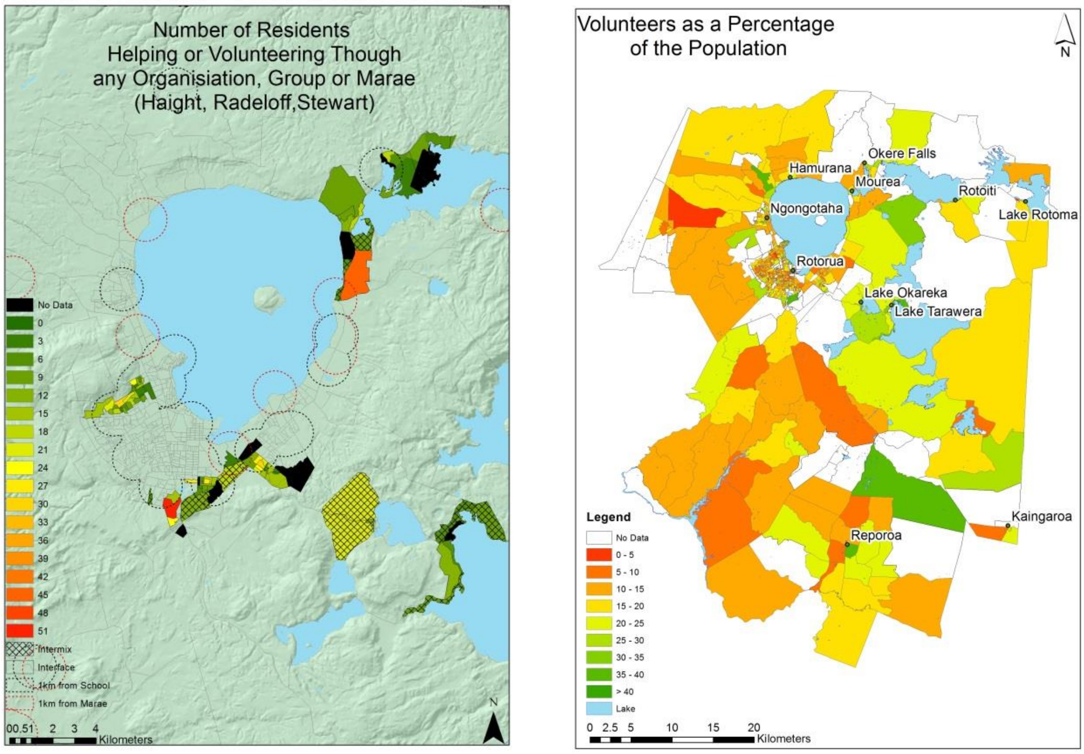

Figure D9. Differences resulting from the use of A) actual numbers versus B) relative proportion for Census meshblock data, in this case for number of people undertaking volunteering within the Rotorua case study area. Note A only includes data overlain onto meshblocks identified as RUI using the Haight, Radeloff & Stewart method, whereas B includes volunteering data for all meshblocks where data was available. [A also includes information on school and marae networks (see Section 5.3)].