Use of Fire As A Land Management Tool — Summary Document

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REPORT INFORMATION SHEET

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EXECUTIVE SUMMARY

Objective

The objective of this research was to assess the current state-of-knowledge on the risks and benefits of using fire as a rural land management tool, including historical and current practices and the effects on New Zealand's environment. This research work is a component of the 'Protecting New Zealand from Emerging Rural Fire Risks' MBIE programme (C04X1203) and contributes to the overall programme objective of understanding and mitigating risks associated with rural fire in the New Zealand landscape.

More specifically, the main objectives of this research in New Zealand were to;

- Understand when, where and how fire is used within different rural-based sectors,
- Identify the reasoning and rationale for the use of fire as a land management tool,
- Seek to understand the varying stakeholder perspectives as to the benefits and risks to local communities, business operations and the rural environment from this practice,
- Identify the differences in the practices, values and concerns of a range of stakeholder opinions,
- Understand the environmental impacts of using fire as a management tool, and
- Identify information and research gaps in our knowledge and understanding on the use of fire as a land management tool in New Zealand.

To achieve this, we conducted:

1. A targeted national survey that consulted relevant agencies, regulatory authorities, landowners, and the general public in rural communities in order to better understand the use of fire in the rural sector;
2. A review and demonstration on the benefits of smoke plume models for prescribed burns or wildfires; and
3. A literature review on the historical use of fire and the environmental effects of the current use of fire as a land management tool in New Zealand.

All relevant information was collated into this state-of-knowledge summary document that outlines what practices are being used, the risks and benefits of these practices, and recommended research for the future. The outcome was to provide enough information to assist in the future development of guidelines around using fire as a land management tool that will lead to safer, more effective and sustainable fire use, help reduce the risk of harm to life and property, and mitigate the adverse economic and environmental consequences of rural fire use.

Key Findings from this Study

Fire is considered a useful tool in rural New Zealand. However, there are growing concerns around its use. This study provides an insight into who thinks what around the risks and benefits of using fire as a land management tool. The results of this work have established the importance of the use of fire in the rural sector. In recognition of the degree of use and benefits to the rural sector in New Zealand, it is important to ensure fire is used safe and effectively to reduce the current level of risk.

The literature review

The historic use of anthropogenic fire, in a country where natural fire frequency was low and the adaptive capacity of indigenous ecosystems was limited, has had an extensive, lasting and irrecoverable impact on today's landscape.

The widespread use of fire reduced the natural forest cover from 85–90% prior to human arrival (c.1320–1350 AD) to 25% by the mid-20th Century. Māori primarily used fire to clear travel routes, hunt for game such as moa, establish and maintain bracken beds and to clear land for crops, whereas Europeans used fire primarily for land conversion to agriculture.

Concerns around the intense use of fire and associated environmental impacts were raised as early as the late 19th Century. As a result, the current use of fire as a land management tool, and the legislative requirements governing its use, have been strongly influenced by past fire use practices.
Not surprisingly, the review on the environmental effects of prescribed burning found that hot dry burns had the greatest adverse impact on terrestrial ecosystems. The review identified conflicting outcomes or a lack of information on environmental outcomes when using fire as a tool on conservation land to maintain desired habitats for conservation purposes or for pest management (i.e. wilding pines).

Lighter burns and burns carried out under cool moist site conditions mitigated some of the adverse environmental effects associated with hotter burn conditions. Judicial use of burning under these conditions, in conjunction with post-burn practices such as fertiliser application and oversowing, has the potential to reduce excess plant material to stimulate pasture re-growth while reduce the severity and duration of burning effects on terrestrial environments.

However, much of our knowledge is based the effects of prescribed fire on terrestrial environments in tussock grasslands. Further research is needed for other vegetation types and land-uses using current prescribed burning practices. No published scientific information was found on the effects of prescribed fire on water quality and freshwater biodiversity.

Smoke Dispersion Models

Currently, there is no smoke plume modelling tool available to end users in New Zealand. Benefits of having such a tool includes: enhancing fire management decision-making around deployment of resources and evacuations, warning the public of smoke health effects and / or poor transportation corridor visibility (roads and airports), and reducing smoke nuisance from prescribed burns.

The BlueSky Framework is the best suited system for implementing operational smoke dispersion modelling. . Originally developed by the US Forest Service, and is in use worldwide (Canada, USA, South Korea, Portugal and Australia). Modifications of the BlueSky Framework for the New Zealand fire environment are minor compared to the overall development and refinement of the Framework to date.

The national survey on the use of fire as a land management tool

Fire is considered a useful tool in rural New Zealand, with 54% of the respondents indicating that they were using fire. Fire was used across the country for a variety of reasons, debris burns or vegetative rubbish removal (small piles) being the major use. The main findings from the national survey show that:

Reasons for using fire:

- Removing encroaching woody vegetation, such as scrub, bracken and wilding pines,
- Clearing and sterilising agricultural crop residues,
- Preparing land for the establishment of pasture or plantation forest,
- Promoting palatable regrowth for grazing and improving access for stock, and
- Disposing of vegetative trash.

Altitudinal beliefs around use of fire:
Land managers and rural populace have very similar rationale for the use of fire as a tool; however there are very different reasons why they don‟t use fire or don‟t want it used. Perceptions around the benefits and risks of fire use are varied, and differ between rural populace and land owners, and also different rural sectors. More research is required to better understand these differences. Land managers perceived a lower level of risk from burning compared to rural fire officers. We did not find significant differences in beliefs for the different age groups, but did between genders, Stake holder types, (rural fire officers, land managers, rural populace), Land management sectors, Regional locations, and the size of the land being managed.

Males agree more than females on the benefits of fire use, whereas **females** were more concerned on the impacts of smoke and the loss of knowledge. **Users** of fire agreed more on that fire was a traditional tool. Whereas, **non-users** of fire agreed more on the impacts fire has as a smoke nuisance and also there is a loss of knowledge on fire practises.

Interestingly, only smoke had a significant effect on a survey respondents' choice regarding the questionnaire item "Is fire a good option for managing land". A respondent's likelihood to opt "yes" decreased with their smoke impacts attitudinal score. In other words, the more a respondent agreed that smoke was negative, the less likely they were to believe that fire is a good option.

Land owners/managers:

- Felt that Regulations were a constraint to using fire more than the rural populace, and agreed more with the statements concerning fire being a traditional tool than either rural fire officers or the rural populace.
- Were much less likely to agree with the statements concerning the impacts of smoke than either rural fire officers or the rural populace.
- With smaller land areas (<40 ha) were in greater agreement with statements concerning smoke impacts compared to managers with land greater than 800ha. Those managing smaller lands agreed more on the benefits of fire as a tool compared to those managing greater areas of land.

There was a varied response between rural fire officers and land managers about the environmental impacts of fires.

- **Rural fire officers** were also in greater agreement with the benefit of fire as a tool than either the rural populace or land managers.
- Both fire officers and land managers agreed on the negative impacts on air quality.
- They both saw the positive impacts for woody weed removal and fire acting as a cost effective tool.
- However, there are a number of actions where there is disagreement between fire officers and land managers on best practise to avoid escapes. It is unclear if it is because there is lack of understanding or scientific information or best practise guidelines out there.

These areas of misconceptions highlight the need for further research, especially comparing reality with perceptions, or "myth busting", by identifying differences in perceived risks and benefits (from the online survey), and marry with facts (from a literature review).

Conclusions and Further Work

Currently there are no training courses, detailed guidelines or consistently agreed protocols to facilitate the safe and effective use of fire as a land management tool in New Zealand. The findings of this research can assist the relevant stakeholders in the development of best practices for the safe, effective and sustainable use of fire as a rural land management tool, without compromising the integrity of the air water and land.

Based on the findings raised around the benefits and risks to using fire, further research is required to investigate:

- the impacts of burning on ecosystems in vegetation types and land uses other than tussock grasslands,
- the impacts of burning on air pollution, water quality and quantity, terrestrial and aquatic biodiversity and riparian environments,
- post fire recovery studies, and
- development of burning prescriptions (seasonal conditions, fire behaviour, etc.) for different vegetation types.

Building on from the qualitative research, the next steps are to:

- Confirm or bust myths/perceptions, and outline best practises, techniques and tools to minimise the risk and maximise the benefits of prescribed fire;
- Better understand the regional differences in fire use practise and concerns regarding these practises for targeted messaging around reduction/prevention campaigns;
- Develop and run training courses to support landowners or managers in understanding how to use fire safely and effectively.
- Develop real-time tools (e.g. BlueSky Framework) that can be used by farmers/ landowners to assist with burn planning.

Fire as a Land Management Tool: Summary Document

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Acknowledgements

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Introduction

Fire as a Land Management Tool

Fire has played a significant role in the evolution of the vegetation cover of New Zealand. Historically fire has been an important land management tool since humans arrived in New Zealand around 730 years ago (See Chapter 1). Fire was heavily relied on to clear pathways, establish village sites, maintain bracken fern beds, hunt for game, clear and cultivate land for crops, and pest control. Around 180 years ago fire began to be used more widely by European settlers (see Chapters 1 and 2) for converting native lands for agriculture.

Fire continues to be used for a wide range of land management practices today, including clearance of woody vegetation and crop residues, and stimulating pasture regrowth. Fire remains one of the most cost-effective and sustainable tools available to landowners, especially when compared to other land-clearing alternatives such as machinery and chemicals (FAR, 2006). The main reasons for burning in New Zealand and worldwide can be grouped into the following broad categories:

- Reducing wildfire impacts (fuel reduction burns)
- Maintaining a healthy landscape
- Large scale vegetation removal (forestry slash, woody weeds, etc.)
- Small scale rubbish removal (hedge trimmings, green waste, etc.)
- Preparing land for agriculture
- Recreation (e.g. campfires)
- Research & training
- Other (i.e. disease prevention & frost pots)

However there are also risks associated with the use of fire as a land management tool, including prescribed burns escalating into uncontrolled wildfires, along with potential impacts on natural and cultural features, soil and water resources, vulnerable ecosystems, biodiversity values, and economic loss and damage to infrastructure.

Over the last twenty five years (from 1991/92 to 2015/16), New Zealand has seen an increase in the number of wildfires from around 3060 to more than 4,580 per fire year. The average area burnt was 5,220 ha per year during this period, a slight reduction from the last analysis reporting 5,860 ha annually. The total area burned fluctuated from a minimum of 1,500 ha in 2011/12 to a high of 17,690 ha and has been influenced by large individual fire events and/or large areas burned in a single region, such as the Alexandra fires (Otago, 7,800 ha) in 1998/99 and Blenheim fires (over 6,500 ha) in 2000/01.

Despite the widespread use of fire and occurrence of escapes from prescribed burns, the risks and benefits of using fire as a land management tool are currently not well understood or quantified, and little is known about the extent of burning undertaken in New Zealand for different (Statistics New Zealand, 2007; Wakelin, et al., 2009; Wakelin, et al., 2010).

In the last five years, around 25% of wildfires have been attributed to Campfires/Bonfires and Rubbish fires; 18% are attributed to land clearing activities, such as shown in Figure 1. While the number of escape fires from restricted and prohibited fire seasons have reduced in the past 8 years in open fire seasons there has been little reduction in the numbers of fires which escape.

The need for this research

Fire has been a long-standing tool in the rural sector; however, the continued use of fire is under pressure due to concerns regarding its impacts on ecosystems, air quality and the safety of those using fire. The use of fire in New Zealand is still a contentious issue and has been raised at a number of forums involving key stakeholders (Scion, 2008, 2009a, 2009b).

Landowners (and their representative group, Federated Farmers of NZ) have been very vocal in identifying a number of issues hindering more widespread use of fire (Aspinall, 2001; Hart, et al., 2006;

Hore, et al., 2009) These include the complex and often contradictory regulatory processes and costs of obtaining the necessary permits and consents, liability issues should fires escape, lack of knowledge and loss of experience in safe burning practices including effective lighting techniques, lack of understanding of fire behaviour, as well as limited understanding of the effects of fire on native vegetation.

In contrast, a growing number of voices are concerned at the continued use of fire in rural settings, seeing the practice as archaic and unnecessary. A number of recent small and large scale burn offs conducted by life-stylers and farmers have received negative feedback in the media from the public, with smoke being the biggest complaint[1]. Public awareness of the dangers from fire use has also been raised, with an increase in the number of urban/rural interface fires damaging homes, property and putting fire fighters at unnecessary risk. A total of 10 deaths over ten years, along with a number of un-documented injuries, have been recorded as a result of undertaking prescribed burns[2].

Land management agencies such as the Department of Conservation (DOC) and Regional Councils have also expressed concern at the lack of scientific knowledge to support policies, highlighting the need for an improved understanding of the risks and benefits associated with using fire. In addition, the lack of verified knowledge regarding how fire is being used, and the extent to which fire is used in rural practices hinders the development of relevant and accurate prescribed guidelines, providing the basis for undertaking this work; i.e. because we don't have the accurate knowledge we can't write good guidelines.

Research approach

Literature review

As the historical use of fire has had a significant and lasting impact on New Zealand's landscape and a strong influence on the current use of fire, an initial review was undertaken on the historic use of fire as a land management tool in New Zealand. This information provided a background (Chapter 1) for the remaining research work presented in this report. The review on the environmental effects of the current use of fire as a land management tool was based on publically available scientific literature (Chapter 5). This information was used to assess the environmental impacts (including smoke – see Chapter 4) of the use of fire on terrestrial and freshwater ecosystems across key rural land-uses and vegetation types (tussock grasslands, shrublands, agriculture and horticulture, planted forests, and conservation land). The review identified information gaps and recommendations for future research.

National Survey

A survey approach was used to gain a broader understanding of when, where and how fire is used within different rural land-based sectors within New Zealand (Chapter 2); the range of stakeholder opinions concerning the benefits and risks of such practices (Chapter 3); and to understand the unique New Zealand situation and setting within which fire is used to manage landscapes and aid forestry, horticulture and farming business. To date, there has been no national survey undertaken to understand the extent of such practises or the range of stakeholder opinions concerning the benefits and risks of using fire as a land management tool.

In 2012, a pilot survey (Bayne, et al., 2012) was initially conducted that involved eighteen interviews with key stakeholders (rural fire officers; representatives from the rural sector (farmers, horticulturists and foresters); Government department staff (DOC, New Zealand Defence Force and Ministry for Primary Industries); members of lobby groups and local government representatives). These interviews gave an initial indication of the range, diversity and direction of opinions regarding fire as a land management tool, the factors driving fire use for this purpose, and identified the key landowners likely to be affected by changes in policy or practice.

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[1] For example, refer to this newspaper article:
http://www.nzherald.co.nz/nz/news/article.cfm?c_id=1&objectid=11346334

[2] For example: http://www.stuff.co.nz/business/farming/81207218/Company-fined-for-burn-off-death-on-farm-near-Cromwell

These initial interviews were either conducted face to face or by phone, and identified the range of topics to explore in the wider national survey. The aim of these conversations was to help refine questions that targeted the most appropriate landowners and managers to capture the wide ranging perceptions and values concerning fire as a tool, and their techniques and methods used to manage vegetation fires. We designed and piloted an online national survey in 2014 based on the earlier findings from 2012. This was trialled with the Canterbury-West Coast Regional Rural Fire Committee. The national survey was administered as an online link, (http://www.surveymonkey.com) that included questions relating to (but not limited to):

- Types of vegetation burned
- Major land operations undertaken
- Proximity of rural operations to neighbours
- Area of land managed
- Frequency of burning; area burned and season of burning
- How fire was used in conjunction with other tools (spray; mechanical removal)
- Changes in burning practices over time

The national survey was promoted via agricultural show days, newspapers, email, social media, New Zealand Federated Farmers, agricultural societies and rural community groups. Random target respondents were contacted via email and had the option to choose whether or not to 'opt into' the survey. To get a representative sample size from across sectors and throughout the country, a target of 700 responses from the three main groups (rural populace; rural fire personnel and land managers) was sought to achieve 5% margin of error. A total of 696 survey responses were returned across the country, with an even split between those who used and didn't use fire. Responses were received from:

- Land Managers (52 %) [People who own or manage rural land for productive purposes],
- Rural Fire Personnel (13 %) [Including rural fire officers and policy makers], and
- Rural Populace (35 %) [People resident in the rural community but who did not own or manage rural land for productive purposes]

The success of the survey response was dependant on the co-operation and engagement of the key stakeholders, but also likely associated with strong interest and recent engagement of these groups in discussions around the issues using fire as a land management tool (e.g. Bayne, 2011; Canterbury Regional Council, 2005; Hunt, 2007)

Smoke plume prediction models

Smoke plume modelling is based on first principal physics, and therefore any one of the models can be used anywhere in the world without alteration. This is unlike the fuels and emissions models, which have to be modified for locality. Here the model choice is determined based on the assumptions used by the model and whether or not the local fire environment is likely to violate those assumptions (Chapter 4). The operational publication, (Strand, et al., 2016) and the scientific publications (Raffuse, et al., 2012; Strand, et al., 2012) and (Drury, et al., 2014; Goodrick, et al., 2013; Larkin, et al., 2010) as well as case study experience of implementing smoke modelling during wildfires and examining a pre-fire smoke dispersion case, were used to draw conclusions on the best operational smoke model and tool outputs for New Zealand.

Figure 1: Rock and Pillar Range, Hyde Otago. Photo credit: Department of Conservation.

Chapter 1: Historical use of fire in New Zealand

The historic use of fire in New Zealand has had an extensive and lasting impact on today's landscape. As a result, the current use of fire as a land management tool, and the legislative requirements governing its use, have been strongly influenced by past fire use practices.

Prior to human settlement in New Zealand, forests covered around 85-90% of the landscape (McGlone, 1989) (Figure 2). While there is evidence of wildfires in New Zealand before human arrival, fires were infrequent with estimated return periods ranging anywhere from 50 to 6,000 years (Ogden, et al., 1998; Rogers, et al., 2007; Wilmhurst, et al., 1996). Sources of ignition were mainly confined to lightning strikes and, to a lesser extent, volcanic eruptions in the North Island. Due to the infrequency of fire in the landscape, few native New Zealand flora species have adapted to fire disturbance (Allen, et al., 1996; Basher, et al., 1990).

Polynesians (Māori) settled in New Zealand around 695-655 years BP (1320-1350 AD) (Jacomb, et al., 2014). Fire was the main land management tool used by Māori for a range of purposes including: clearing travel pathways, establishing village sites, maintain bracken fern beds, clearing and cultivating land for crops, and hunting for game (i.e. moa) (McGlone, et al., 1995; McGlone, et al., 1999; McKelvey, 1973; McWethy, et al., 2010; Rogers, 1994; Stone, et al., 2015). Burn patterns were influenced by climate and topography, and were more extensive in areas associated with low rainfall (particularly summer rainfall), and flat to undulating topography, such as the eastern and central South Island and central plateau areas of the North Island (Perry, et al., 2014; Rogers, 1994). Most of the burning and deforestation occurred within 200 years of Māori settlement in New Zealand, and by the time of European settlement (around 180 years B. P.) an estimated 40% of New Zealand's forest cover had been lost (see Figure 2).

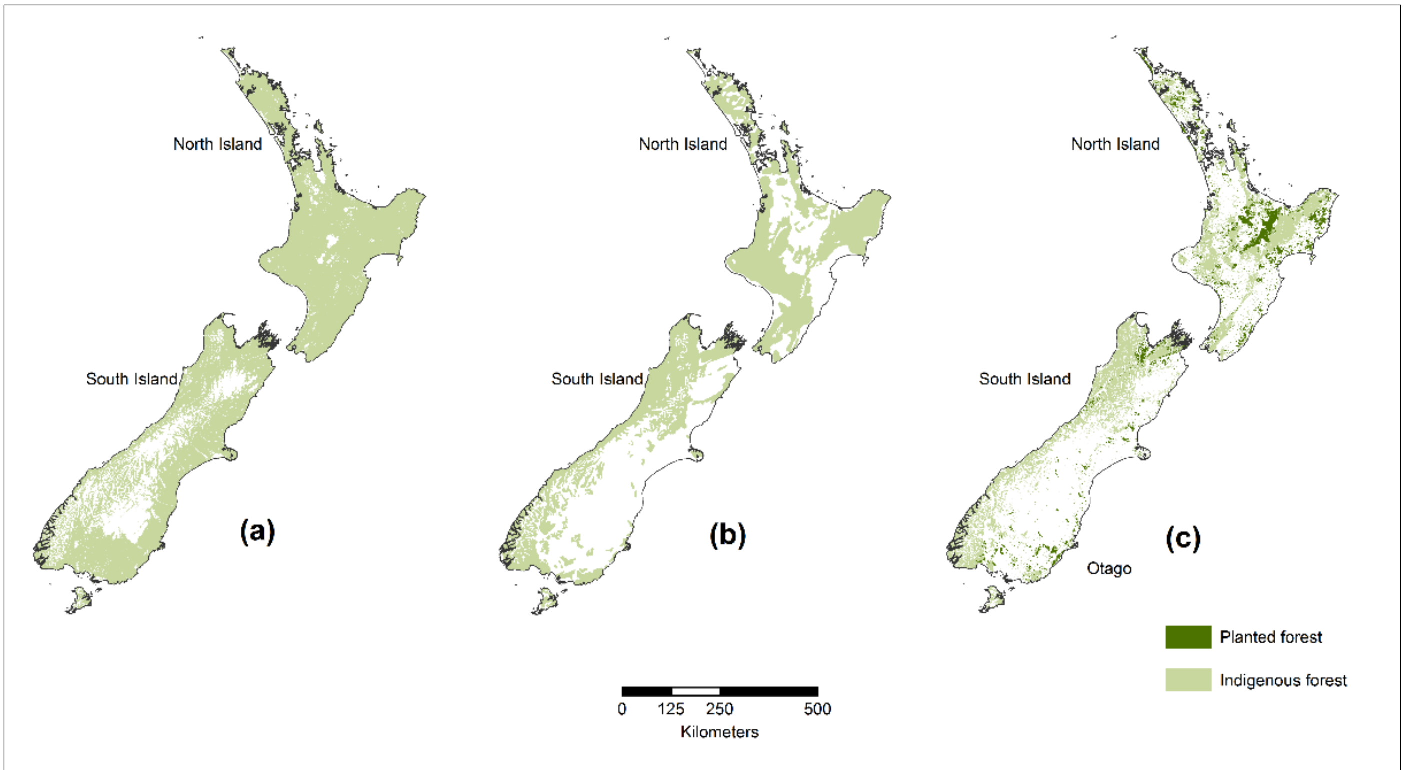

Figure 2: Forest cover in New Zealand (a) prior to human settlement; (b) prior to European settlement; (c) current day (McGlone, et al., 2004; McGlone, 1989; Pairman, 2014). Figure compiled by M. Heaphy, Scion, New Zealand.

The intensity of burning by Polynesians over a large portion of the landscape in a comparatively short time frame, was repeated with the arrival of European settlers who continued to use fire as a land management tool. It was a cost-effective means of clearing large areas of land in flax, tussock grasslands, scrub and indigenous forest for agricultural production and the development of high country grazing runs, particularly in the South Island (Knight, 2013; O'Connor, 1982; Peden, 2006). At times, out of control burns extended across large areas of the landscape, often with serious consequences to human life, infrastructure, livestock, pasture and remaining forested areas (Arnold, 1994; Beaglehole, 2012; Knight, 2013). This second wave of burning resulted in large areas of land clearance within two decades of European arrival (see Figures 2 & 3). By the end of the 1950's, around 25% (5 million ha) of indigenous forest remained. The intensity of burning over a large portion of the landscape in a comparatively short time frame by both Māori and European is difficult to match elsewhere in the world (Whitlock, et al., 2015). The persistent use of fire disrupted natural vegetation succession processes and regeneration of forests, resulting in long-term deforestation that is still present today (Perry, et al., 2014). These changes also contributed to the decline and extinction of many indigenous flora and fauna species, particularly the avifauna (Holdaway, 1989; Holdaway, et al., 2000; McGlone, 1989).

Figure 3: The beginning of a bush burn on Puketora Station, in the East Coast region (left); remains of a forest after a burn off, at Rip Station, Tapuwaeroa Valley, Gisborne, circa 1890s (right). Photographs taken by Frederick Ashby Hargreaves These photos are from the Hargreaves, Frederick Ashby, 1854-1946: Collection of photographic prints and negatives. Reference 1/1-023274-G and PAColl-3047-1-01. Photos provided by the Alexander Turnbull Library, Te Puna Matauranga o Aotearoa, Wellington, New Zealand.

While concerns over the indiscriminate use of fire and the impact on the environment were evident from the mid to late 1800s, a 1945 review of Canterbury runholders showed that the use of fire had declined in the previous 30 years, although it was still an important land management tool (Cumberland, 1945). A review of archival records from South Island farm station diaries (1850-1890) found that, in contrast to common belief, fire was not used discriminately, and that there was no evidence of repeat burns (Peden, 2006). However, it wasn't until the early 20th Century that several Acts came into being along with associated regulations to control the use of fire as a land management tool. Legislation such as the Forests Act 1921 (1921-22) established fire districts across New Zealand, and the Soil Conservation and Rivers Control Act (1941) placed limits on the level of agricultural burning to address erosion concerns. The Forest and Rural Fires Acts (1947, 1956, 1977) included requirement for consents for some types of burning, prohibited burning of high-altitude snow tussock, and restricted burning to winter and early spring months only.

Chapter 2: Current use of fire in New Zealand

Fire is one of a range of options available as a land management tool, particularly when managing competing vegetation.

Fire in agriculture and horticulture

Fire is used as a management tool in the control of undesirable shrub species on agricultural land such as *Dracophyllum* spp., matagouri (*Discaria toumatou*), manuka (*Leptospermum scoparium*) and gorse (*Ulex europaeus*). Fire is used in the agriculture and horticultural sector for a range of activities including crop and stubble burning, removing orchard residues, frost control, maintenance and removal of hedges and shelter belts and burning rubbish (Bayne, et al., 2012). Published research on the environmental effects of these practices is lacking in New Zealand, highlighting an information gap in this area.

Stubble burning in New Zealand is used mainly to remove wheat, barley or oat residues and to establish small seeded crops (Williams, et al., 2013). Around 40% of cereal crop residues (average 50,172 hectares) are burned each year with a large proportion of the burning occurring in the Canterbury region.

Fire and planted forests

Excess vegetation can restrict access for planters and silvicultural operators, impacts on seedling survival and supresses early tree growth. Fire is primarily used in planted forests as a tool to prepare land for the establishment of tree seedlings although its use has declined over time mainly due to environmental concerns (Robertson, 1998). Controlled burns are used to reduce logging residues or to remove unwanted vegetation which is frequently pre-treated with herbicides to improve combustibility.

Understanding the rationale for current practice

One of the earliest surveys on the use of fire as a management tool was undertaken by the North Canterbury Catchment Board in December 1944 (Cumberland, 1945). This survey showed that while the use of fire had declined in the previous 30 years it was still an important land management tool. Virtually all the runholders used fire, even if only occasionally. Its use was limited in the drier areas of the high country (burn intervals 5 – 20 years) but more widespread in the wetter regions (burn intervals 3-5 years). Burning was discriminate, predominantly carried out in spring, and was used for a range of purposes (Table 1). Although the survey respondents recognised the disadvantages associated with the use of fire (Table 1), most run holders thought there were no alternatives that could completely replace fire (Table 1) and the majority of survey respondents felt that the system of fire regulations in place at that time were unsatisfactory. More than two-thirds thought they would be adversely affected personally and financially if burning was prohibited, but practically all thought fire prohibition would improve vegetation and soil with the exception of increased risk of accidental fire.

Table 1: Advantages and disadvantages of using fire as a land management tool in the Canterbury, South Island hill and high country in the mid 20th century. After Cumberland (1945).

Advantages of burning	Disadvantages of burning
• reduce the amount of scrub • remove dead, rank tussock • improved access and mustering • reduced risk of accidental fire • improved grazing • improved stock health	• loss of humus and soil • reduced pasture cover and vigour • encourages plants unsuitable for grazing • reduced feed in dry periods • fire encourages rabbits • removes shelter for lambs • dirty wool from ash • overgrazing of burnt sites • new pasture growth and exposed soil more susceptible to frost

The lack of a comprehensive understanding of how fire is currently being used in the rural sector, across a range of landowners and property types, was addressed through the design and implementation of a national survey into rural sector burning.

Survey Design

Sampling instrument and distribution

In addition to land owners and managers, the survey responses were sought from two further key audiences:

1. Rural populace – persons living in rural communities or on the urban fringe who are affected by rural land management activities involving fire; and
2. Rural fire personnel – fire officers and staff at territorial authorities responsible for policy and administration regarding rural fire operations.

The pilot study undertaken in 2012, identified Forestry, Arable cropping, Horticulture, Sheep and Beef (meat production), Dairying, and Specialist animal and egg production (non-dairy) including lifestyle blocks. It became apparent early in the survey that the dairy units were not using fire to manage their land, except on initial conversion from forestry, or to remove hedgerows in the way of irrigators. In light of the above, the dairy sector was removed from the sample population, resulting in a population of 36,000 production units.

The 2012 Urban/Rural Profile data table[3] was used to estimate the population size for the rural populace of New Zealand. The rural populace target population focussed on areas where the use of fire was known to be a more contentious issue – Otago, Mid and South Canterbury, and Nelson/ Marlborough. The total rural populace from the urban/ rural profiles for persons living in non-urban areas from within these 3 regions was 167,000. A sampling instrument (Table 2) to stratify target subsectors was created, to ensure a proportionate response from the rural sector, aimed at reducing the margin of error to 5%, requiring 700 responses:

Land managers
Possible survey respondents were identified from Association registries, and assistance distributing the survey was provided through the Federated Farmers of New Zealand. The survey was also advertised at the Canterbury Royal A&P Show (Year?) and visitors to the stand were given information on how to find and complete the survey, in the form of a poster and small business card.

Rural populace
The following groups were targeted using Local newspaper stories (Helensville News, Coromandel Chronicle and Motueka News) about the survey, and social media:

- Parents of early childcare centre children in Central Otago and Canterbury
- Queenstown and Wanaka Chamber of Commerce
- Local residents' associations in Nelson/Tasman
- Royal Forest and Bird protection society branches in these regions
- Rural Women New Zealand
- New Zealand Deerstalkers Association

Rural fire personnel
Persons involved in rural fire management and policy were identified from the National Rural Fire Authority directory, and from local Council contacts. This identified 131 people, who were sent an email invitation linking to the online survey.

In addition, the country was split into 18 rural provinces, and the rural population statistics for each used to provide a target proportion for rural populace respondents from each province.

[3] http://www.stats.govt.nz/browse_for_stats/Maps_and_geography/Geographic-areas/urban-rural-profile-update.aspx

Table 2: Target Number of respondents for an aim of reducing the margin of error.

Respondent type	Target number of respondents
Rural fire officers	71
Rural populace	383
Land managers:	285
Horticulture	*56*
Arable Cropping	*33*
Forestry	*36*
Sheep and Cattle	*130*
Specialist	*33*
TOTAL	*739*

Survey Instrument

This was the first time that a large-scale national survey into burning practice in the rural sector has been conducted within New Zealand—therefore there were no prior survey instruments available. To design the survey instrument, a pilot study was undertaken with eighteen rural fire officers to determine the relevant questions to include; and to identify who to target.

From the pilot interviews a survey was drafted that included questions relating to:

a) How fire is being used,
b) Where and when fire is being used,
c) Who is using fire,
d) Perceptions relating to benefits and risks from using fire as a land management tool,
e) Attitudes towards, and experience with, fire use in rural land management.

The resulting survey[4] was administered using an online service (SurveyMonkey).

Statistical Analysis

Respondents quantitative answers were analysed using two statistical packages: PASW version 18.0 (SPSS) (SPSS Inc., 2009); and R version 3.2.3. (R Core Team, 2015).
Demographic variables were analysed using standard statistical testing procedures (chi-square; t-test) to evaluate average means and to compare and contrast results between grouping variables. The results were graphed using MSExcel software; SPSS or R 3.2.3 graphical interface.

In addition, an assessment of benefits and risks from the use of fire was measured using a 5-point Likert-type scale across 34 statements. To reduce this list into a manageable number of variables for further statistical analysis, a principal components analysis (PCA) was run using PASW v18.0. This analysis produced nine original components, which on further inspection were reduced to five core components.

A generalised linear model (GLM) with binomial errors and logit link fitted by maximum likelihood was applied to analyse the proportion of respondents using fire as a land management tool (R version 3.2.3, R Development Core Team 2015). The model contained a two-column matrix holding the number of successes (fire users) and the number of failures (non-fire users) as response variable and age, gender, type, years in region and all two-and three-way interactions as explanatory variables. The model failed to convergence due to quasi-complete separation issues, which were overcome by switching to a bias-reduced binomial GLM (R package *brglm*) (Kosmidis, 2013). Likelihood ratio tests were used to assess the significance of the explanatory variables (Zuur, et al., 2009.).

[4] Available on request from Scion'Rural Fire Research Group

Research aim 1: Understand when, where and how fire is used within different rural-based sectors, including techniques used in vegetation management

Who responded to the national survey?

A total of 696 people responded to the online survey, translating to a 68% response rate from the rural fire personnel and 5.1% and 6.3% margin of error for the land managers and rural populace, respectively. Responses were received from throughout New Zealand (Fig 4), for a diversity in age (Fig 5), and from across the five land managing sectors (Fig 4). Fifty two percent (52%) of respondents were land managers/owners, 13% rural fire officers, and 35% rural populace.

Age and gender

Age distribution of survey respondents by type of fire user (land managers, rural fire officers and rural populace) followed a normal distribution (Fig. 5), and for those that were willing to admit their age (n=422), the majority of respondents were between 55-64 years old, followed closely by 45-55 years old. Of the 61% of respondents stating their gender (n=421), 30% were female and 70% male (Fig. 6).

Land management sectors

A total of 361 responses were received from productive land managers, targeted across five key rural sectors based on their main productive land use (Fig. 7):

- Sheep and Cattle (51%)
- Horticulture (21%)
- Forestry (6%)
- Arable cropping (14%)
- Specialist (8%) (Productive lifestyle blocks, alpaca farms, lavender crops, apiarists etc.)

Figure 4 (right) highlights the proportions of land manager types and their locations on the map of New Zealand. The majority of land management respondents were from the Canterbury area (South Island), and most common land sector respondents were from the Sheep and cattle sector (grey). At least one response from a rural fire officer was received in each of the fifteen regions surveyed. A large number of responses from the rural populace came from the South Island, particularly in areas where fire is used a lot, or there has been a lot of debate over burn-offs and media focus on them (Otago, Canterbury and Nelson).

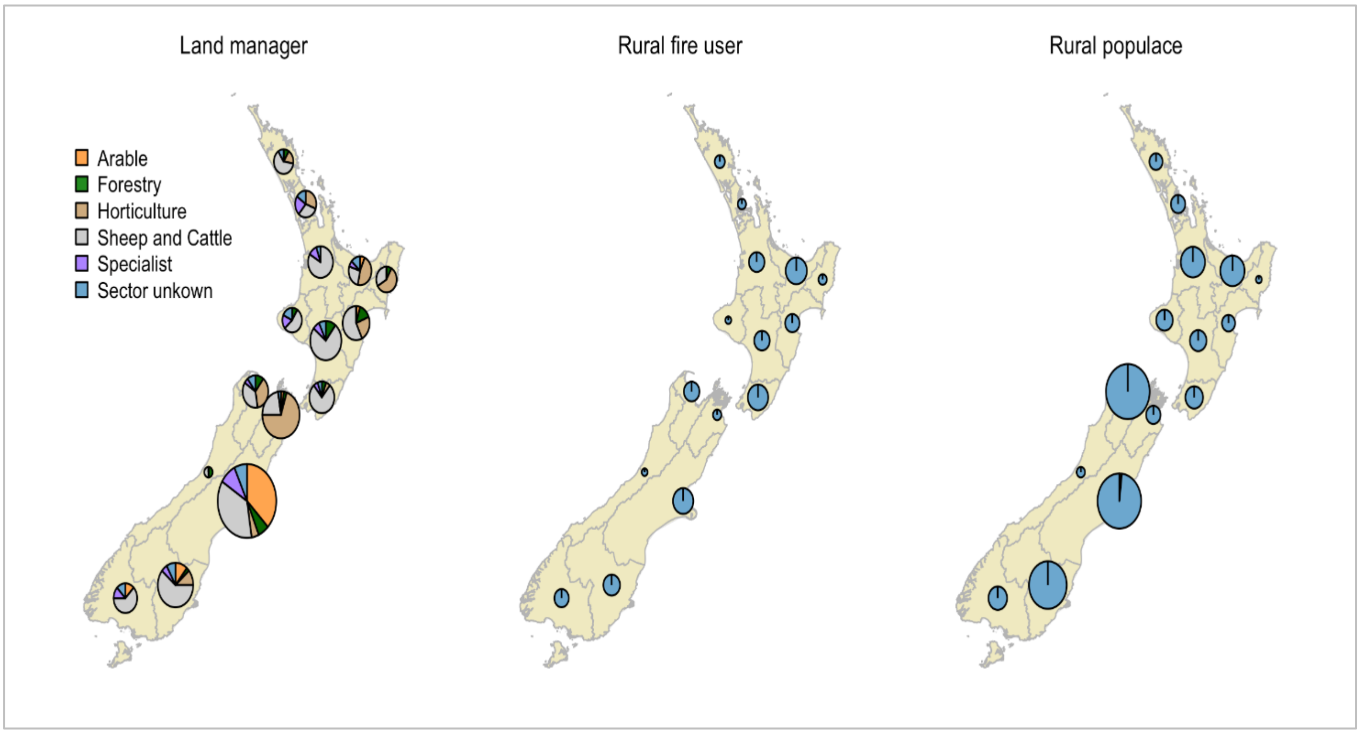

Figure 4: Proportions of land manager types by sector and region across New Zealand.

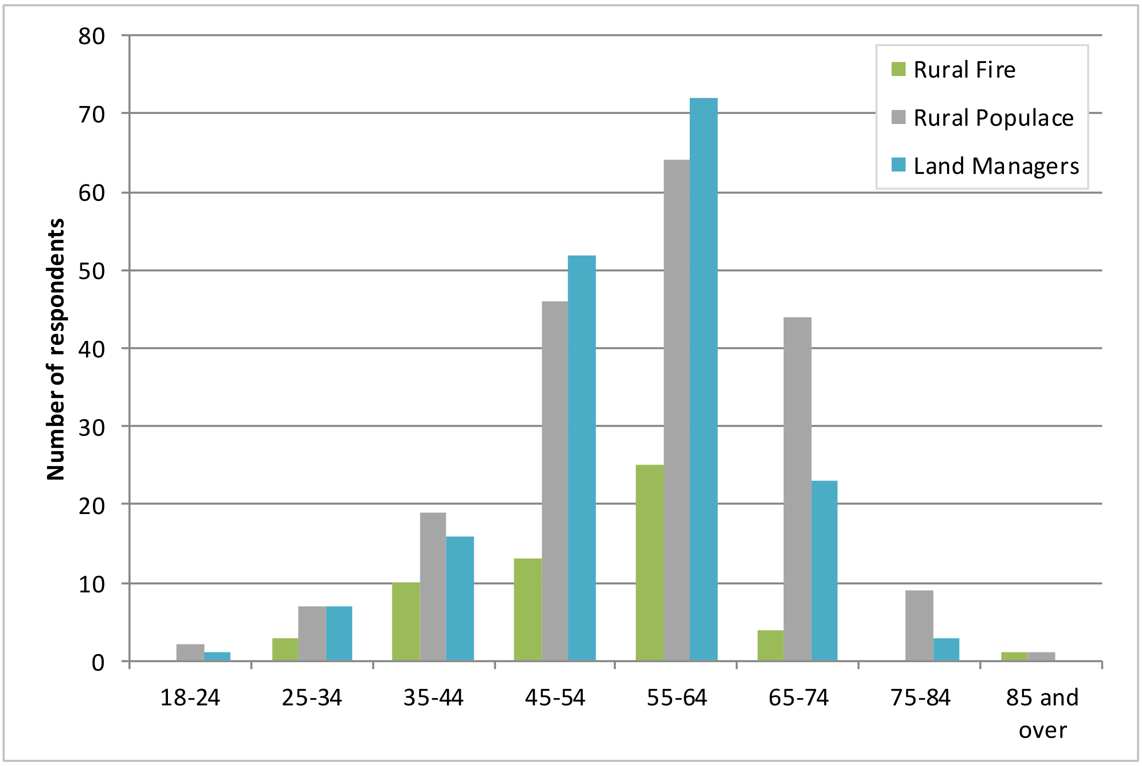

Figure 5: Age distribution of all respondents (n = 422)

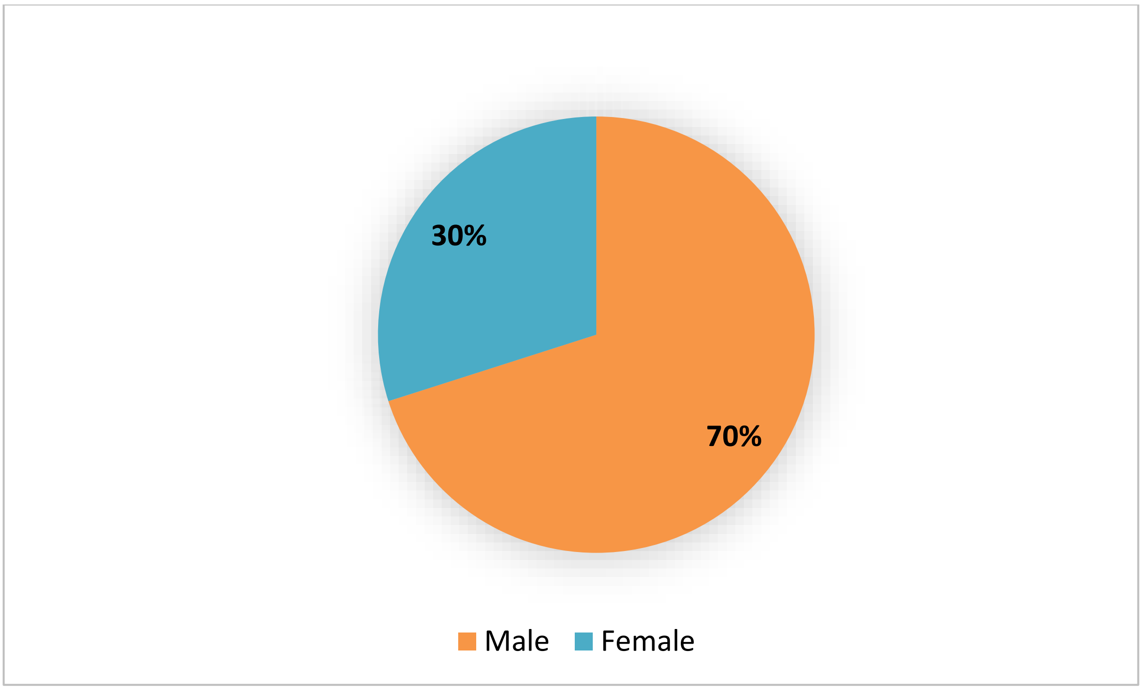

Figure 6: Gender of those who responded (n = 421)

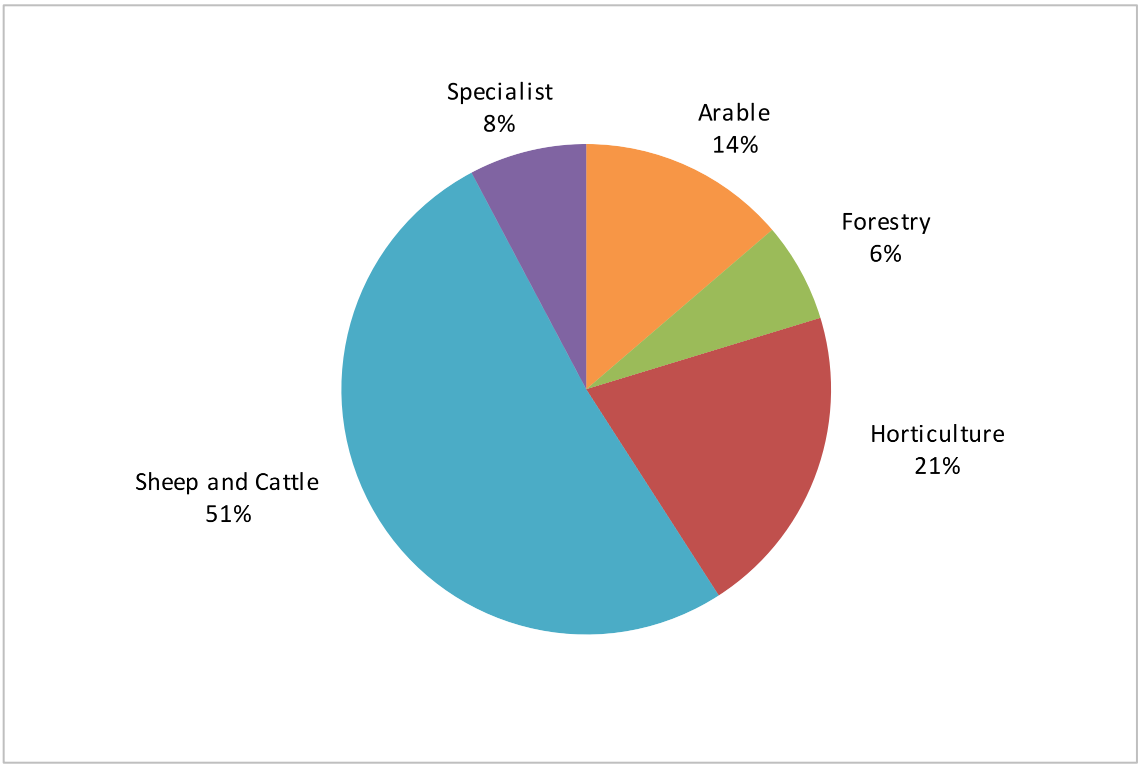

Figure 7: Proportion of respondents by land management sector types

How is land being used?

Land managers were asked to indicate the size of the parcel of land they were managing. Figure 8 shows the significant difference in area for land operations according to different sectors [$\chi^2(30, n=305) = 952.095$ ($p<0.000$)], with larger parcels of land mostly managed for Sheep and cattle operations along with Forestry, Arable cropping farmers managing medium sized land areas, and smaller parcels being used for Specialist and Horticultural operations. The majority of land under rural management is on flat plains (36%); rolling foothills hills (26%) or the hill and high country (21%) (Fig. 9) Not surprisingly, the type of land being managed was significantly different between sectors (p< 0.000).

Land managers (both fire and non-fire users) were also asked to rate the importance of eleven land management activities to achieve or support land management objectives, on a scale from 1-10 where 1 was very unimportant to their business, and 10 was of critical importance (Fig. 10). Providing public access was ranked the lowest on their list, whereas, providing cost effective solutions and maintaining cropping and grazing areas were the highest ranked. In descending order of rank, reducing weeds and disease, clearing rubbish and access for stock were also considered important. Reducing fuel loads, regenerating native ecosystems, maintaining native ecosystems and visual amenity were considered of some importance.

The pie graph (Fig. 11) shows some of the more common activities or operations that all land managers—whether they use fire or not—need to undertake. It shows that weeds, slash and rubbish removal were important or major land management activities, whereas, fuel reduction is not a major farming activity in New Zealand.

Who is using fire to manage land?

From the respondent population, the rural populace and land managers were asked whether they used fire to manage their land (89 rural fire officers were exempt from answering the question, as the question related to personal land). Amongst the remaining respondents (n=607), 54% reported fire use, 42% were not burning and, curiously, 4% did not answer this question (Fig. 12). The biggest users of fire were in the Sheep and cattle sector, followed by Arable cropping and Horticulture.

Regionally, Figure 13 shows fire is being used as a tool throughout rural New Zealand. However, there appears a very high proportion of people burning in the more remote areas with high Māori populations (Northland and the East Coast of the North Island). Whether this higher proportion of use relates to the nature of the terrain, the remoteness or due to cultural factors is not known however, and presents a research gap to explore in more detail. The Nelson region in contrast has a much lower proportion using fire compared to other regions, and may reflect the negative debate concerning the use of fire within this area. This might also reflect a stronger demographic presence of those concerned with environment impacts than in other regions.

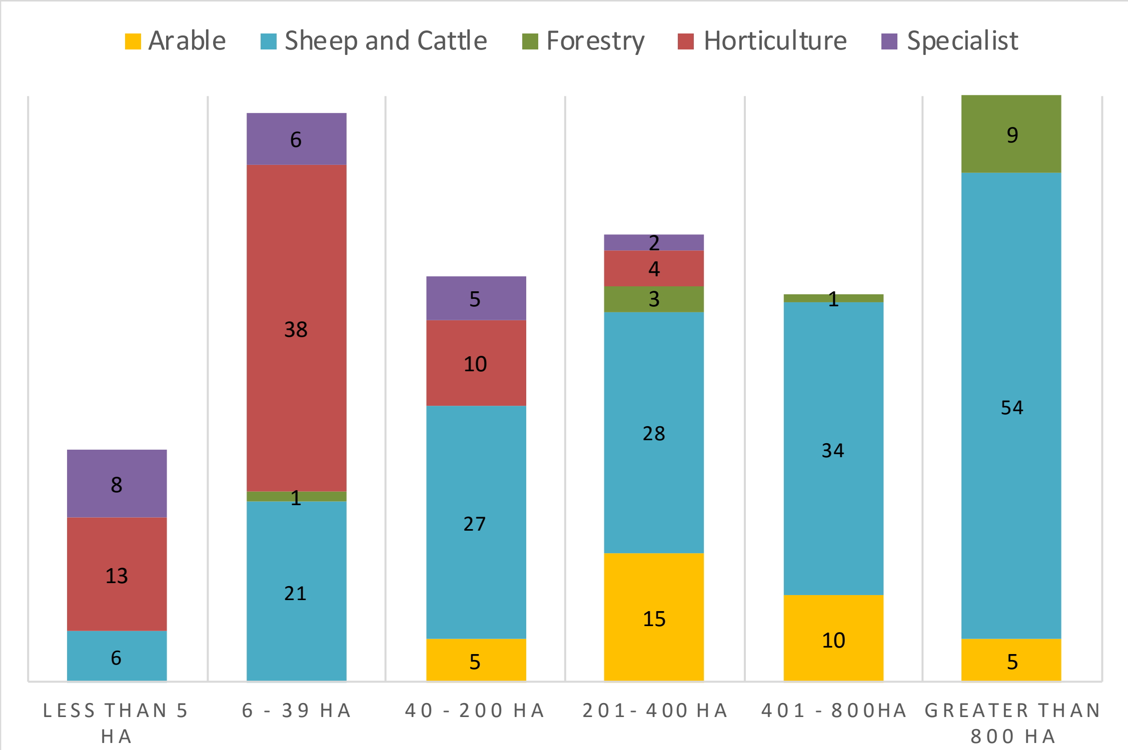

Figure 8: Area of land parcels being managed by the rural sector (numbers indicate the number of responses).

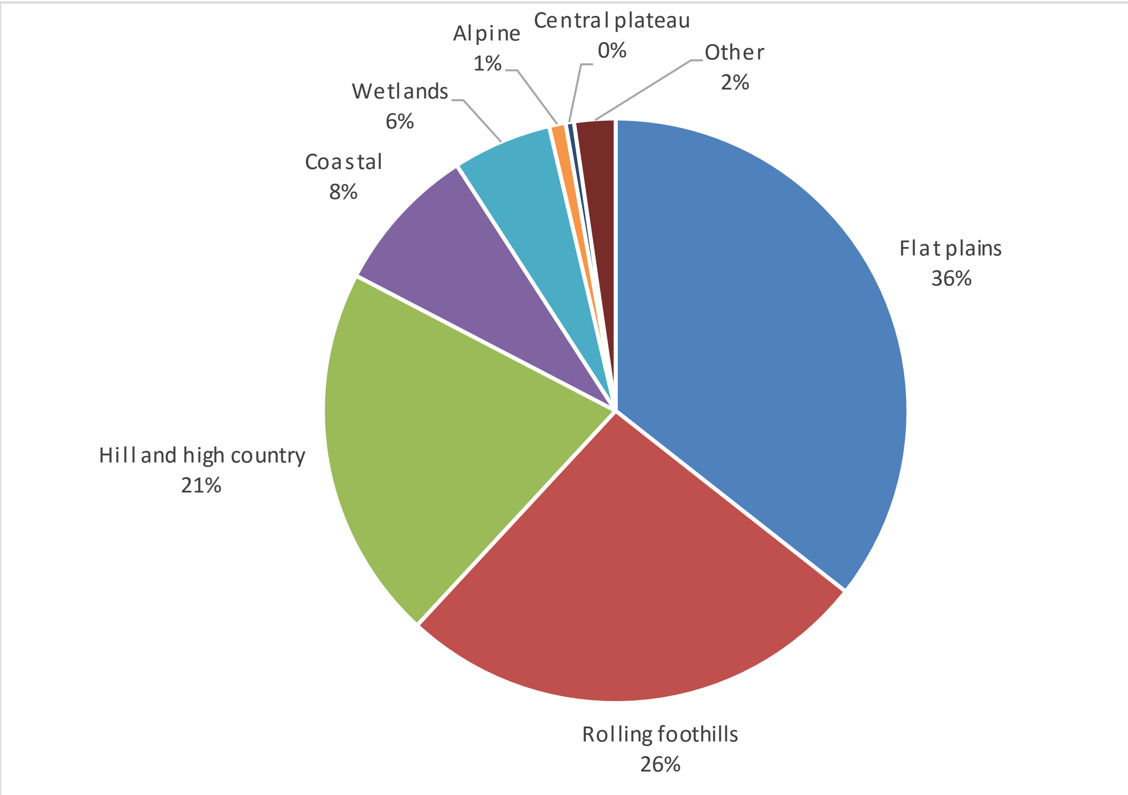

Figure 9: Type of land managed by respondents (n = 306)

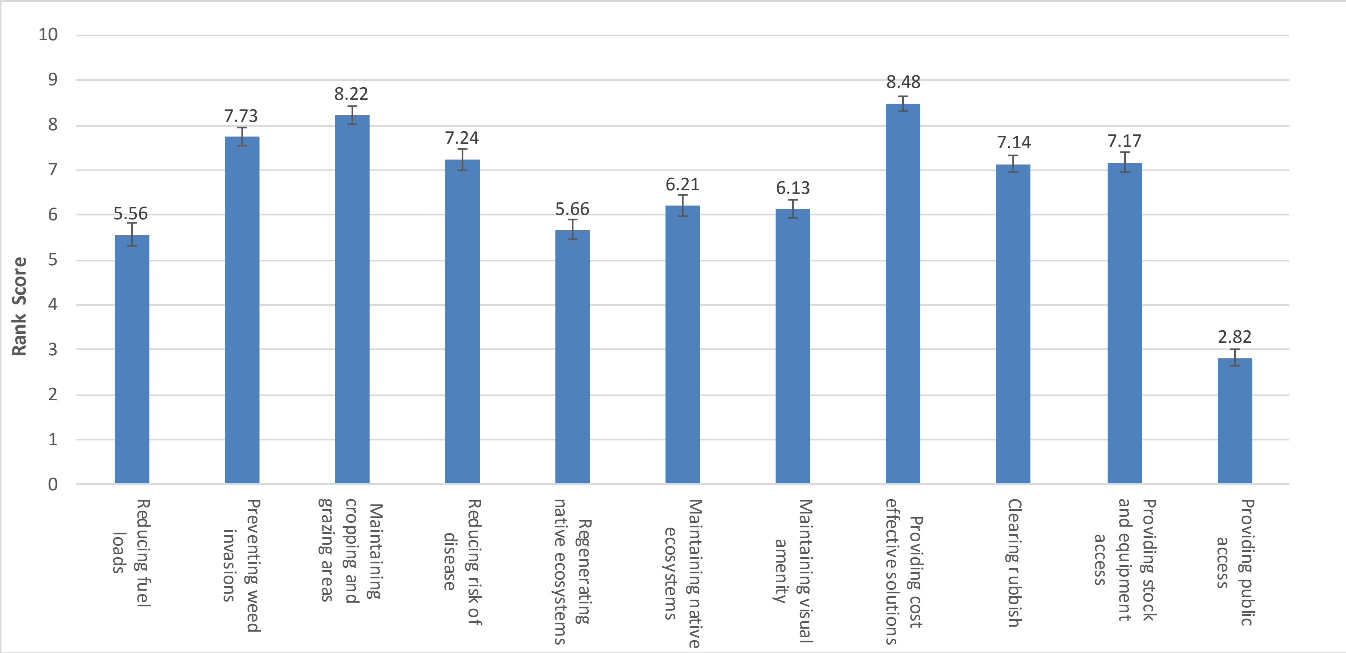

Figure 10: The mean importance of fire & non-fire activities to support land management objectives

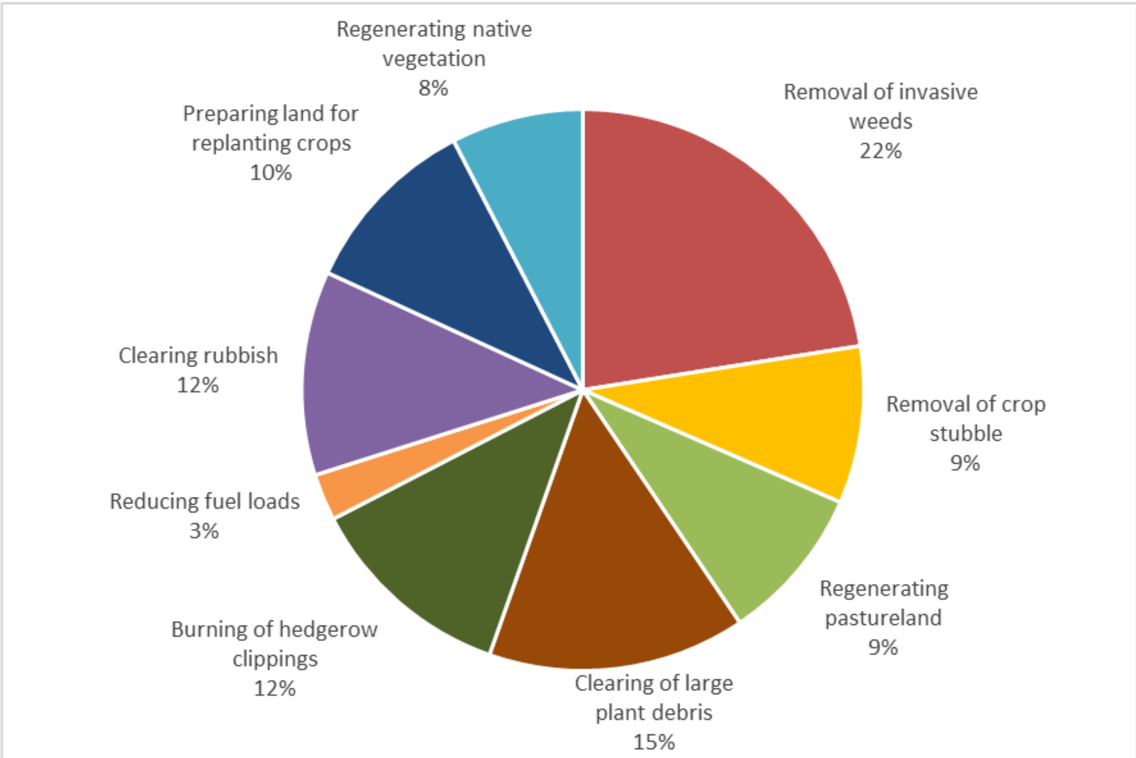

Figure 11: Common fire & non-fire activities used to support land management objectives

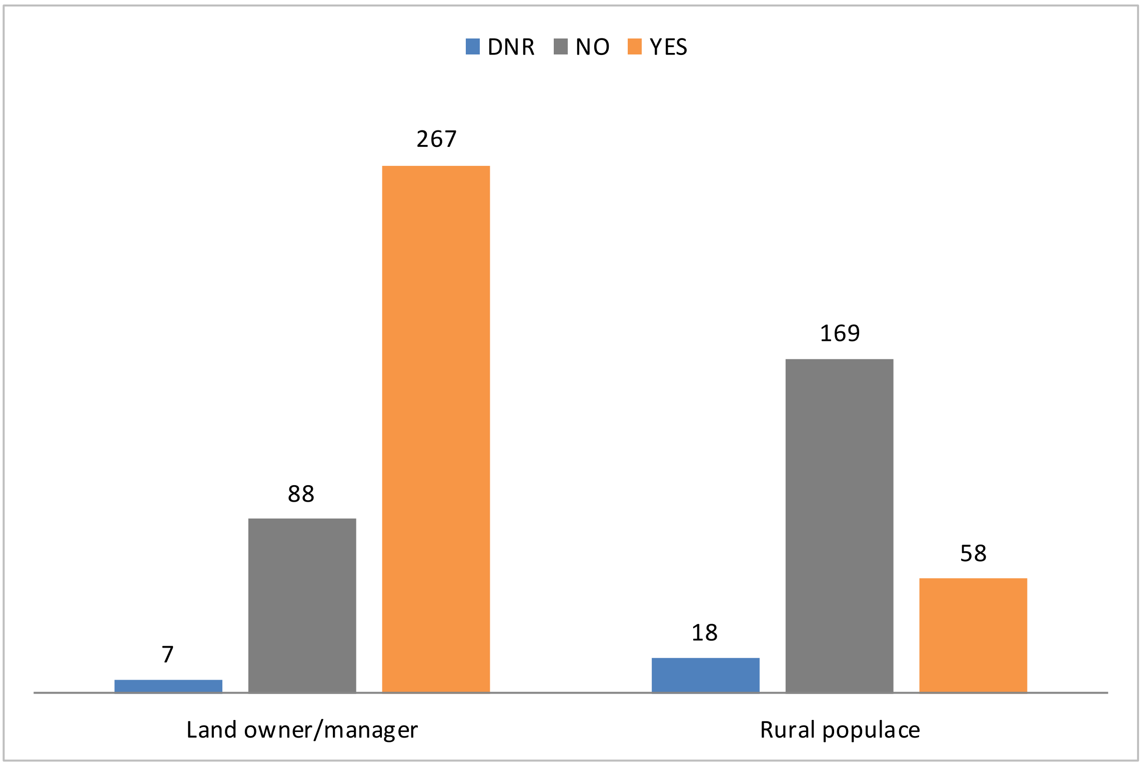

Figure 12: Number of respondents (land owners/managers and the rural populace) who are using fire, or not. (DNR indicates did not respond).

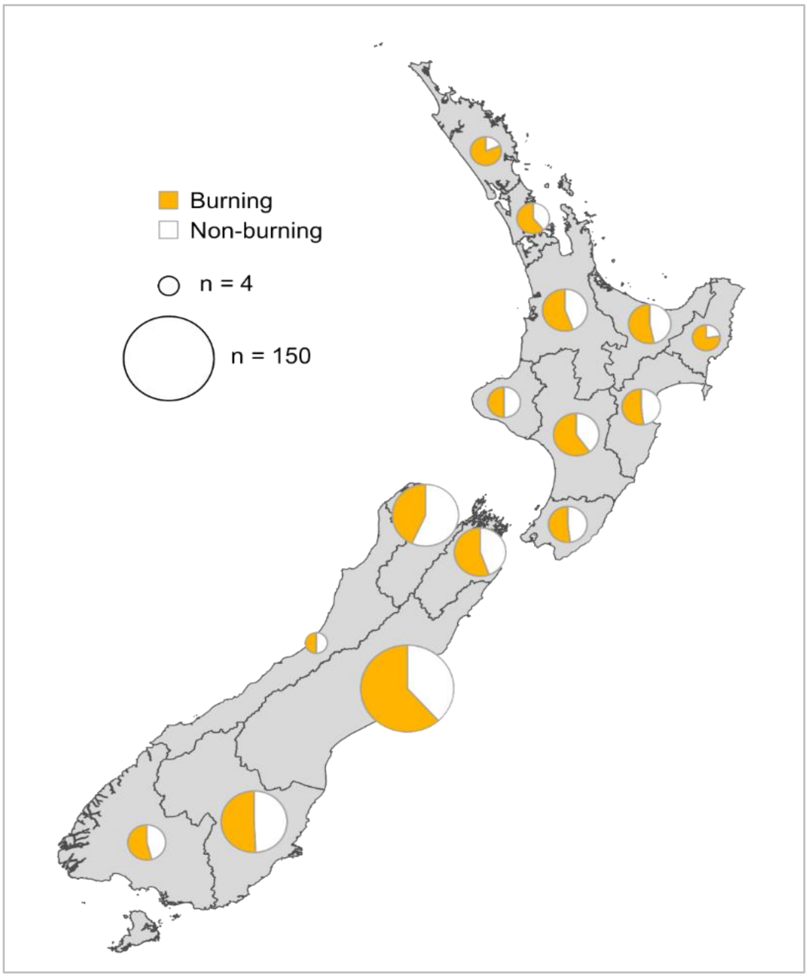

Figure 13: Proportion of respondents across the country who are using fire or not

Why and where is fire being used?

Some of the main reasons given, from the pilot interviews and validated through survey responses, for the use of fire as a land management tool within New Zealand include:

<u>High country practises:</u>

- Controlling rank feed,
- Clearing new areas into pastoral grazing areas,
- Maintaining grazing access for stock, and
- Reducing potential fuel loads (wildings, bracken and scrub).

<u>Arable burning practises:</u>

- For new cropping, usually in autumn following harvest,
- Removing post-harvest trash residues for ease of re-planting,
- Killing soil pathogens and stopping the build-up of diseases.

<u>Farm and life stylers:</u>

- Burning hedgerow clippings in small piles, where hedgerows are trimmed for both amenity and also to control vegetation on roadsides and from intrusion into powerlines.
- Large slash heaps, for example as a result of hedgerows and shelterbelts being removed and burnt for dairy conversion to allow irrigators to move freely,
- Burning of large stumps following tree removal,
- Burning of waste and offal pits to reduce odours and disease spread,
- Clearing vegetation on marginal lands, such as gullies, and where the land has regenerated back to scrub or natives. Usually this is as a land preparation to generate new grazing areas for stock.
- Controlling wilding trees, broom and gorse,
- Burning of infected apiary equipment (e.g. hives).

<u>Horticulture:</u>

- Burning of prunings to remove the waste and restrict disease spread;
- The use of frost pits. These are small fires used to raise the night air temperature and therefore prevent frosts on fruiting buds and shoots.

<u>Forestry harvesting site preparation</u>

- Removal of slash following harvesting, usually prior to replanting of trees
- Clearing birds-nests (tangles of harvesting debris that is piled up due to being of no commercial value). Removing debris from the site also reduces the risk of the debris washing into streams and rivers and causing dams during storms; and also reduces the risk of forest ground collapse from decayed slash at the landing site. Burning large material rather than letting it rot down also provides more even terrain for the forested site.
- Clearing of grass or scrublands for new forest plantings (Fig. 14). The ash provides valuable nutrients back into the soil.

Figure 14: Using a helicopter for a prescribed burn in scrub fuel for forestry conversion. Waihopai, Marlborough (2014)

These reasons for why fire was used in New Zealand were pooled into the following major classes for subsequent analyses:

- Preparing land: controlling rank feed, regenerating seeds, opening up pasture lands,
- Controlling weeds,
- Disease prevention: killing soil pathogens, insects and fungi
- Recreation: campfires and bonfires, social gatherings
- Debris removal: clean-up of hedge clippings, green waste, stump removals, orchard pruning,
- Fuel reduction: Slash, reducing large amount of drift wood following large storm,
- Other: frost pots for warming the air, burning off offal pits

Figure 15 shows which landowners/managers use fire split into the various sector types. Figure 16 shows the proportion of land managers in each sector, using fire for a particular operation (colour coded). It highlights that fire is used across a range of operations by Arable cropping, Forestry and Sheep and Cattle sectors, but, is more selectively used in Horticulture and Specialist sectors (either mostly for removing slash, rubbish or hedgerow clippings).

Figure 17 shows the type of land operations being undertaken using fire as a tool regionally. A large proportion in each region was attributed to vegetative debris burns. This was a surprising result as the expectation prior to undertaking the survey was that a greater proportion would be conducting pastoral burning of grass and scrubland.

While only two sectors (Sheep and cattle and Horticulture) had sufficient data points for a regional analysis of this sort, it highlights a difference in burning practices by similar sectors according to their regional location. In the case of Horticulture, most of the burning relates to removal of vegetative debris (vine trimmings and prunings), although in Nelson and Hawkes Bay regions fire is also being used for removing invasive weeds and clearing or regenerating land. The Sheep and cattle farmers are using fire in different ways depending on location, with a larger proportion using fire to remove invasive weeds in the South Island than the North Island (particularly around Marlborough), and burning of rubbish occurring more in northern regions.

Figure 18 highlights the proportion (by region) for each of the four major fuel types (forest, scrub, grass, debris) being burnt. The overlaid pie charts are proportionally sized indicating the number of fuel selections (n) made by respondents in a region. Because of the possible multiple answers per respondent, the type of fuel used for burning cannot be expressed as a proportion of respondents. This again emphasises the significant amount of debris burning being undertaken in all regions of the country. In addition, it is evident only a relatively small amount of forest is burned compared to other vegetation types, which might reflect that most productive land has now been cleared of forested vegetation. Scrub burning is occurring in the lower North Island, the Bay of Plenty region, and also across the South Island (especially Nelson/Marlborough).Grass is a major vegetative fuel being burned across the South Island, especially lower regions, which in many cases is likely to be tussock burning.

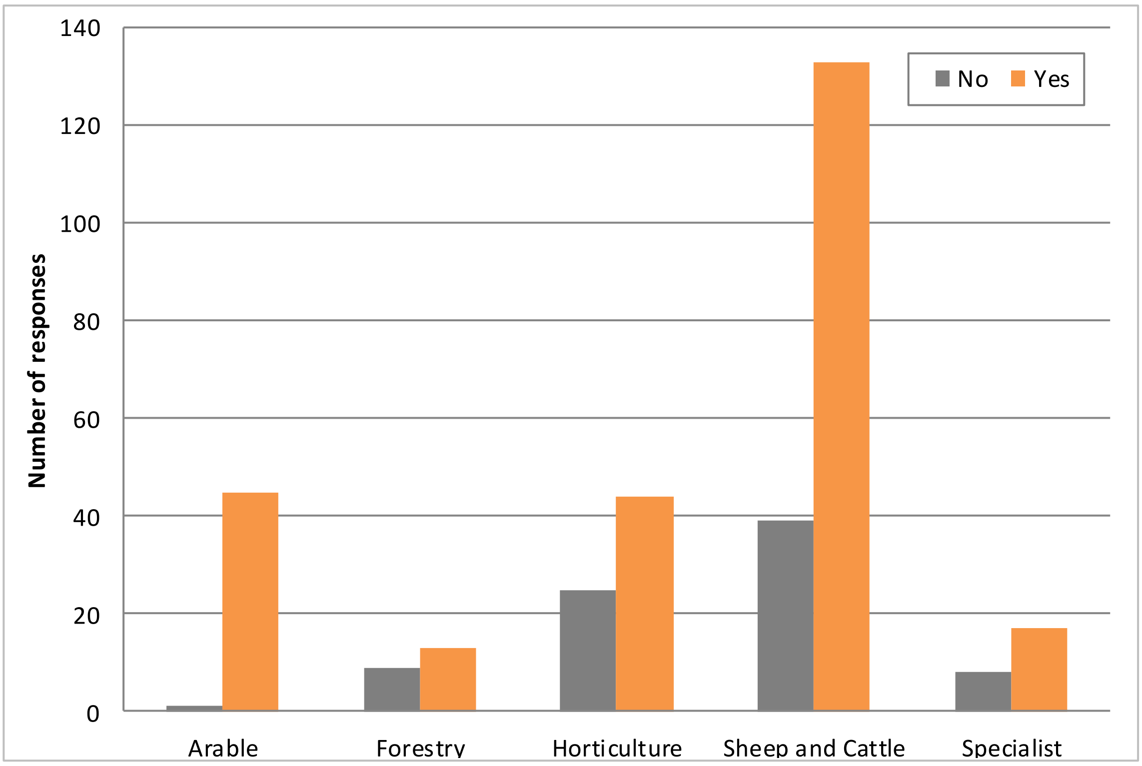

Figure 15: Number of Land owners/managers by sector who stated whether they used fire or not

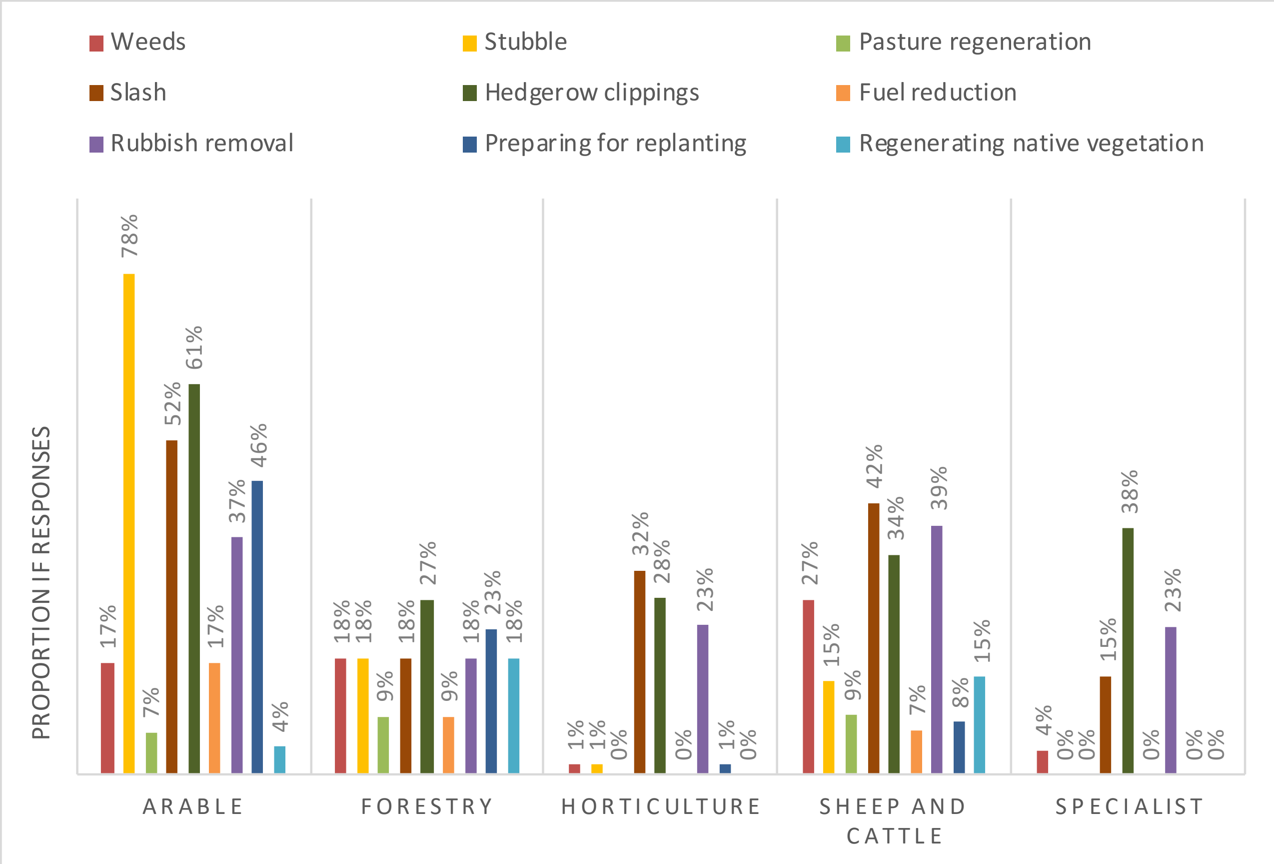

Figure 16: Main reasons for using fire as a land management tool by sector

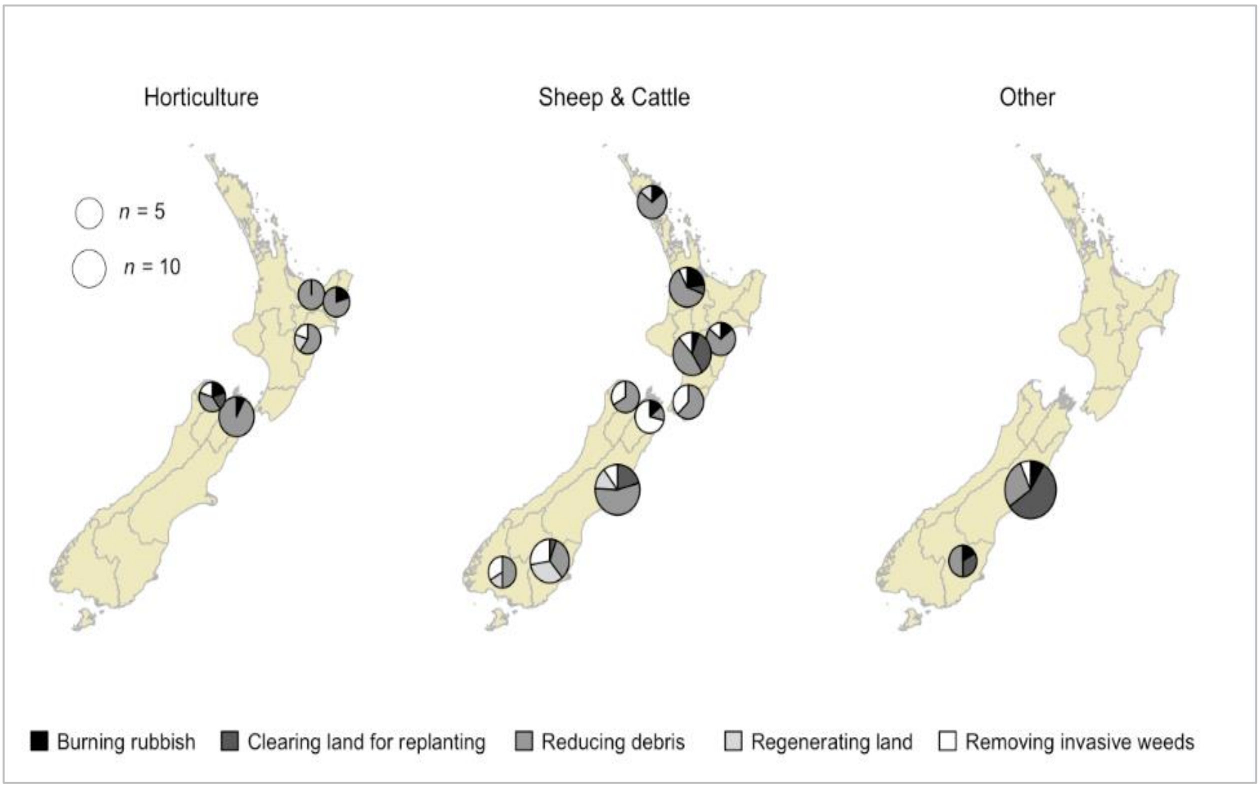

Figure 17: Use of fire regionally for major land management groupings

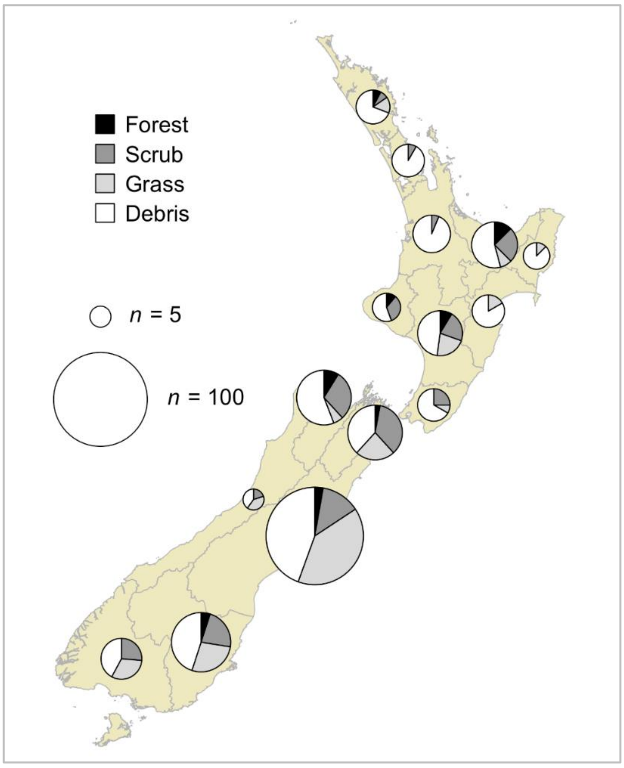

Figure 18: Fuel types most commonly being burnt across the country

When is fire being used?

Land managers were asked to indicate the last time they had used fire in the management of rural land. The majority had used fire within the past year (Fig. 19). While all respondents from the arable sector had used fire to manage land, and all within the past decade, a quarter of those from both the specialist and horticultural sectors had never managed land using fire.

Most burning operations occur once per year or less. Several land operations are requiring land managers to burn multiple times per year, most notably rubbish clearing, clearing of large plant debris (slash and stumps etc.) and hedgerow clippings (Fig. 20). The timing around when land managers are using fire varies by sector, and also by the operations undertaken. The 'heat maps' on the following pages (Fig. 21) give an indication of the seasonal level of fire use by sector for each of the nine operations:

- The Sheep and cattle sector are using fire throughout the year to manage invasive weeds; and the Horticultural sector has a heavy use of fire to combat weed infestations during spring.
- Arable crop stubble (Fig. 22) is not burnt in winter and spring, but burning is being undertaken on crops by more than just the Arable sector.
- Removal of rubbish is undertaken throughout the year by all but the Forestry sector, who appear to clean up in autumn/ winter.
- Preparation of land for replanting using fire occurs in the summer and autumn months.
- The Sheep and cattle sector are using fire to regenerate pastureland throughout the year; interestingly Specialist land managers are undertaking this practice solely in spring.
- Removal of large plant debris occurs throughout the year.
- Forestry undertake slash burning solely in the cooler months during autumn and winter, likely prior to replanting before spring.
- Hedgerow clipping burns occur throughout the year, as does fuel load reductions by the Sheep and cattle sector.
- Vegetative regeneration burns are very sector dependant. Only two sectors are undertaking this practice: Sheep and cattle during the cooler months, and Arable cropping during the warmer months.

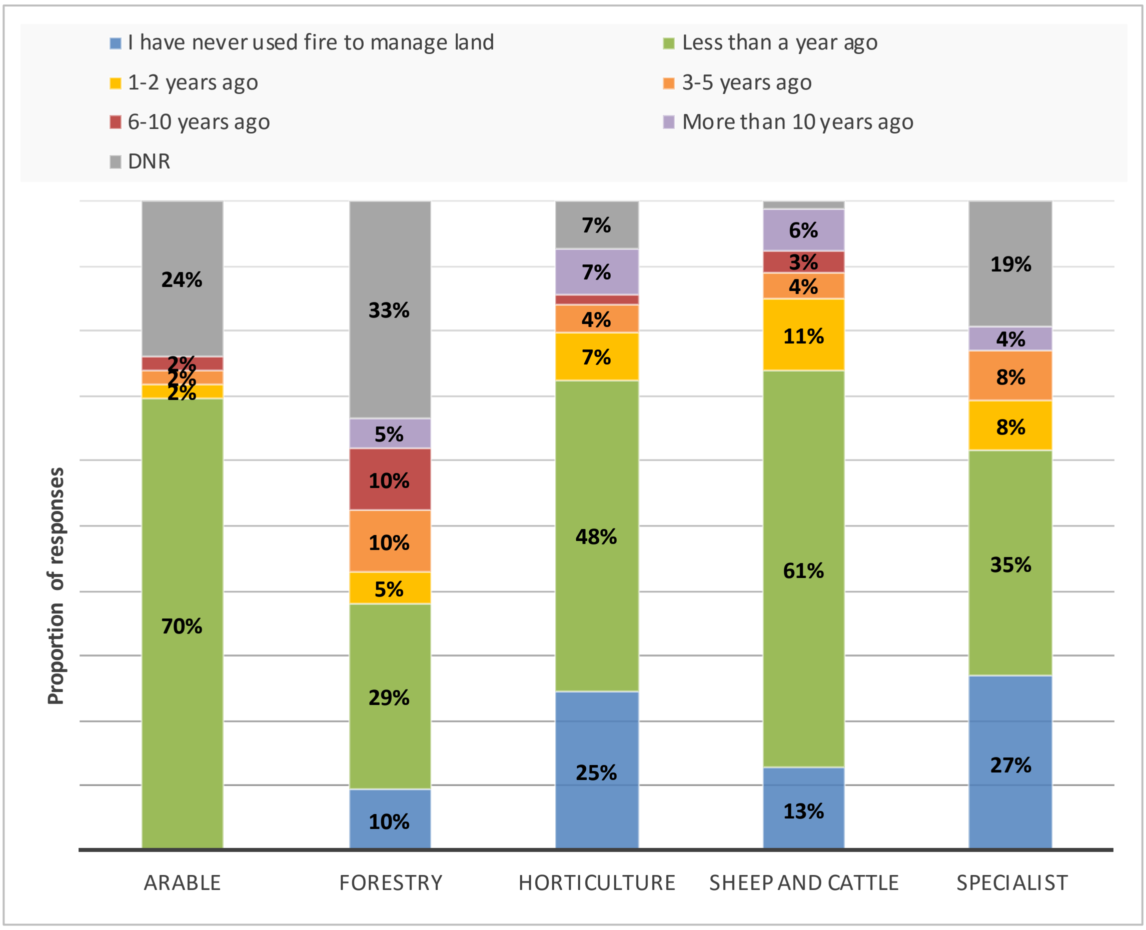

Figure 19: The last time fire was to used manage land by sector type

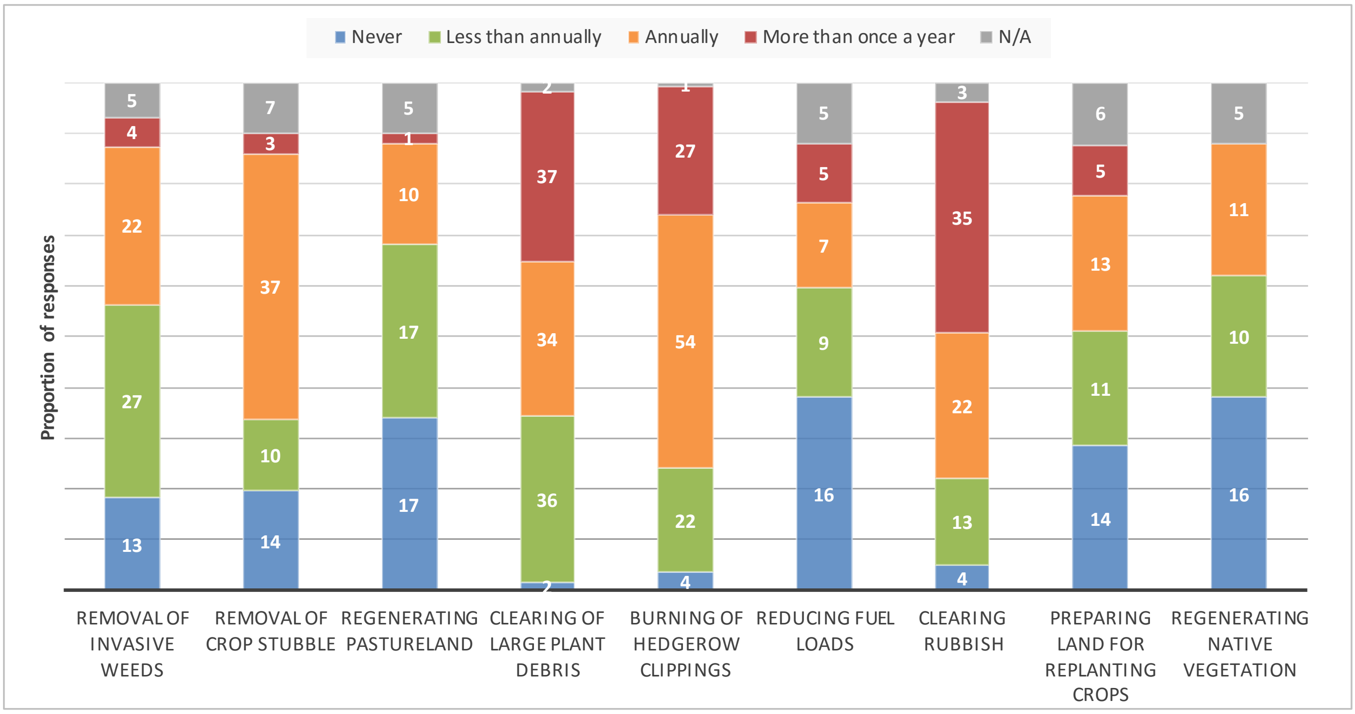

Figure 20: The frequency of burning by the various land operations

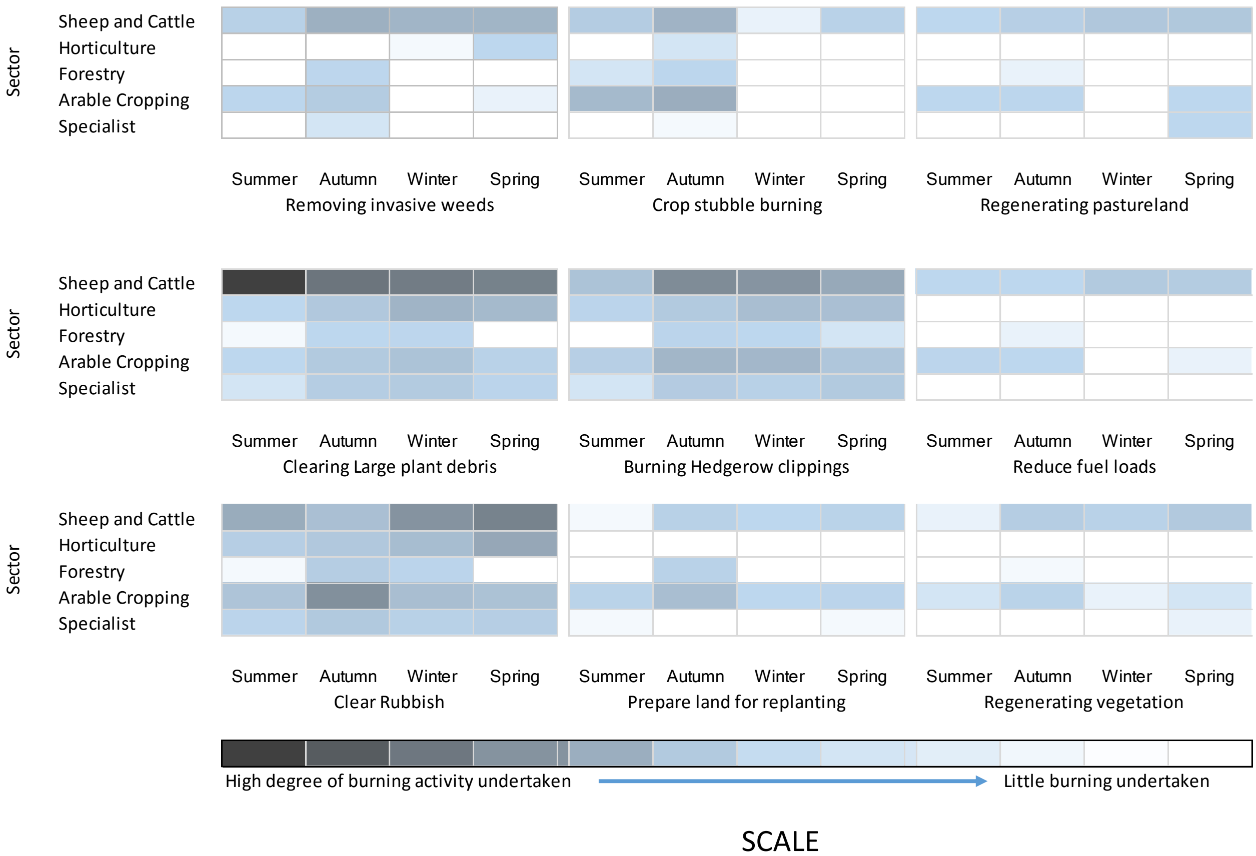

Figure 21: Heat maps showing the timing around various activities for use of fire for the various sectors

Figure 22: Stubble burn off, Darfield, Canterbury (2010)

How much area is being burned?

Figure 23 shows the proportion of total reported land being burned by respondents for each of the management activities. Although the purpose of most of the fires was to remove vegetative debris (Figs. 21 & 23), these involved a small area of land compared to activities such as burning of crop stubble and invasive weeds, crop preparation and pasture regeneration.

Most rural sectors who used fire recently typically burned areas less than one hectare (Fig. 24) of which most were pile burns of vegetative rubbish and debris; however areas burnt did range between 1 and 100 ha or more. Those burning less than one hectare tended to be undertaking pile burns, with a high proportion of Sheep and cattle (57%) and Horticultural (26%) land managers undertaking this type of burning in comparison to other sectors.

The Arable cropping and Forestry sectors tended to be the sectors undertaking the larger area burns of between 50 ha to more than 100 ha (Figs. 25 & 26), in contrast to the Horticultural and Specialist sectors who were burning less than a hectare (most probably pile burns).

The average size of the majority of burning piles are more than ten cubic metres (Fig. 27). This represents a large scale of vegetative matter being burned through the use of fire. Figure 28 shows the size of pile burnt by sector. Specialist and Horticulture sectors are mostly carrying out smaller pile burns (see example in Fig. 29), while as expected in Forestry there are much larger piles being burned.

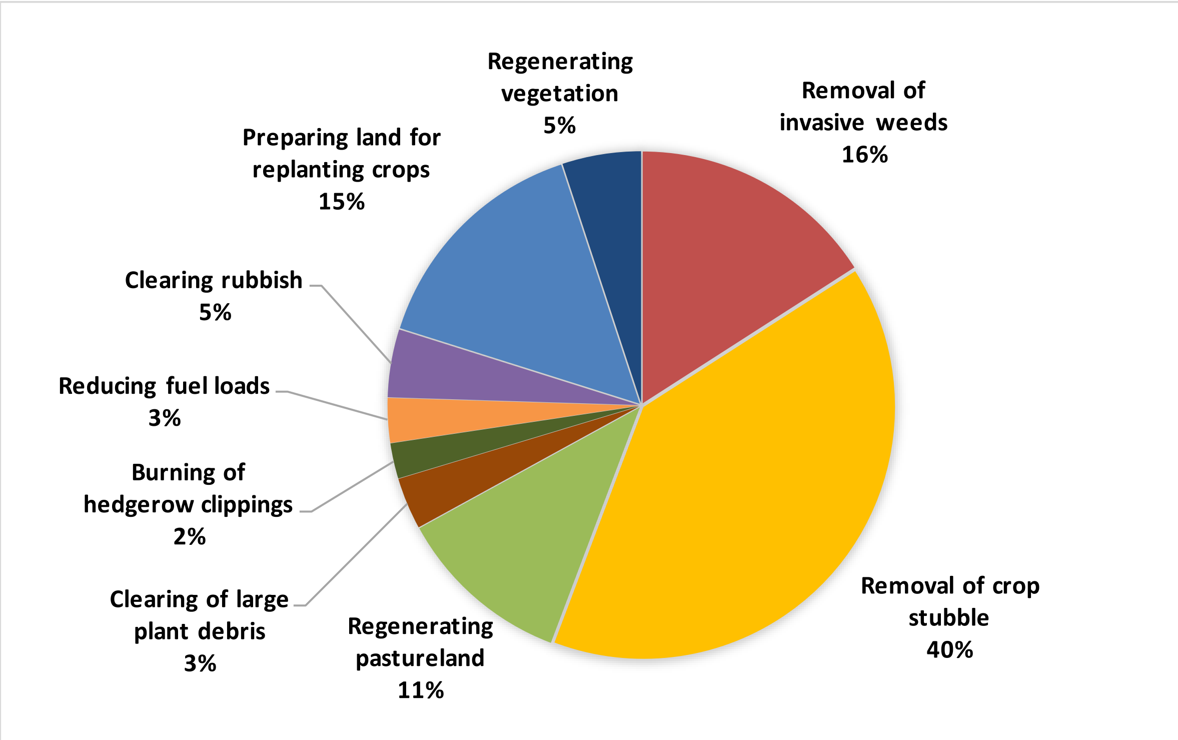

Figure 23: Proportion of the total reported area burned in the past five years for different land management activities

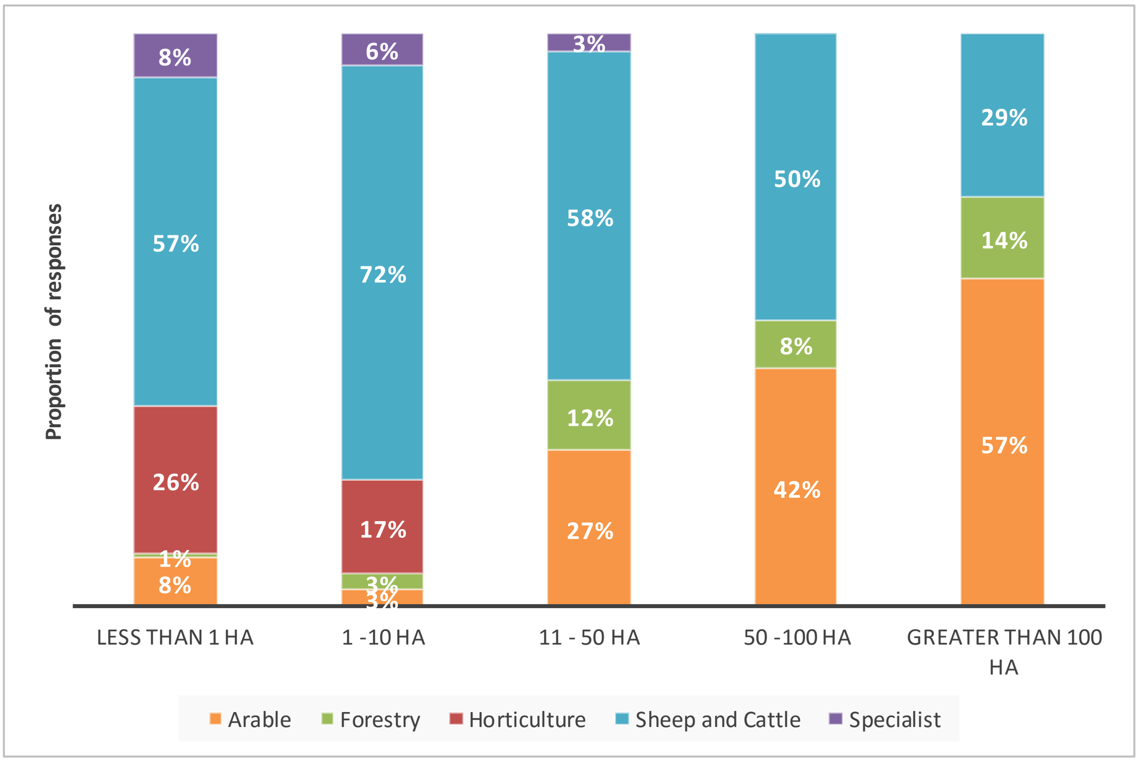

Figure 24: Area cleared in the last prescribed burn, by sector type (n = 229)

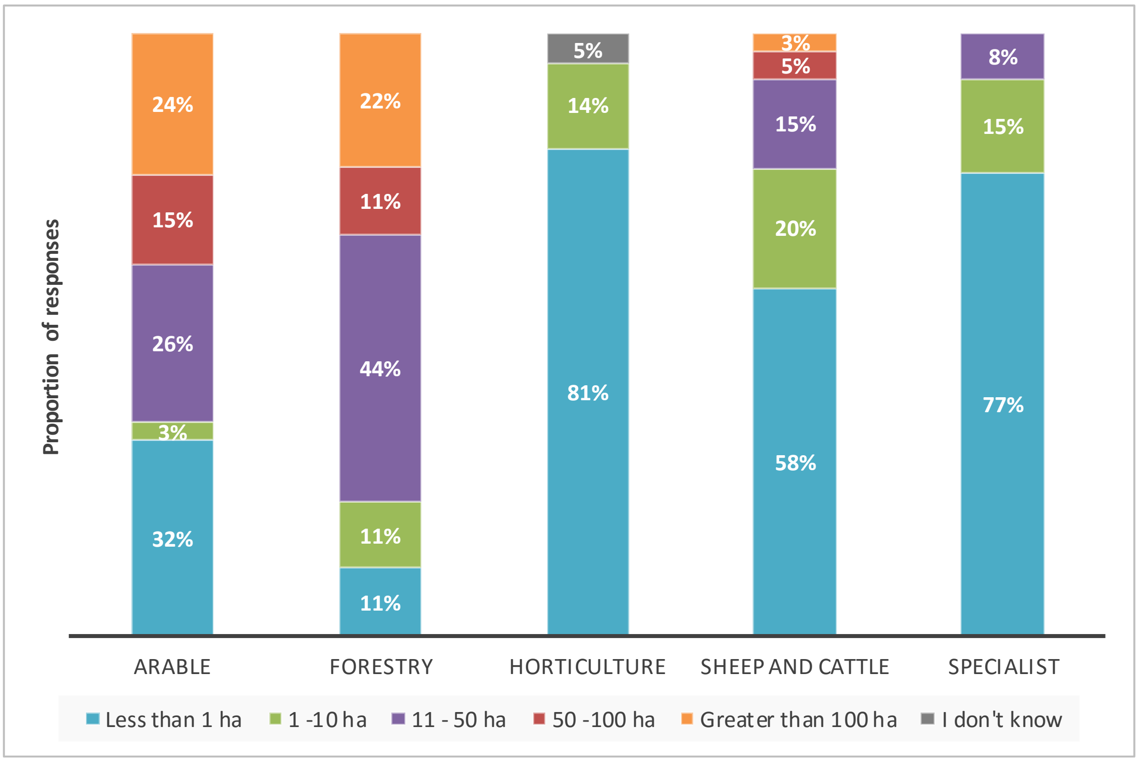

Figure 25: Area of the last prescribed burn by each sector (n = 229)

Figure 26: Large scale prescribed burn conversion of retired sheep farm to forestry. Tordarroch, Marlborough (2013)

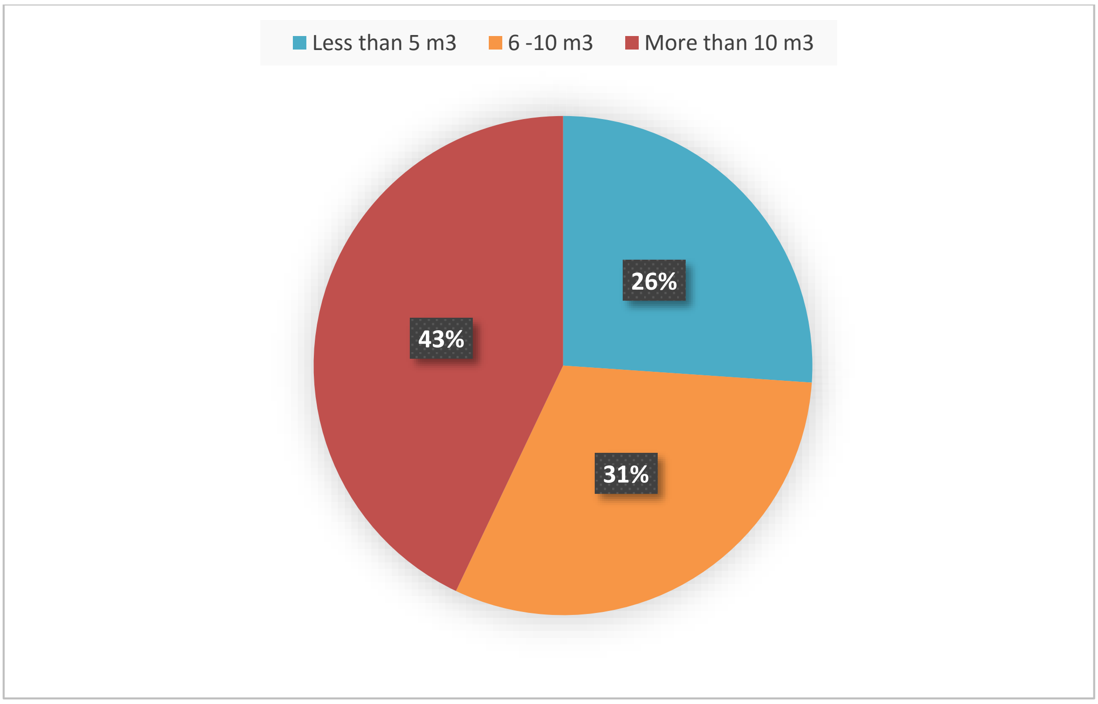

Figure 27: Average size of pile burns across all sectors

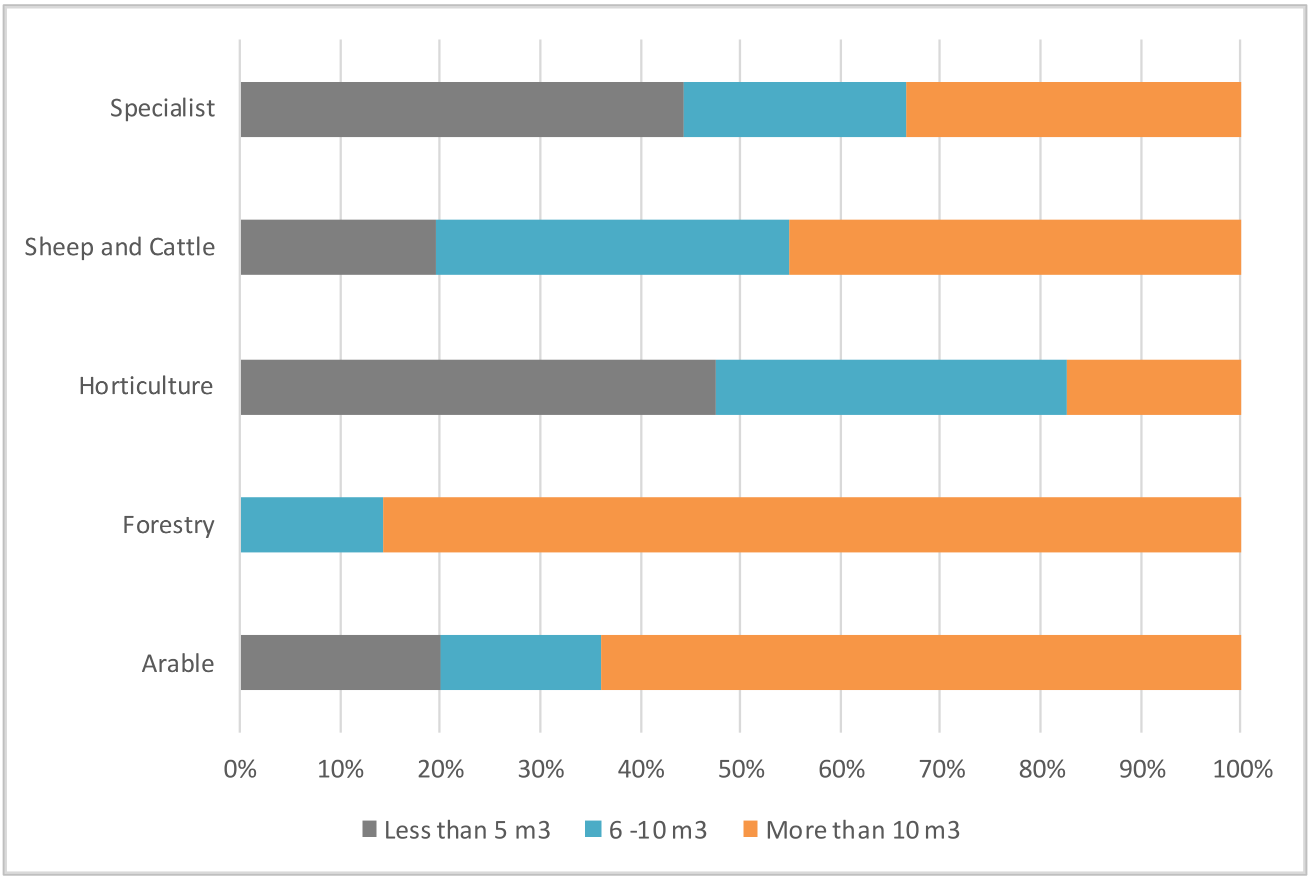

Figure 28: Sizes of piles by sector type.

Figure 29: Pile burns continue to burn into the night, Queenstown (2012)

How are practices changing over time?

On average, respondents have lived for 32 ± 0.8 years in their region (mean ± standard error, n=674). The majority of fire users indicated they **burnt less land area** today compared to 10 years ago (Fig. 30), and half felt they burnt the same or less area compared to 5 years ago. Respondents also indicated that they were conducting **fewer burns** today compared to 10 years ago (Fig. 31). Half felt they carried out the same number or less compared to 5 years ago. They also felt that these were trends that will continue in the future.

Do users have adequate knowledge and experience?

Confidence level around using fire

The level of confidence that land managers have in their ability to use fire to manage land differed significantly depending on whether they were currently using fire or not, with those who were burning [$\chi 2(4, n=171) = 43.437$ ($p<0.001$)], and also who had used fire more recently [$\chi 2(20, n=171) = 52.835$ ($p<0.001$)] being more likely to feel greater confidence in using fire as a tool. There were no differences found between the level of confidence and other demographic factors such as age, gender, where they lived or how long they had been a land manager. The area of land being managed, and the land management sector did not have a significant impact on confidence levels in using fire to manage land.

Adequate policies and guidelines

Those who were currently burning felt that there were adequate guidelines and policies in place to manage rural fire and more than those who were not using fire [$\chi 2(1, n=159) = 18.012$ ($p<0.001$)]. People who last used fire on their properties within the past two years were more likely to support there being adequate guidelines in place than those who had burnt land less recently, where the yes/ no result was more evenly split [$\chi 2(5, n=159) = 19.847$ ($p=0.001$)]. Those who were more confident in their ability to use fire also felt adequate policies were in place to manage rural fire [$\chi 2(4, n=159) = 16.574$ ($p= 0.02$)]. There was also a slight difference by region in the perceived level of adequacy of guidelines [$\chi 2(17, n=213) = 27.105$ ($p=0.057$)], with the differences outlined in Figure 32 overleaf. There were no significant differences between rural fire personnel and the land managers themselves in whether they thought that guidelines and policies were adequate, nor between different age groups, although males were more likely to agree with there being adequate guidelines and policies in place than females [$\chi 2(1, n=213) = 8.331$ ($p=0.004$)]. Amongst land managers, no significant differences were found in perception of adequate guidelines based on area of land, length of time as a land manager, or sector.

Adequately informed on how to use fire

Similar results were found for the question of whether respondents felt that fire users were adequately informed in the safe practice and effective use of fire to manage land. As expected, those who were currently burning felt that they were adequately informed more than those who were not using fire, but this was not overwhelmingly significant: [$\chi 2(1, n=157) = 4.149$ ($p= 0.042$)]. The length of time since prior burning also had an influence on the perception of knowledge, with those who had not used fire for over a decade less likely to agree that rural land managers were adequately informed: [$\chi 2(5, n=157) = 12.992$ ($p=0.023$)]. There were significant differences in both age [$\chi 2(7, n=157) = 13.021$ ($p=0.072$)] and gender [$\chi 2(1, n=157) = 6.083$ ($p=0.014$)] , with more older respondents perceiving fire users were adequately informed, and males feeling they were adequately informed more than females. Those land managers indicating they were “very confident” in using fire were also more likely to state they were adequately informed; while interestingly, those who were “quite confident” were less likely to agree they were adequately informed [$\chi 2(4, n=156) = 10.946$ ($p=0.007$)]. This indicates that those in the “quite confident” camp may be wanting to understand more about effective and safe practices, and could be good to target for burn training. There were no significant differences found between land managers for this aspect based on region, sector or area of land managed. Where large variation exists between regions, as shown in Figure 33, this is because in some cases the response is skewed by only a small number of responses per region.

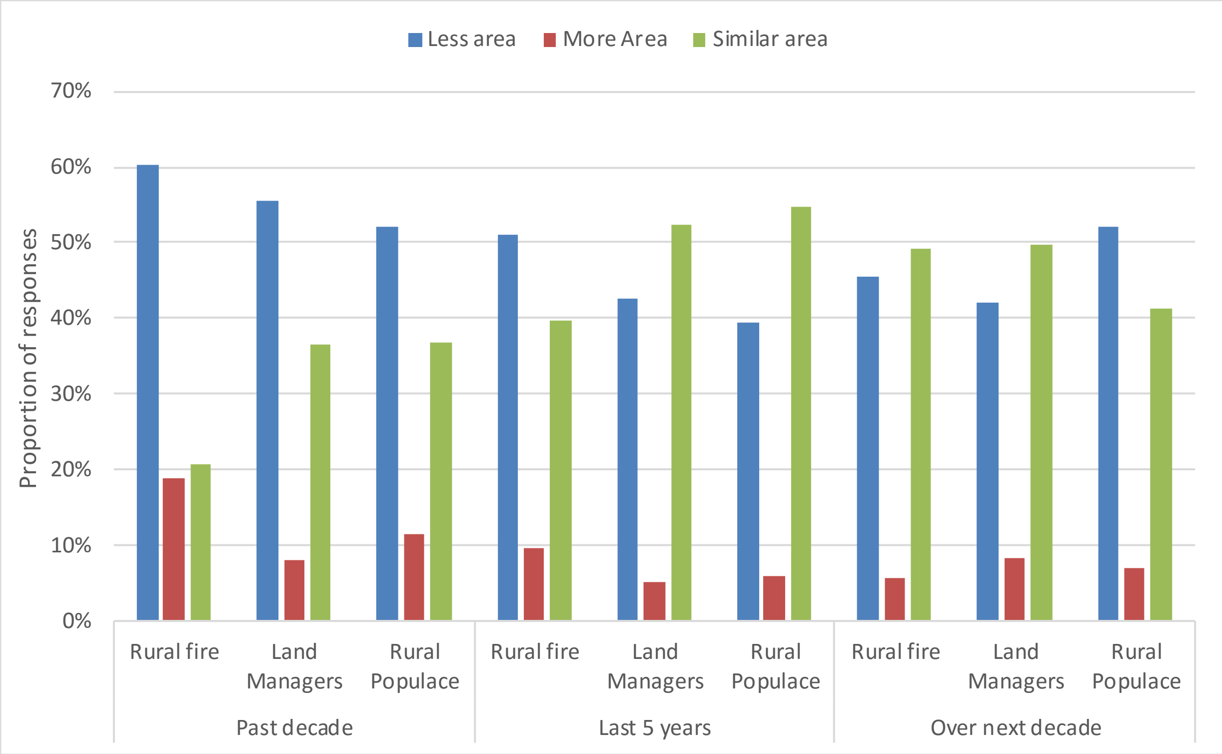

Figure 30: Estimation of changes in land area being burned

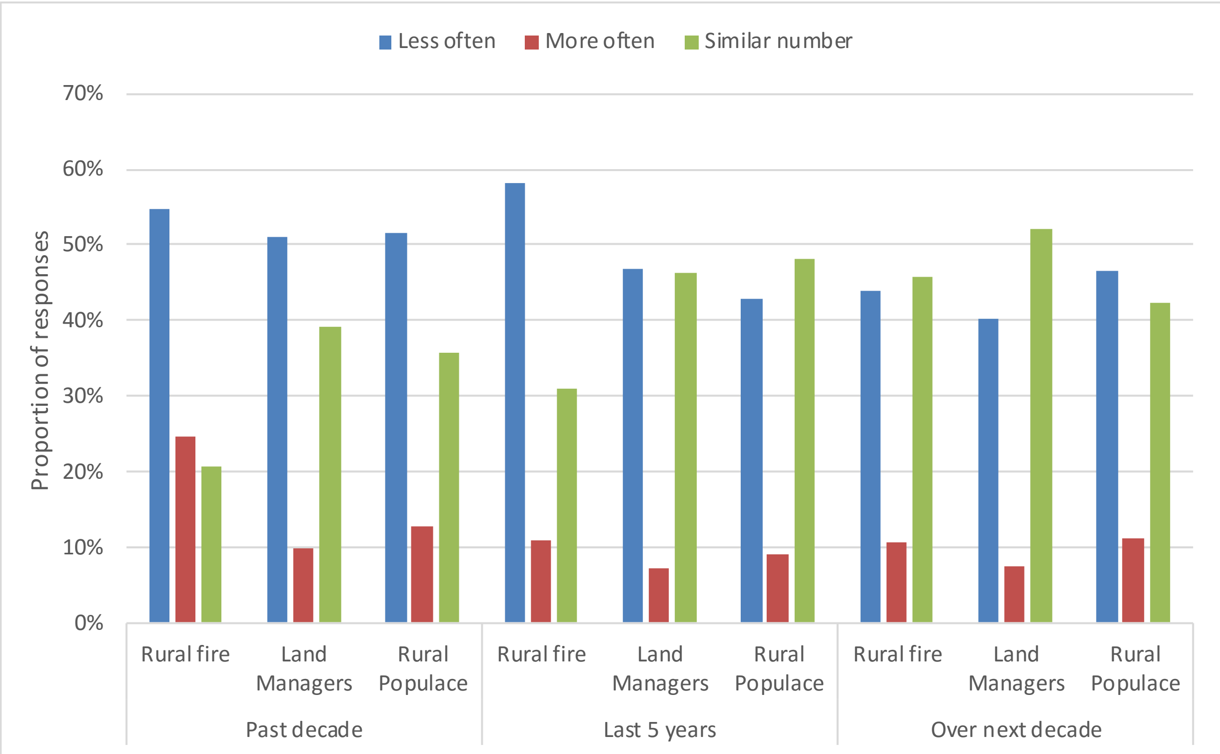

Figure 31: Estimated frequency of burning over time

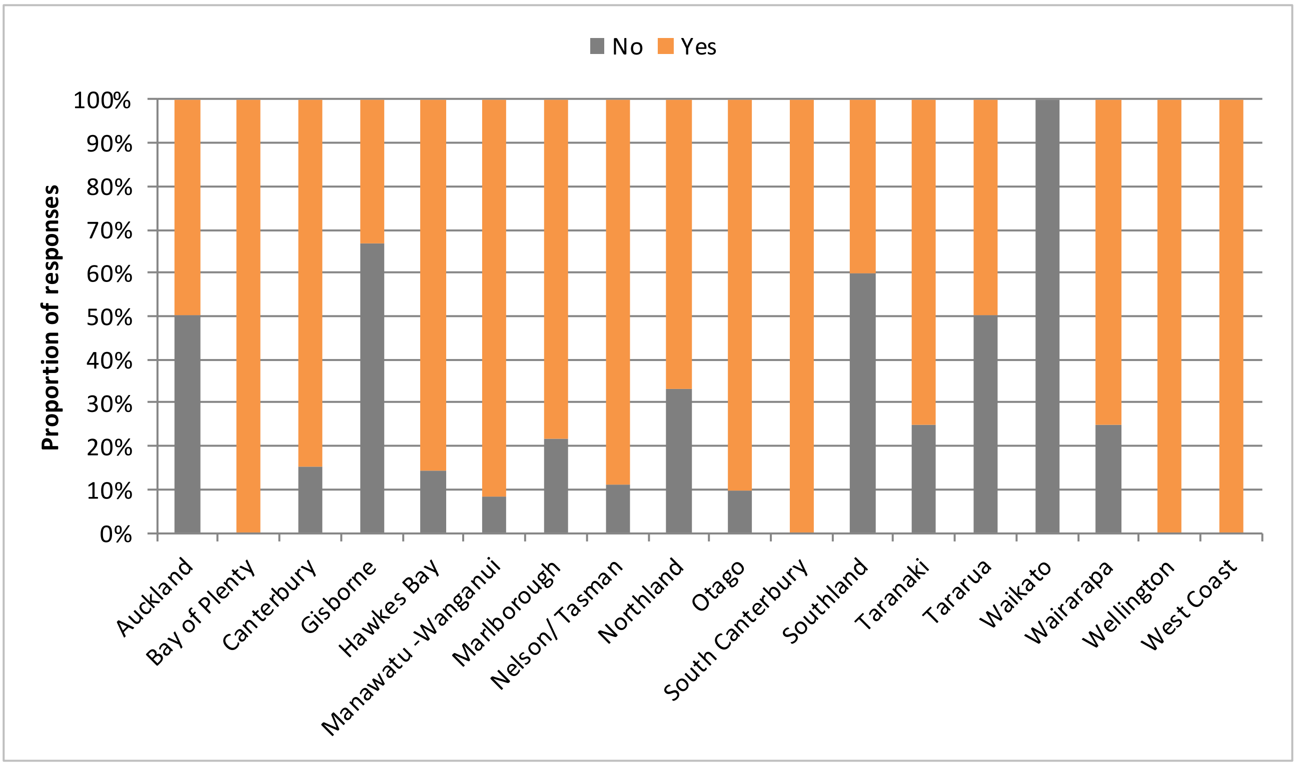

Figure 32: Land managers' views on whether they believe they have adequate policies and guidelines in place to manage their land

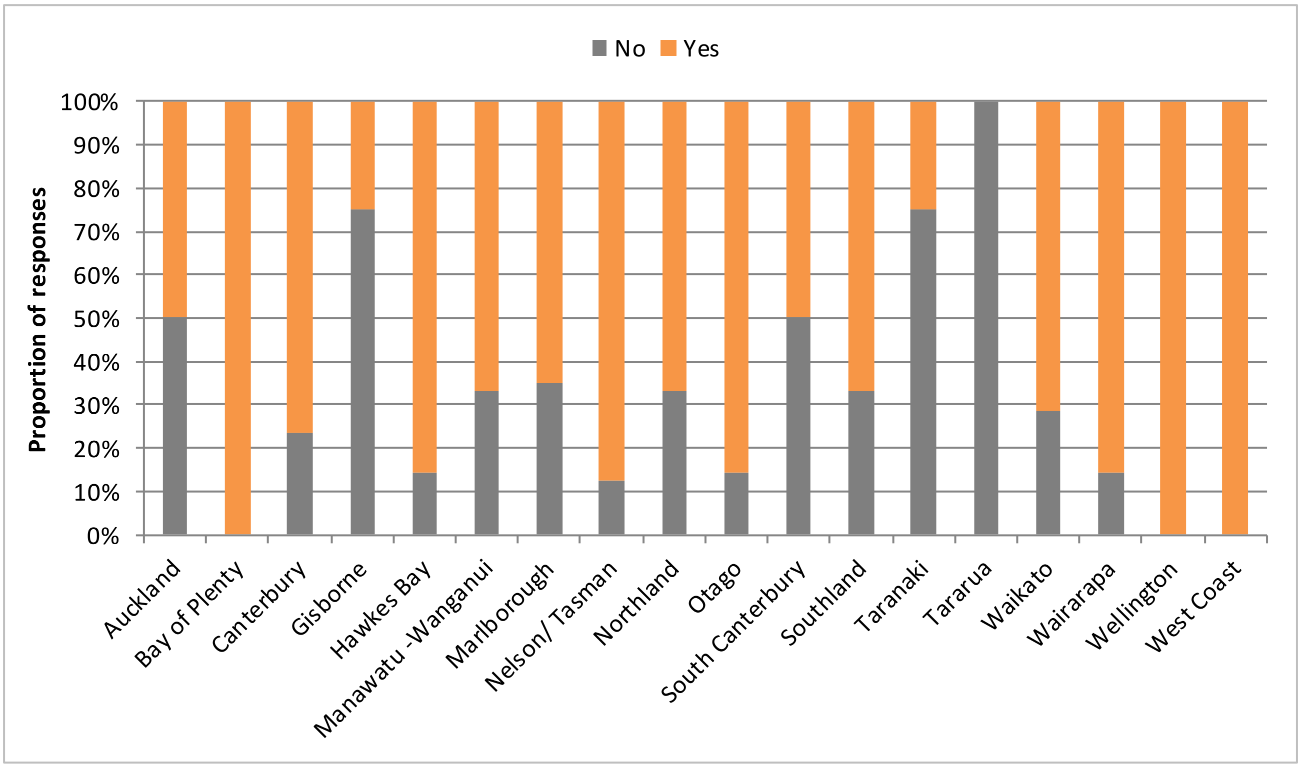

Figure 33: Land managers' views on whether they believe they are adequately informed regarding the safe and effective use of fire as a land management tool

Research aim 2: What is the range of stakeholder opinions concerning benefits and risks of these practices?

Do people think fire is a good option?

A central question within the study was based on respondents' opinions about whether fire was a good option for managing land. For the Rural Populace, this was a generic question about any land; but for land managers, we asked specifically about the land they were managing. Rural fire officers weren't asked this question, as the management of land by fire is central to their role. Land Managers were in greater agreement with the statement of fire being a useful tool to manage land (46%) compared to the Rural Populace (only 29%). However a large proportion of respondents from the Rural Populace (42%) chose not to answer this question compared with the number of Land Managers who did not (33%). The reasons for not answering this question are unclear, but as people who did not respond came from all regions this would indicate that perhaps they did not feel strongly enough one way or the other.

The main aspects that determined whether the respondents felt that fire was a good option for managing land included whether the respondent currently used fire as a tool ($p<0.001$) (those who were using fire presently felt it was a good option), and how long they had lived in the region ($p<0.001$) (a higher proportion of people who were long-term residents felt fire was a good option) and gender ($p<0.001$).

There was a significant difference between males and females in whether they thought fire was a good option for managing rural land (Fig. 34). Interestingly there was also a weak significant difference for age ($p <0.01$) with older people being more likely to feel that fire is a good option.

The majority of respondents saw it as a very good option, with particular support for the use of fire on land managed for sheep and cattle production and arable cropping, with less clear support for use of fire on properties used for other purposes. A clear difference in support for the use of fire was seen between different sectors ($p<0.001$) (Fig. 35).

The more confident Land Managers felt in their ability to use fire, the more likely they were to think that fire was a good option to use in land management ($p<0.001$). In addition, those managing larger parcels of land ($p=0.001$), and those that were currently using fire to manage land ($p<0.001$) had significantly greater support for fire as a tool and, respectively.

However, amongst the Rural Populace, there was no significant difference in opinions about whether fire was a good option depending on the length of time they had lived in the region. Nor were their differences based on whether the rural populace were currently using fire on their property to manage land or not. Rural residents living in larger villages showed no differences compared to those living in or near more remote villages in their opinions as to whether fire was a good option to manage land ($p=0.056$).

Reasons for why fire was used or not

Productive land owners/managers who use fire
Reasons behind the support for fire as a rural land management tool by productive land managers differed based on whether they were currently using fire to manage their land or not.

Fire was seen for some as being the ONLY effective option, and a good option due to no practical alternatives. It was seen as safe, practical and clean. Productive land managers who <u>were</u> using fire thought it was a good option due to:

- Being a natural tool;
- Being proven and traditional;

- Providing a quick and immediate solution;
- Removing fuel loads;
- Returning nutrients back into the soil;
- Reducing weed and disease spread;
- Keeping the property tidy;
- Being cost effective;
- Being able to open up tussock country;
- Effectively managing the size and volume of vegetative waste present; and
- Combatting scrub reversion.

However, some Land Managers currently using fire also thought it was not a good option because of:
- The impact of burning on their neighbours;
- The location of their property (being too close to town or bounding a native reserve);
- Being bad for the ecology (soil, flora, fauna); or
- Because they preferred to compost material rather than to burn it.

Productive land owners/managers who do not use fire
Productive land managers who <u>were not</u> using fire thought it was a good option due to:
- Being cost effective;
- Having less impact than other alternatives (in terms of chemicals and soil disturbance) and recognised that it can be an effective tool *when managed well*.

However, those not currently using fire did not do so mainly due to a lack of need to burn, or due to the risk from either escape or potential litigation from escape.

The Rural populace
The Rural Populace had very similar reasons to productive and managers who used fire, for thinking fire was a good option. In addition to the reasons given by Land Managers, the Rural Populace also mentioned:
- The regeneration of land;
- Sterilising the soil; and
- The ease of use of fire compared to other options, including that using fire reduced the risk of worse outcomes.

However they had very different reasons around why they thought fire was not a good option. There was much more concern from the Rural Populace around smoke impacts, inconsiderate or bad burning practices, and ecological or environmental impacts. They were also concerned about the negative aesthetics of burnt landscapes.

A comparison of two high fire-use regions:
<u>Canterbury (central eastern South Island)</u>: This region's land managers were very supportive of the use of fire although they also recognised risks, which mainly pertained to the risk of escape, potential loss of biodiversity, and the impacts from smoke pollution (reduced road traffic visibility, neighbour inconvenience). The benefits were, however, seen to outweigh these risks, particularly due to the fast, clean and efficient manner in which fire can be used to reduce particularly stubble and hedgerow trimmings (compared to mulching, which was seen as prohibitive), and the ability to reduced cultivation and thus the use of tractor fuel. Some farmers in the high country considered it essential for removing snow grass and combatting scrub and weeds. In contrast, while the rural populace in Canterbury outlined similar benefits to land managers for using fire as a land management tool, it appears that there are also significant risks that they feel should preclude its future use, in particular effects of smoke on air pollution and public respiratory health. While some rural populace considered fire to be a traditional tool, others

felt this was an outdated and unnecessary practice given modern tillage options, and that there "must be a better way". Those that still supported the use of fire did so based on quick and relatively smoke-free stubble burning more than other fire uses.

Nelson: This region's land managers all saw the benefits of fire as a land management tool, with none indicating that fire was not a suitable tool for use on their land. The support for fire was due to it being a safe and practical tool that regenerated grass quickly, and destroyed disease. Perhaps tellingly, the land managers saw there was "no alternative cost effective solution" to removing trash and unwanted materials, with one stating: "Fire is cost effective and the only practical way to get rid of all our unwanted [rubbish]". The rural populace accepted the need for fire due to the amount of tree debris and disease present, but were more concerned with the manner in which fire is being used by land managers in the district. Comments indicate that along with green vegetation being burnt causing significant levels of unnecessary smoke, land managers are also burning non-vegetative waste on these fires, including plastic, rubber and household waste along with chemical containers. One rural resident commented that they were "opposed more to the way certain neighbours use fires rather than to fire itself".

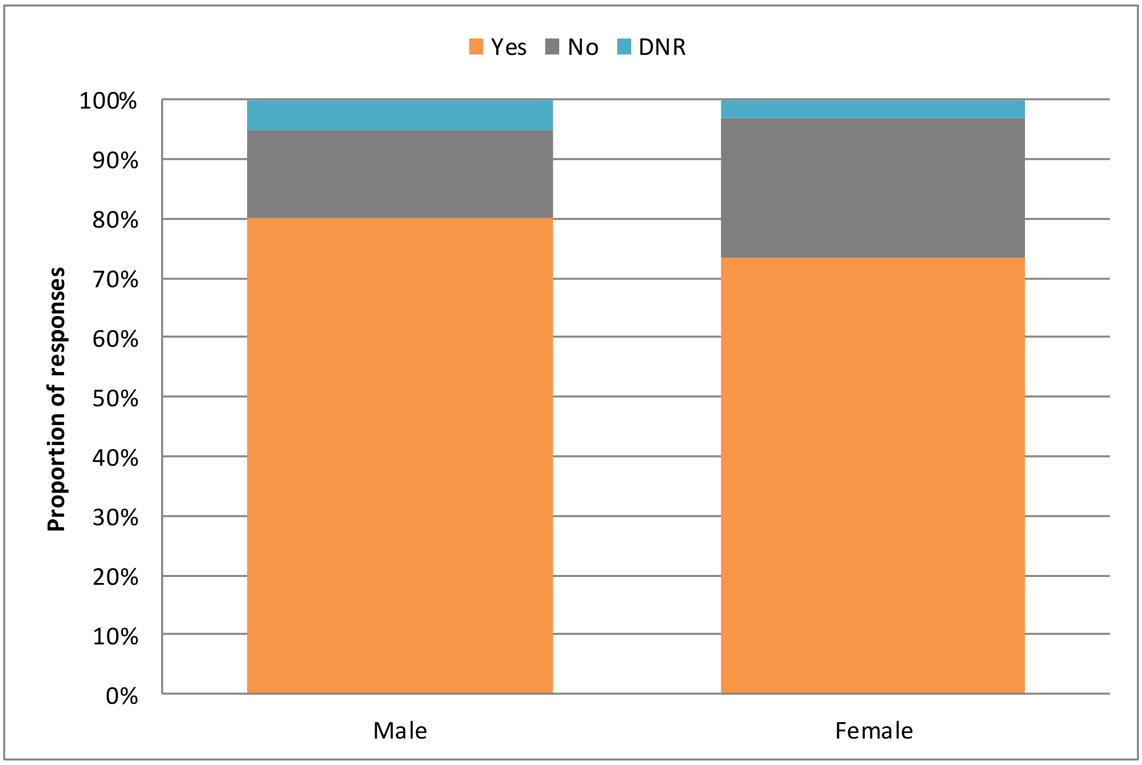

Figure 34: Responses by gender to the question "Is fire a good option for managing land?". DNR indicates "did not respond"

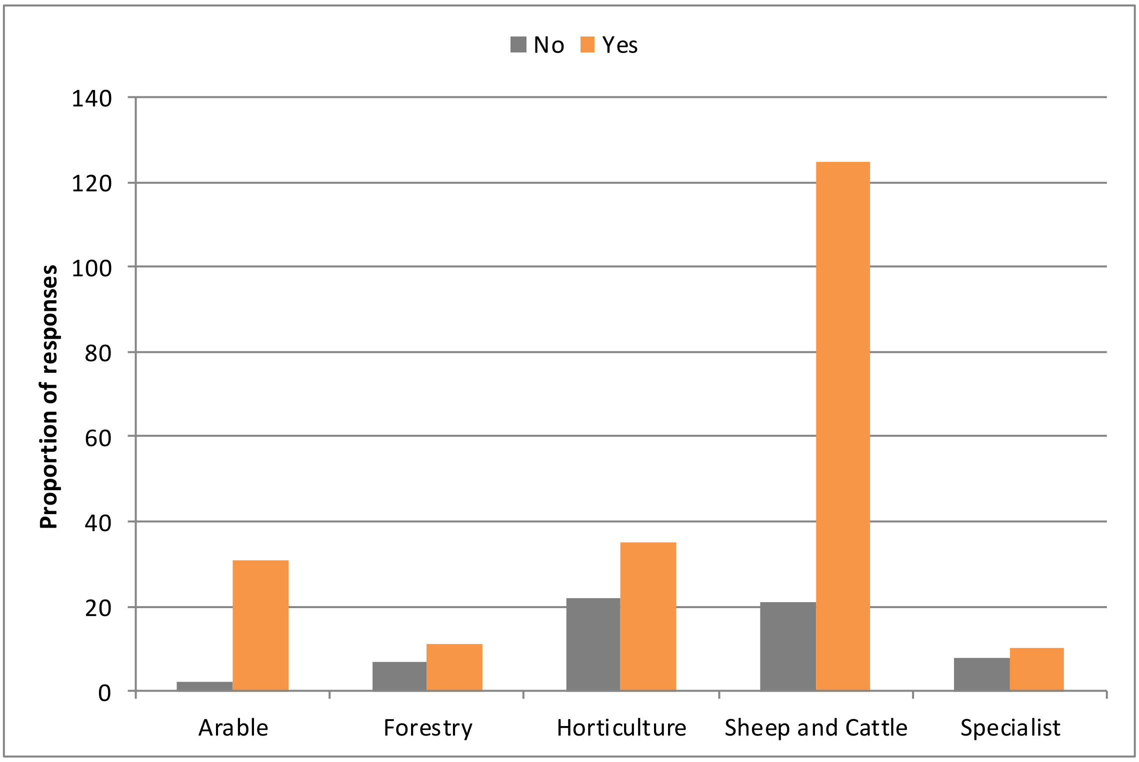

Figure 35: Sectoral responses to the question "Is fire a good option for managing your land?"

What influences someone to use fire?

A binomial general linear model tested the relationship between certain factors (such as gender, age, type and years spent in region) against if the respondent used fire to manage rural land, to determine if and what variables could explain why they used fire.

As a result of the backwards selection procedure (Table 3), the final model contained 'gender', 'type', 'years in region' and the 'gender × type' interaction as explanatory variables; however the type of respondent was the most significant variable (in other words, being a rural land manager significantly increased the probability that you would be using fire on your rural property).

Table 3: Results of backwards binomial regression model. SE relates to the standard error of the mean; z provides the test statistic and P provides the level of significance

Coefficients	Estimate	SE	z	P	
Intercept	1.17	0.44	2.667	0.008	**
Gender	-0.36	0.45	-0.791	0.429	
Type	-2.96	0.52	-5.739	< 0.001	***
Years >10-20	-0.04	0.42	-0.097	0.923	
Years >20-30	0.13	0.45	0.278	0.781	
Years >30-40	1.13	0.54	2.106	0.035	*
Years >40-50	0.56	0.48	1.171	0.242	
Years >50-60	1.03	0.48	2.157	0.031	*
Years >60-70	0.69	0.7	0.979	0.327	*
Years >70-80	0.20	1.00	0.202	0.840	
Gender × type	1.50	0.64	2.352	0.019	*

How do various groups perceive the risk from fire use?

Responses from the survey showed that fire remains a preferred method for managing rural land due to both tradition, and being particularly cost effective. The major benefits seen from the use of fire for this practice is in the timeliness, and in some cases the low perceived risk of escape. However risks to the practice include:

- The potential for over-burning, and the associated risks of having to control and monitor a moving fire.
- The high degree of smoke generated, and the likely negative public response to this.
- The significant potential for re-ignition given a sudden wind change.
- Temptations to turn hedgerow clippings and slash into a larger rubbish fire, and introduce items such as tyres and other material that should not be burnt.
- Negative visible amenity of high country burnt landscapes, and public disapproval for altered visual amenity.
- The potential for high costs (loss of vulnerable ecosystems, and loss of life and property), and potential for high consequences (liability) from escape.
- P The neighbouring land being more likely to be DOC reserve (due to tenure reviews), or visible to residential subdivisions (due to encroaching development into traditionally rural landscapes).

Level of risk associated with using prescribed burning

Those who have knowledge or experience with using fire in land management (Rural Fire officers and Land Managers) were asked to assess the level of risk associated with use of prescribed burning. Each of seventeen categories were given a ranking from 1 to 10 by the respondents, where 1= very low risk; 10 = very high risk (Fig. 36). Respondents saw greatest risk from the fire escaping, creating public nuisance or annoying neighbours, followed by the potential for the fire to escape, reigniting at a late date, and costing more than anticipated. Rural fire officers also saw a sizeable risk in loss of biodiversity and destroying native ecosystems, and the potential for litigation and human injury. Overall, rural fire officers perceived a higher level of risk compared to land managers for each of the seventeen categories. Interestingly, respondents didn't class the loss of human life as a "high risk" compared to the other categories, despite several high-profile deaths from prescribed burning in recent years.

What are the main concerns if a fire were to escape onto your property?

The largest concerns across **all respondents** (Land Managers, Fire Officers and Rural Populace) were in the risk to neighbouring properties and loss of assets (Fig. 37). There were some differences between the different respondents concerning the level of risk they saw about fire escaping onto their properties. For example, the rural populace (grey) had more concern for stock loss than fire officers (orange).

Surprisingly, there was a very low level of concern about causing air pollution, which contrasts with the public concerns highlighted in the media. (This may indicate the media are highlighting the concerns from a minority group of the public but not the general public feeling).

Risk of fire to ecosystems

Land Managers and Rural Fire officers were asked whether they felt fire had a positive, negative or neutral impact across a range of nine ecosystem service factors, including cost (Fig. 38). Fire is seen as positive for:

- Removal of woody weeds,
- Increasing the soil productivity – disease control or to get crops in the ground quick following harvesting; but not so much for recycling soil nutrients.
- New growth for stock due to land regeneration,
- A cost effective tool.

There was also a large difference between the two groups around cost, where land managers STRONGLY felt it a positive thing, but fire officers said it was only somewhat positive.

However, the perceptions around the impact of fire on ecosystems were largely negative, particularly in terms of the impact on air and water quality, and biodiversity. Surprisingly, despite very little support for positive benefits on water quality, water quality appeared as predominantly neutral rather than negative. There are also significant differences (p =0.001) between Land Managers and the Fire Officers on perceptions around the impact of fire on water quality in particular.

Reducing and increasing the risk from using fire as a land management tool

Statements of actions that could be taken by Land Managers when conducting prescribed burning practices for rural land amendment were assessed by respondents as either likely to increase, likely to decrease or have little influence on the risk of escape. A comparison of answers between rural Land Managers and Rural Fire officers revealed in general, both Land Managers and Rural Fire officers believe that the following actions reduce the chance of a fire escaping:

- Regular removal of rubbish,
- Conducting burns more often,
- Digging out stumps before burning,
- Wider fire breaks,
- Having suppression equipment nearby,
- Making a burn plan prior to burning,
- Rainfall during a burn,
- Checking weather conditions before burning.

Generally, Land Managers and Rural Fire officers believe that the following actions would INCREASE the chance of a fire escapes:

- Burning very dry vegetation,
- Wind strength increasing during the burn,
- A change in wind direction during the burn.

There were contrasting opinions between the two groups, however, for the following actions (Fig. 39):

- Spraying before burning
- Burning on a steep slope,
- Using a helicopter to light the fire,
- Burning in the morning,
- More stringent controls on how and when to burn,
- Ploughing cropland following a fire,
- Burning after mid-day,
- Burning late in the afternoon/evening,
- Burning quickly with high heat.

These results show areas where research can be undertaken to either better establish the risk from such actions, or to better educate land managers (or RFOs) in terms of risk levels associated with each action.

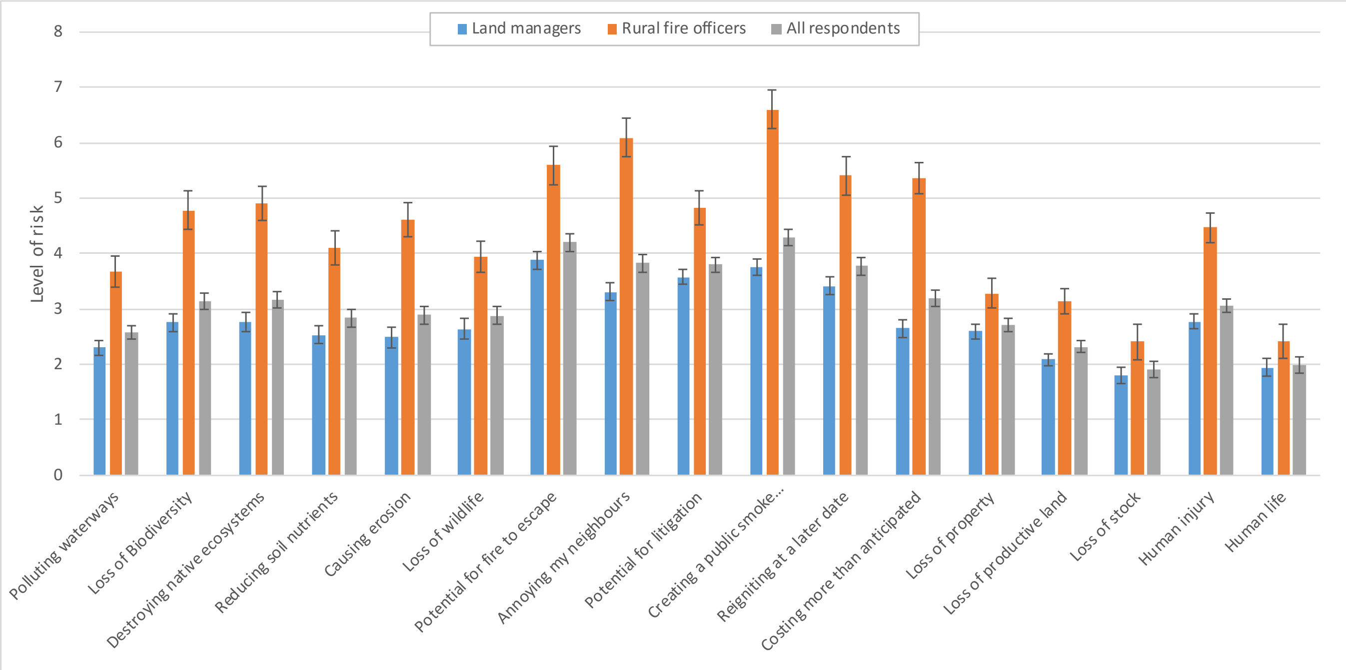

Figure 36: Perceptions of the risks from undertaking prescribed burns. Where 1= very low risk; 10 = very high risk

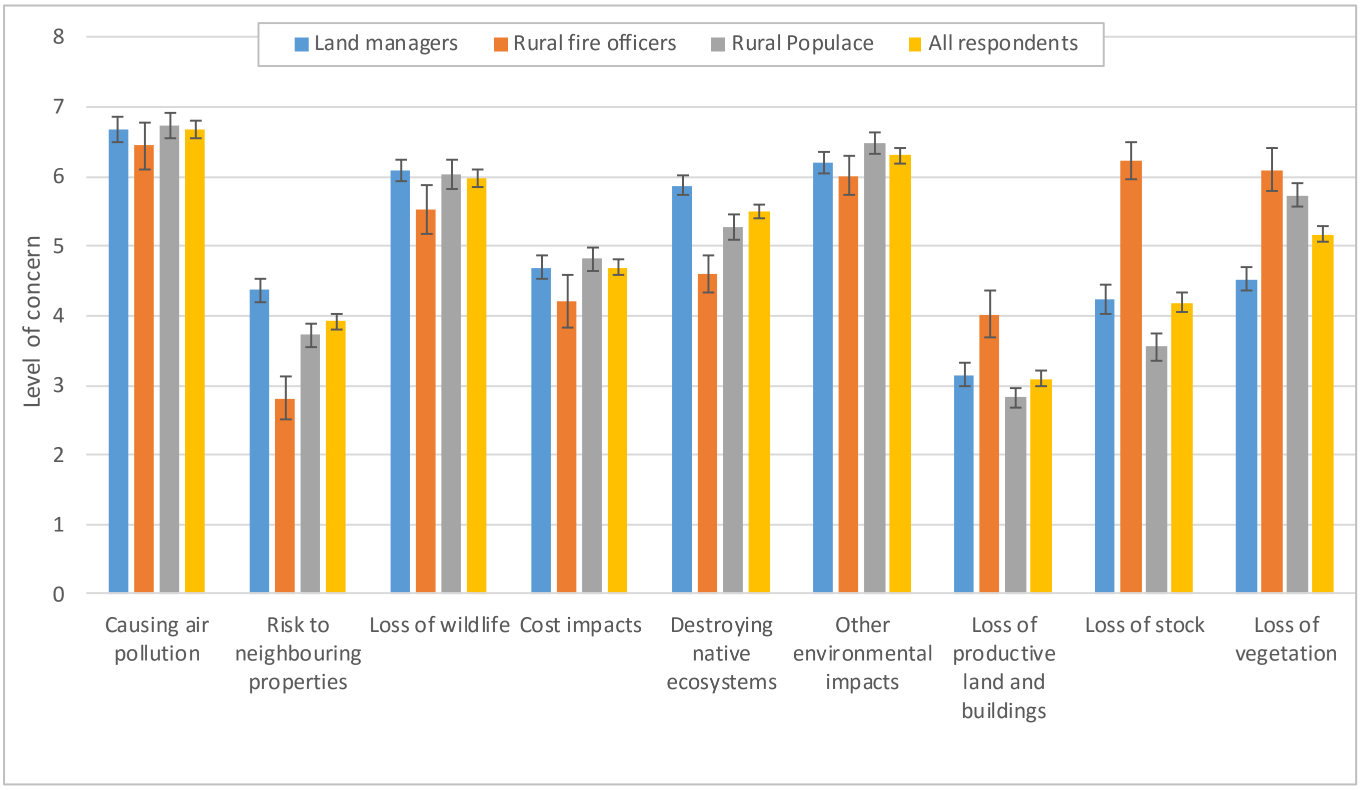

Figure 37: Perceptions of the risks from prescribed burns impacting your own property

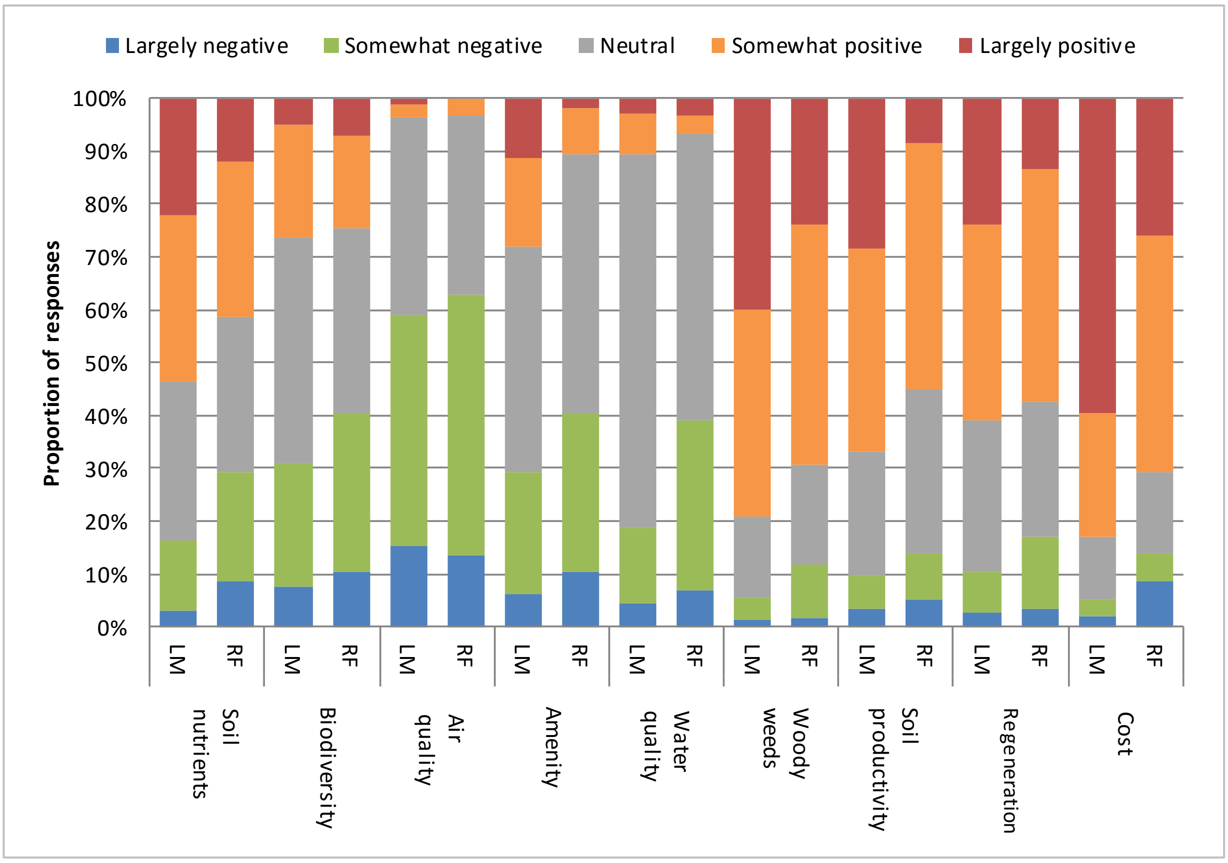

Figure 38: Perceptions of the impact of fire on ecosystem services from land managers versus rural fire officers

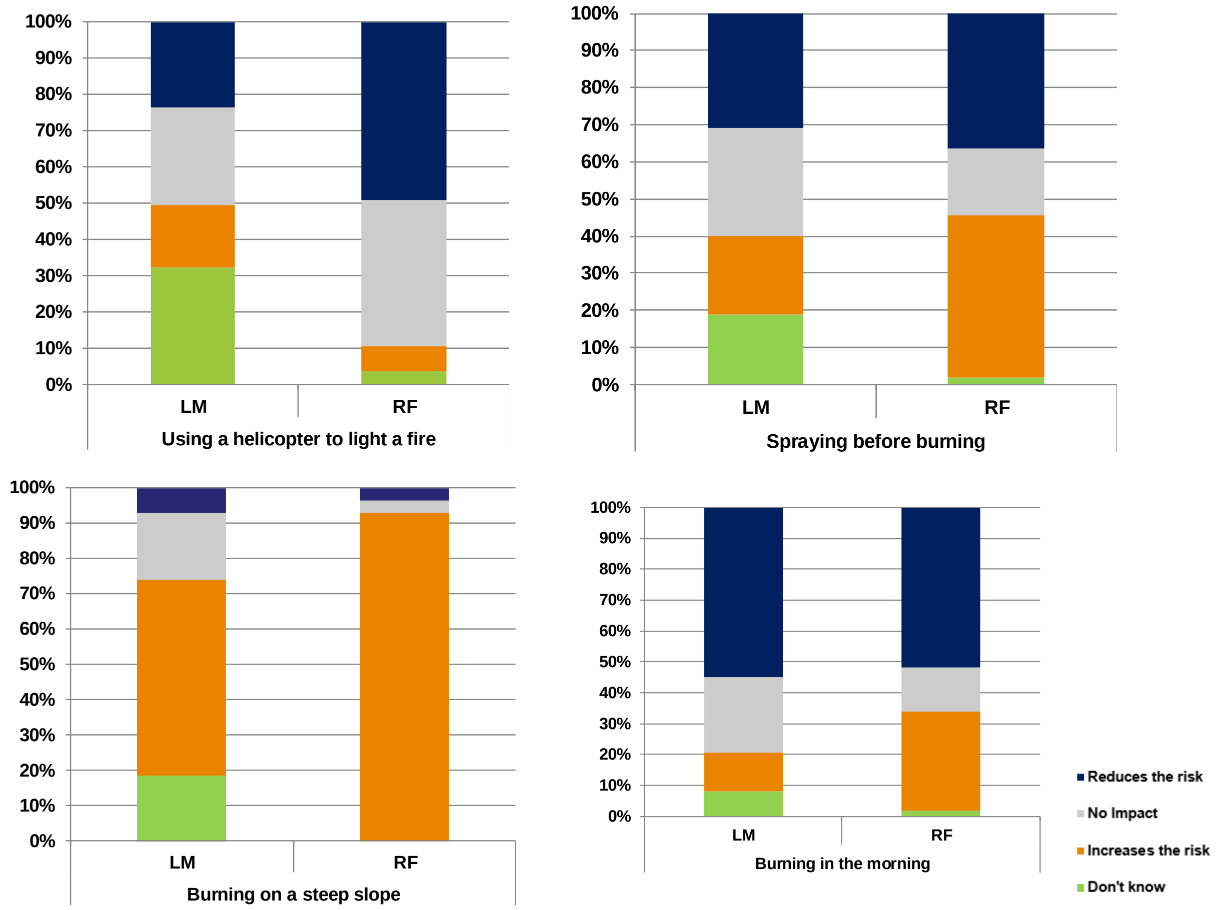

Figure 39: Examples showing differences between land managers and fire officers on perspectives on actions contributing to the risk of burn escapes. The colours represent the proportions who answered if the actions shown either reduced the risk (blue), increased the risk (orange) had no impact (grey), or when they don't know (green)

How is the performance of fire seen as compared to other land management tool options?

Tools for rural land management, such as chemical sprays and mechanical removal, can be used either instead of or in conjunction with prescribed burning. The proportion of land managers who were using various tools for each of eight rural land management operations is shown in Figure 40. Fire is the main tool for rubbish removal, hedgerow clippings and slash removal by Land Managers. Otherwise, chemical sprays were used to tackle vegetative weeds and debris, with the exception of slash and land preparation, where a large proportion of Land Managers use mechanical tools for removal.

Different tools were preferred between land management sectors, for the same land operations. Sheep and cattle farmers tend to use only fire to manage invasive weeds, as well as spraying before burning while the Horticulture sector had a particularly low number of respondents using spray before burning for this operation. Arable cropping farmers were predominantly only using fire to remove crop stubble, as well as spray before burning and only mechanical removal. The Horticulture sector showed a preference for mechanical removal to clear large plant debris. Sheep and cattle farmers in particular were using fire as the predominant method to regenerate pastureland (Fig. 41), and had a higher proportion of farmers not burning hedgerow clippings than other sectors.

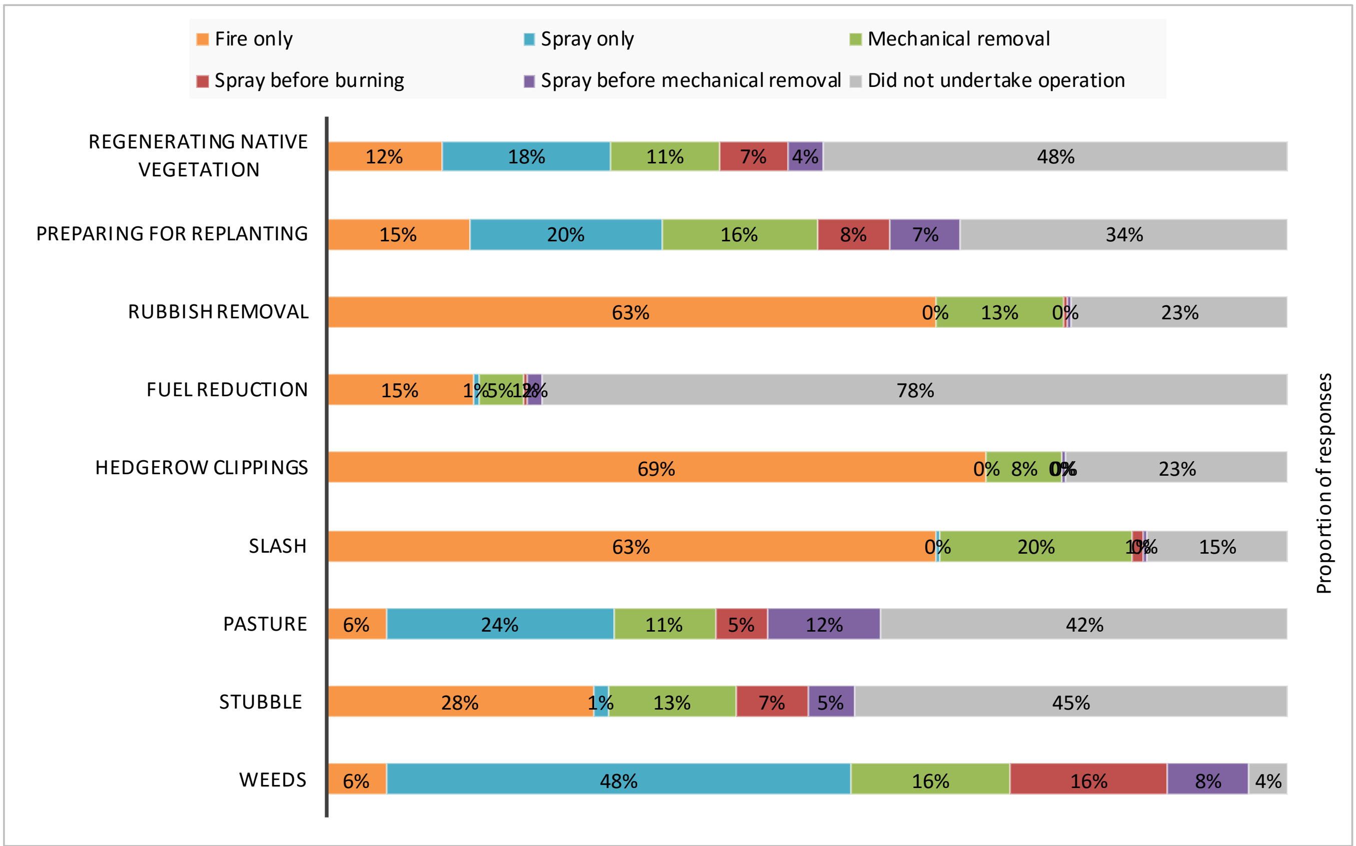

Figure 40: Predominant tools used for common land management operations

Figure 41: Prescribed burn in rank grass via hand drip torch. Waihopai, Marlborough (2012)

Research aim 3: Landowner and other stakeholder perceptions and values concerning fire as a tool

How do beliefs and attitudes impact on the likelihood of using fire?

Respondents were asked to indicate their level of agreement across 34 statements that represented people's attitudes and beliefs to the use of fire. The statements were determined from an earlier pilot study using interviews with rural fire officers from across New Zealand. The statements had a scale of 1 (strongly disagree) to 5 (strongly agree), and the results were run through a Principal Components Analysis using PASW v 18.0 software to reduce the dimensions from 34 items to 5 key factors.

These key factors were found to relate to the:

1. Benefits of fire use (Cronbach Alpha[5] = 0.902)
2. Smoke impacts from fire use (Cronbach Alpha = 0.822)
3. Tradition of fire as a land management tool (Cronbach Alpha = 0.726)
4. Constraints on use of fire from regulations and liability (Cronbach Alpha = 0.7)
5. Knowledge loss regarding how to use fire due to changing land use (Cronbach Alpha = 0.651)

Differences between different respondent's attitudes across these factors were assessed on demographics (i.e. age, gender, size of land being managed), whether they were currently using fire on their property, the type of respondent (rural populace; land manager or rural fire officer) and where they lived (North or South Island).

[5] Cronbach Alpha refers to the reliability score for a set of variables in a scale. It provides a measure of internal consistency, that is, how closely related a set of items are as a group. A score of ≥0.7 indicates good reliability.

Demographic differences in attitude and beliefs about fire use

The study found no significant differences based on the age of respondents; however, there were significant differences based on gender. Males agreed more with statements around the benefits of fire use [t(317, 3.897), $p < 0.000$], and also its use as a traditional tool [t(349, 4.560), $p < 0.000$]. Females were more concerned than males about the impacts of smoke [t(163, -4.171), $p<0.000$], and the loss of traditional knowledge due to changing land use [t(345, -3.697), $p<0.000$].

There were significant differences in attitudes and beliefs around the smoke impacts of fire based on the area of land being managed. Land Managers with smaller land areas (<40 ha) were in greater agreement with statements concerning smoke impacts of fire use compared to Lan Managers with land greater than 800ha ($p=0.018$). Those managing smaller land areas agreed more with the benefits of fire use as a tool compared to those managing greater areas of land ($p=0.011$).

Differences in attitude and beliefs about fire use based on burning behaviour

There was a strong and significant difference in attitudes between those using fire on their property and those who are not. Users of fire agreed more with statements relating to the tradition of using fire as a tool [t(315, 7.359), $p<0.000$]. Respondents who were not using fire agreed more with the statements regarding the smoke impacts of fire use [t(211, -9.841), $p<0.000$]; and the loss of knowledge about fire practice due to changing land use [t(307, -5.319), $p<0.000$].

Differences in attitude and beliefs about fire use based on respondent type

Significant differences in attitudes and beliefs to fire use were found between the three respondent groups (Land Managers, Rural Fire officers & Rural Populace). Land Managers felt stronger agreement with statements relating to constraints in using fire due to regulations and liability compared to the Rural Populace ($p=0.040$). They also agreed more with the statements that fire is a traditional tool, compared to Rural Fire officers ($p=0.008$) or the Rural Populace ($p<0.000$). Land Managers were less likely to agree with statements regarding the smoke impacts of fire use, compared to either Rural Fire officers ($p<0.000$) or the Rural Populace ($p<0.000$). Rural Fire officers were also in greater agreement with statements around the benefits of fire as a tool compared to the Rural Populace ($p=0.015$) or Land Managers ($p<0.000$).

Differences in attitude and beliefs about fire use based on regional location

Only one out of the five key factors showed any significant difference in attitude based on where the respondents resided, and this related to the tradition of fire as a land management tool. The South Island respondents had a much higher agreement with statements relating to fire being a traditional tool compared to the North Island respondents ($p=0.005$).

Which attitudes influence perceptions around fire use?

A binomial general linear model (GLM) was created to describe the explanatory power from respondents' scores to each of the five factor sets based against their response to the question "*Is fire is a good option for managing land?*" Of the five attitudinal factors tested, only the construct relating to smoke impacts from fire use had a significant effect on survey respondents' choice regarding the questionnaire item "*Is fire is a good option for managing land*" ($p<0.001$). A respondent's likelihood of opting 'yes' to the question decreased with an increasing score for the Smoke Impacts factor (in other words, the more a respondent agreed with the statements that smoke was a negative impact from fire use, the less likely they were to believe that fire is a good option). The pseudo-R^2 indicated that the final binomial GLM with Smoke Impacts as sole predictor explained 62% of the deviance (Fig. 42).

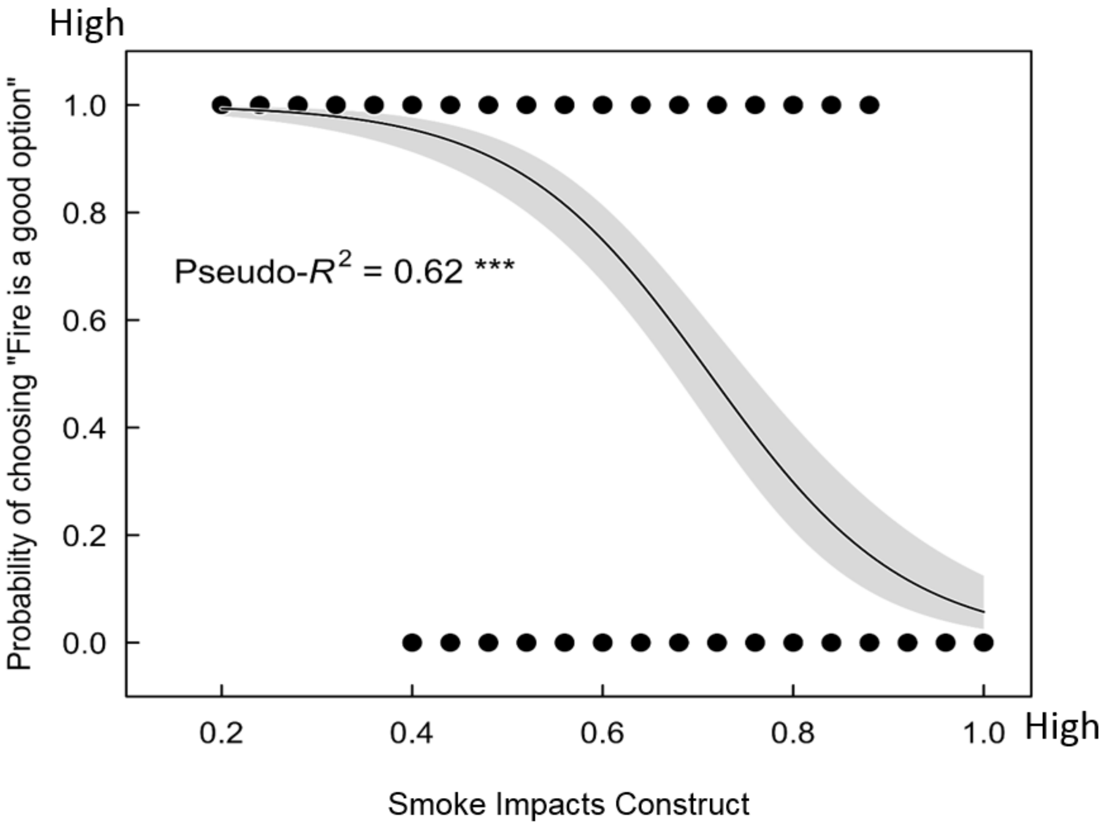

Figure 42: A significant negative relationship was found between the agreement around smoke impacts of fire use and the probability of choosing “fire is a good option”

Chapter 4: Benefits of smoke plume prediction tools

Currently, there is no smoke plume modelling tool available to end users in New Zealand. Benefits of having such a tool includes: enhancing fire management decision-making around deployment of resources and evacuations, warning the public of smoke health effects and / or poor transportation corridor visibility (roads and airports), and reducing smoke nuisance from prescribed burns.

Introduction

Smoke modelling is essential for warning of the public for health issues related to wildfire smoke, notification to airports of potential low visibility due to smoke, and prevention of smoke nuisance during and after controlled burning. Smoke modelling combined with fire behaviour modelling completes the wildfire impact 'picture' during the event.

Luckily smoke modelling is based on first principle physics, this means that any smoke plume model can be used anywhere in the world without modification. This is unlike the fuels models where fuels are specific to region and must be altered for best results. Smoke models vary in the assumptions made and range from simple to complex depending on the type of assumptions.

The Smoke Prediction Models chapter within the Smoke Management Guide for Prescribed Fire distributed by the US National Interagency Fire Centre, Boise, ID (Strand, et al., 2016) describes the type of smoke models available in detail, the assumptions used and situations where they are best applied. This Guide was developed for operations use and was peer reviewed before publication and highly recommended for interested readers.

The smoke model type that is best suited for New Zealand, due to its complex fire environment and local proximity to complex terrain is the puff / particle model. These are two of the more complex models because they are closer to the first principle equations and contain fewer assumptions in their plume calculations. Figure 43, as presented by Strand et al. (2016), below gives a schematic description of each type of plume model available ranging from simple to the most computationally expensive and complex, one-atmosphere. The simpler models will not work in the New Zealand Environment due to the assumptions made around terrain, source simplicity, and meteorology. The one-atmosphere type of model is computationally expensive and should only be used when secondary chemistry and particle production is required, such as for ozone concentration modelling, which is currently not a major concern in majority of New Zealand.

Goodrick et al. (2013) describes these models in further scientific detail and Larkin et al. (2010) first introduced the concept of the BlueSky Smoke Modelling Framework (BlueSky Framework). A globally unique coding that allows for many models to be put together in order to describe the fire source and derive the input fields needed to run the smoke dispersion model. Strand et al. (2012), Raffuse (2012), and Drury et al. (2014) scientifically describe the BlueSky Framework sensitivities and strengths.

Significant input information is required before the smoke model can run and predict downwind smoke plume footprints and surface concentrations. Figure 44 describes the information needed.

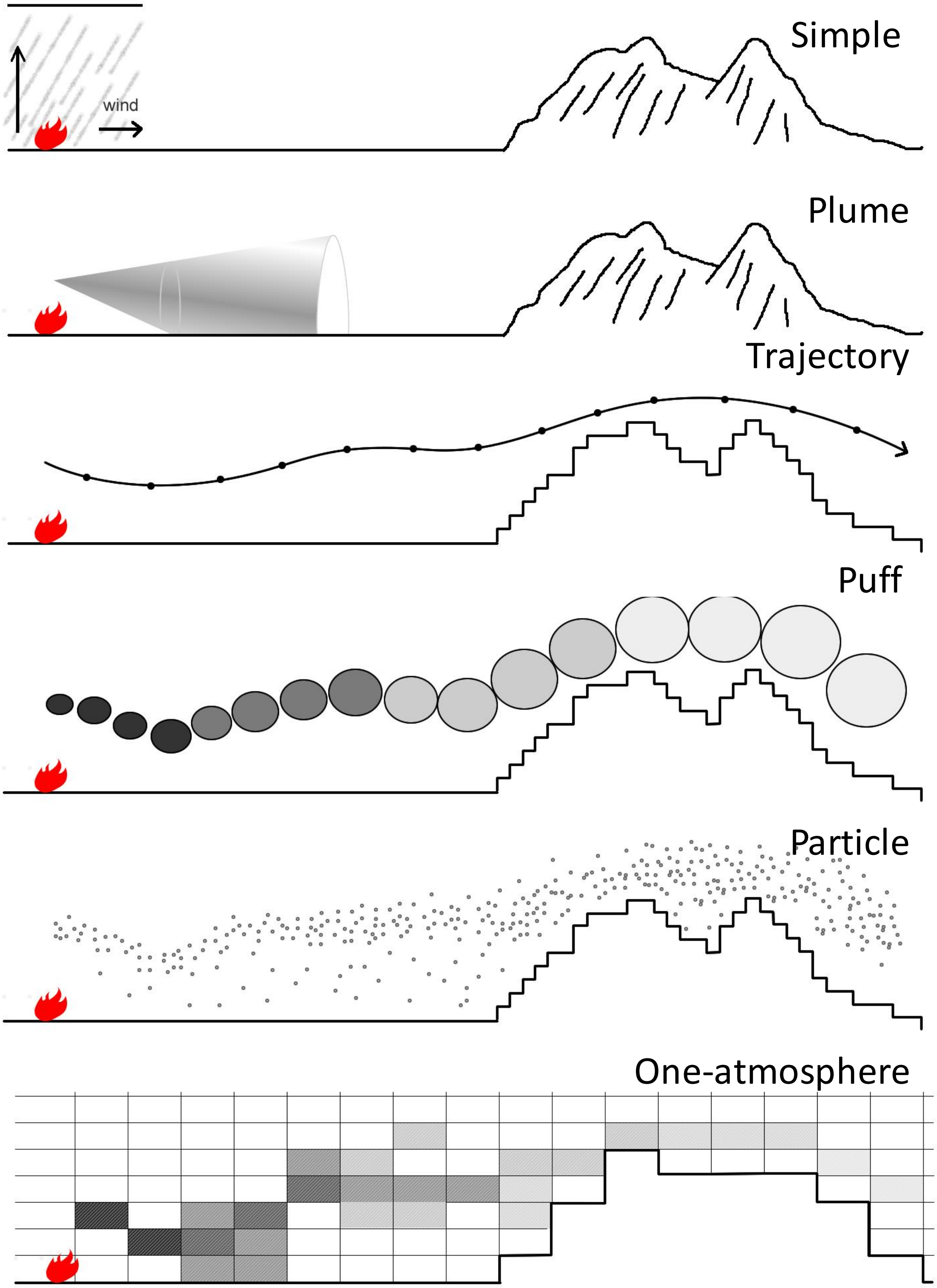

Figure 43: As presented by Strand et al. (2016), a schematic of each type of plume model one can use to describe smoke dispersion ranging from simple to the most computationally expensive and complex, One-atmosphere. The puff and particle models are best suited for the New Zealand environment due to how plume movement relative to complex terrain is handled

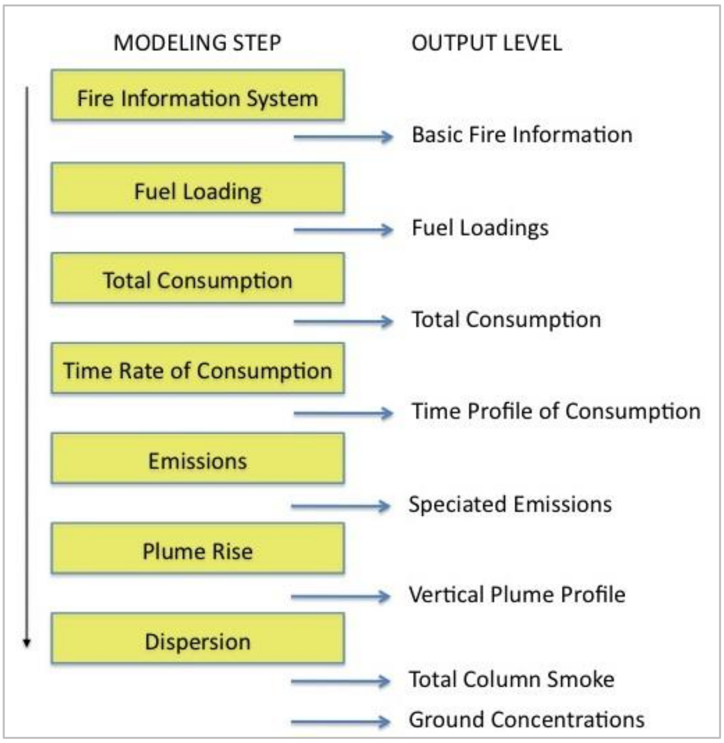

Figure 44: Modelling steps (yellow boxes, left) that are needed for producing smoke plume concentrations and footprints (final output, right). The BlueSky Framework gives output at every step, allowing for evaluation at each level and a description of uncertainty. Figure from Larkin et al. (2012)

BlueSky Smoke Modelling Framework

The BlueSky Framework, the foremost smoke modelling system and is globally unique, is the engine behind many operational smoke modelling tools and visualisation products used around the world (USA, Canada, South Korea, and Portugal). Victoria, Australia's smoke model output product is based on the BlueSky Framework concept, but adapted for the Australian environment. The BlueSky Framework was originally developed by the US Forest Service and is modular in design, allowing for the choice of models that best represent the local fire environment.

The BlueSky Framework is powerful in that at every modelling step the user can choose the type of model to use, satellite data, or user data. Due to its module design and coding new models can be easily woven into the Framework. For example, New Zealand's fire behaviour model, Prometheus, can be linked into the Framework to give improved predictions of fire spread and growth in area.

Output after each modelling step allows for checking against observations and instinct and for defining uncertainty and error. This is useful scientifically, but more importantly it allows for operational burners to do what-if scenario 'game playing'. For example, the US Forest Service's BlueSky Playground allows users who are planning a burn to examine smoke concentrations and impacts based on fire size, timing of the fire start and stop, ratio of flaming to smouldering, and mixture of fuels.

BlueSky Framework in New Zealand

The BlueSky Framework is well suited for New Zealand. It has several fuel models that are similar to New Zealand's plantation forests and new fuel types (native, gorse shrub, etc.) can be easily added. The existing New Zealand fuels information can be used to modify the fuel models within the Framework. There are two major limitations that inhibit its immediate implantation and use, these are:

1) Good real-time fire information of fire location and current size; and

2) Four dimensional three day (or five day) predicted meteorological model output on a refined grid < 4 km square, 1.33 km square preferred.

Good real time fire information, minimally fire location and current size, is the first set of information required to initiate the BlueSky Framework. This information gives the location and size of the fire 'source'. Without it the smoke dispersion model cannot predict the smoke concentrations. There is no real-time fire information database in New Zealand that gives this information. This can be mitigated by using satellite information. New Zealand is lucky in the sense that the fire satellites tend to fly over the country during prime burning, mid-afternoon, and are therefore more likely to 'see' the fire. Unfortunately, New Zealand is often covered with cloud (even during big fire seasons) and satellites cannot detect fires through cloud cover.

The US Forest Service's SMARTFIRE system (https://www.airfire.org/smartfire/ Downloaded 19th May 2017) is ideal for New Zealand. This fire information system uses all freely available satellite based fire information and is tuneable to take in real-time fire information from incident command / Rural Fire Authority. The user can choose which dataset to use based on their 'trust' of the incoming data. Implementing this system within New Zealand would allow for immediate use of the satellite data when it's available and for inclusion of any real-time incident command information.

Four dimensional three day predicted meteorological output is needed by the smoke dispersion model to produce smoke predictions. To resolve terrain influenced meteorology meteorological predictions are required on a fine grid, preferable 1.33 km square, however 4 km square will suffice as an initial test of the smoke predictions. All testing of the BlueSky Framework was completed using free meteorological output from the US. Unfortunately, this is approximately a 12 km square grid, which essentially smooths out the effects of terrain on the local weather and introduces error in the smoke predictions in areas of steep or rugged terrain as shown in Figure 45. New Zealand's meteorological weather output from New Zealand weather agencies can be used as input into the Framework. There are hurdles to overcome:

1) Cost of the data, NZ weather agencies charge for use of their data,
2) Willingness to give the full raw prediction, which is needed, to the Framework; NZ weather agencies have expressed reluctance in giving unprocessed data,
3) The Framework is not designed to input the type of meteorological output used by NZ weather agencies. Luckily, this data are similar to what the Australian Bureau of Meteorology uses. We can rely on their knowledge to assist us as we develop the meteorological module needed for ingesting New Zealand data.

The BlueSky Framework has been in use, tested, and refined for almost ten years around the world. Over $3 million USD have been invested in its development and refinement. The BlueSky Framework is open source and freely available to use. It is recommended that New Zealand use the Framework, with modifications for the New Zealand environment, for smoke prediction modelling.

Example of BlueSky Framework based smoke predictions

BlueSky Framework has a visualisation module. One visualisation output is a series of Google Earth layers of smoke (Fig. 46).

Qualitative review, from fire personnel survey flying in the area during the fire, is that the model did well to predict the smoke going southeast rather than due east. This gives confidence that the general trend is correct despite the large meteorological grid used as input for the smoke dispersion model. The use of this model during a wildfire event demonstrated the benefit of having this information. "*We would love to get the plume model reports/images as we can show the public we are monitoring that as well in a big event*." Richard (Mac) McNamara, General Manager/Principal Rural Fire Officer, Marlborough Kaikoura Rural Fire District

Figure 45: Smoke dispersal patterns in steep high country terrain

Figure 46: Smoke modelling is essential for warning of the public for health issues related to wildfire smoke, notification to airports of potential low visibility due to smoke, and prevention of smoke nuisance during and after controlled burning. Smoke modelling combined with fire behaviour modelling completes the wildfire impact 'picture' during the event

Fire and tussock grasslands

The largest body of research on the environmental effects of fire, when used as a land management tool in New Zealand, is on the plant communities of the tussock grasslands in the eastern, central and southern South Island high country. Experimental fires in the Otago region recorded similar maximum temperatures for both early season (winter-spring) and late season (summer-autumn) fires, typically 500-1010°C at the ground surface, compared with 101-760°C, 1 m above-ground (Payton, et al., 2009; Pearce, et al., 2009). Surface temperatures peaked for around 45-75 seconds, reaching near-ambient temperatures in less than 10 minutes. Soils provided an effective insulation layer with no increase in soil temperatures at 2.5 cm and 5.0 cm below the soil surface.

In a number of studies, under hot, dry burning conditions, burning initially increased plant and tiller mortality, leaf dieback and area of bare ground (Greenall, 1965; Mark, 1965; Payton, et al., 1978; Payton, et al., 2009; Rowley, 1970) (Fig. 47). Recovery of tussock grassland plant communities after burning varied markedly across sites. Re-establishment of plant cover on bare ground was rapid in some areas (within 12 months) (O'Connor, et al., 1964; Payton, et al., 2009; Yeates, et al., 1997), whereas in mid-altitude snow tussock grasslands, litter and vegetation showed limited recovery three years after burning (Greenall, 1965). However the increased light exposure, warmer soil temperatures (Mark, 1965; O'Connor, et al., 1964; Rowley, 1970), and the short-term pulse of nutrients from ash and internal plant nutrient reserves, often initiated post-burn increases in tussock grassland productivity, plant nutritional content and flower and seed production, particularly in the first two years (Mark, 1965; Payton, et al., 1978; Payton, et al., 1986; Rowley, 1970; Williams, et al., 1977). Although immediate post-fire conditions stimulated some aspects of plant growth, plant vigour and yield was sometimes comprised (O'Connor, et al., 1964; O'Connor, et al., 1963; Yeates, et al., 1997).

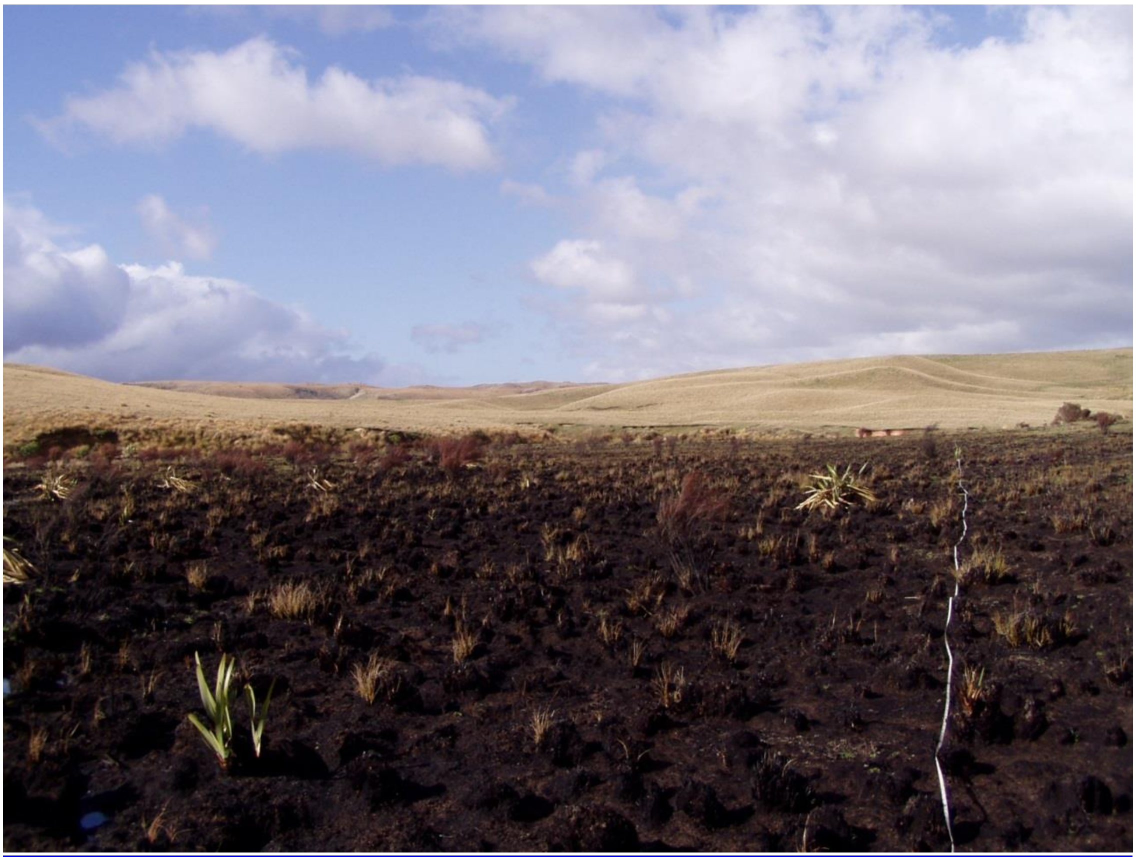

Figure 47: Remaining ground cover following a fire in tussock grasslands in the central North Island, New Zealand

The initial stimulation in plant growth was often followed by a subsequent decline in plant productivity and vigour in the following years (Mark, 1965; O'Connor, et al., 1963; Payton, et al., 1986; Payton, et al., 1979), in association with the loss of nutrient reserves from burning. In nutrient-poor soils, repeat burning and grazing may compromise long-term soil fertility, contributing to the deterioration of tussock grassland communities (Mark, 1965; Payton, et al., 1986; Payton, et al., 1979; Williams, et al., 1977), although at Flagstaff Hill near Dunedin, various studies on the effects of an uncontrolled autumn burn and controlled spring burn on snow tussock found contrasting long-term effects (Allen, et al., 1988; Calder, et al., 1992; Gitay, et al., 1991). Overall, the most extensive landscape change initiated by fire has been a shift from tall-tussock grasslands/woody shrubland communities to short-tussock grasslands more favourable for animal grazing. Burning has also altered inter-tussock vegetation composition with various studies recording increases in herbaceous cover, exotic grasses and weed species (Connor, 1965; Connor, et al., 1964; Greenall, 1965; O'Connor, et al., 1964; Perry, et al., 2014; Wardle, 2011). The extent of these changes is not attributable to fire alone and has occurred in combination with grazing and other land management practices such as oversowing and application of fertilisers.

However, the magnitude of the impacts of fire on tussock grasslands was mediated to a large extent by conditions at the time of burning. Cooler, spring burns with higher soil and plant moisture levels, left litter layers relatively intact, and had a less deleterious effect on tussock plant communities than hotter, drier burns (Fig. 48). Burns undertaken in the late summer or autumn and can achieve the goal of removing excess above ground plant material while minimising the impacts on the long-term health of tussock grasslands (Clifford, et al., 2009; Mark, 1965; Payton, et al., 2009). Where trials have measured a range of management activities on tussock grasslands, post-burn fertilising and oversowing were most effective at mitigating any adverse impacts of burning, markedly reducing the area of bare ground within a year of the burn (O'Connor, et al., 1964). Greenall's (1965) survey of mid-altitude snow tussock grasslands found that burning significantly increased the amount of palatable herbs within three years of burning and suggested that if managed well, burning provides a management tool for improving pasture and increasing stock production.

Figure 48: Tussock grassland condition following a damp spring burn at Mt Benger (left) compared with a dry spring burn at Deep Stream (middle). Mt Benger spring burn, ten year later (right) Otago, New Zealand

Nevertheless, long-term studies on tussock grasslands in Canterbury and Otago have measured significant declines in plant species richness and hence biodiversity in these communities (Day, et al., 2007; Duncan, et al., 2001). Small herbaceous plants were one of the most affected groups. The cause for the decline remains elusive. The rate of decline appears to be unrelated to grazing or burning and is occurring on both farmed and conservation land. The strongest predictions for the decline are linked to elevation, geology and soil type. Duncan et al. (2001) commented on a similar trend across large areas of the South Island and suggests that landscape level processes may be behind this change. For many tussock species and communities their current distribution, structure and composition no longer reflects their natural status prior to human intervention.

Fire in tussock grassland has the greatest impact on insect communities in the first few years after burning. While some insect groups such as *Thysanoptera* (thrips) and *Hemiptera* (bugs) increased in density after burning, the use of fire usually resulted in a significant reduction of invertebrate densities and changes in community structure. Changes in habitat, microclimate, food sources, reduced thermal insulation and limited protection from predators have been suggested as likely contributors to these results (Barratt, et al., 2009; Barratt, et al., 2006; Barrett, et al., 2009; Carlyle, 1988). While *Coleoptera* are often used as indicator species, these trials showed that amphipods (litter dwelling insects) were more sensitive to fire and may be a more pertinent indicator to use when assessing the impacts of fire. In contrast, predators were one of the least affected groups, with spiders showed the most rapid recovery, although in the case of Malumbres-Olatre et al. (2013), the post-burn shift in spider community composition was associated with an increase in more generalist exotic species over the more specialised and less abundance indigenous species. Carlyle's (1988) assessment on the short term effects of fire on insect communities identified the potential use of fire to control pest species such as weevils, but further monitoring is needed to assess the effectiveness of this method in the long term. However, the work by Malumbres-Olatre et al. (2013) highlighted the need to balance these potential benefits of fire against the potential risks to indigenous invertebrate species.

Water yield generally declines in the first few years after burning tussock grasslands, due to the increased water uptake and transpiration from rapid post-fire tussock regrowth. In the Lammermoor Range, central Otago, Duncan and Thomas (2004) examined the effects of burning a catchment in tussock grassland on water yield in the absence of grazing. Summer water runoff declined in the first few years after burning, particularly in the 2nd and 3rd summers (32% and 19% respectively) as tussock regrowth was limited in the first year. While there was little change in low flows, the authors recorded a reduction in quick flow and number of flood peaks and flood size, although these differences were not significant. Mark et al. (1980) recorded similar results when burning at the plot scale on the Rock and Pillar Range in central Otago. In the first 2 years, water yield from the burning and clipping treatments was significantly lower than the untreated snow tussock plots. As the treatment plots recovered, so did the increase in water yield. Over a 6 year period the untreated snow tussock produced the highest water yield (63% of the total rainfall), blue tussock the lowest (49%), with water yields from burnt or clipped tussock and bare soils intermediate between the two (60%, 54% and 56%, respectively). Results from these trials are likely to be modified under a typical grazing management regime.

Fire and scrub control

The use of fire to manage undesirable shrub species on agricultural land such as *Dracophyllum* spp., matagouri (*Discaria toumatou*), manuka (*Leptospermum scoparium*) and gorse (*Ulex europaeus*) (e.g. Fig. 49) show similar environmental effects to tussock grasslands. Burning was used to clear an area of gorse and manuka for the establishment of pasture on hill country in the Hutt Valley, Wellington region (Miller, et al., 1955). Temperatures in the litter reached 200-250°C in the light to moderately burnt areas, reaching over 600°C in the heavily burnt areas, but declined rapidly down the soil profile. Within 2.5 cm of the surface temperatures had declined in the light to moderate burn areas to 20°C and <100°C respectively, and approximately 25°C at a depth of 50 cm in the heavily burnt area. Similar to Miller et al. (1955), a trial in the southern Ruahines to assess a range of techniques to control gorse, showed the effectiveness of soils as a heat insulator when burning (Rolston, et al., 1980). High temperatures were recorded above the soil surface (up to 293° and 977°C 10 cm above the soil surface) and in the first 1-2 mm of soil depth, with small changes in temperature further down the soil profile. Burning provided a pulse of nutrients to the newly established pasture (Miller, et al., 1955), which leached rapidly from the litter layer, but a large proportion was retained in the soil profile 10 months after the fire.

Figure 49: Manuka scrub – prescribed burn off Torlesse ranges, Canterbury, New Zealand. Photo courtesy of Scion

The insulating properties of soil from the heat produced during burning also provided protection for the soil fauna. With the exception of the lightly burned areas, the litter fauna was most severely affected when fire was used to clear gorse and manuka (Miller, 1962; Miller, et al., 1955; Stout, 1961). Faunal biodiversity was highest in this layer compared with the topsoil and subsoil fauna. Amphipods and micro fauna in the litter and topsoils were most sensitive to burning, whereas fauna in the subsoil and topsoil were largely unaffected except in the heavily burnt areas. The sterilising effect of the fire saw an initial decline in fauna populations with subsequent recovery under newly established pasture climaxing around three months after the burn, albeit with fewer species and a different community structure to that prior to burning. Rates of recovery were affected by individual species life cycles, available food sources and the ability to adapt to pasture conditions. Five years on from the burn, the pasture fauna remain less diverse than the pre-burn forest fauna, mainly a result of physical differences in moisture capacity, aeration and temperature and chemical composition of the forest litter compared with the pasture topsoil (Miller, 1962; Miller, et al., 1955; Stout, 1961).

Fire in agriculture and horticulture

Less is known about the environmental impacts on the use of fire in the agriculture and horticultural sector where fire is used for a range of activities including crop and stubble burning, removing orchard residues, frost control, maintenance and removal of hedges and shelter belts and burning rubbish (Bayne, et al., 2012). Published research on the environmental effects of these practices is lacking in New Zealand, highlighting an information gap in this area.

Stubble burning in New Zealand is used mainly in the Canterbury region to remove wheat, barley or oat residues and to establish small seeded crops (Williams, et al., 2013) (Fig. 50). Advantages include a rapid and inexpensive method to prepare land for planting, reducing cultivation, soil disturbance and chemical use, and assisting in pest, weed and disease control (Williams, et al., 2013 & references therein) has drawn predominantly on overseas studies and reviews to assess potential environmental impacts of this practice in New Zealand These studies show that the remaining ash after stubble burning increased pH. Nutrient losses varied depending on the intensity of the burn with most of the nitrogen, carbon and sulphur lost to the atmosphere. Around 50-70% of the residue carbon was volatilized as either carbon dioxide or carbon monoxide. Varying quantities of remaining nutrients were retained in the ash residues. Williams et al. (2013) noted that similar amounts of carbon are lost to the atmosphere regardless of whether the residues are burnt or incorporated into the soil.

Figure 50: Stubble burn, Darfield, Canterbury, New Zealand. Photo courtesy of Scion

One New Zealand study on the effects if different cereal residue management practices on earthworms, found that earthworm populations and biomass declined after burning over the four year trial period (Fraser, et al., 1998). As New Zealand produces some of the highest cereal cop yields and hence high quantities of crop residues, New Zealand based research is needed to quantify the environmental advantages and disadvantages noted above of using fire to manage crop residues.

Fire and forests

Fire is primarily used in planted forests as a tool to prepare land for the establishment of tree seedlings (Fig. 51) as excess vegetation can restrict access for planters, impact on seedling survival and supress early tree growth. Controlled burns have been used to reduce logging residues or to remove unwanted vegetation such as scrub and gorse, which is frequently pre-treated with herbicides to improve combustibility. A number of trials were undertaken in the 1960’s to 1980’s to improve the effectiveness of fire, often in combination with herbicides and diesel, in removing unwanted vegetation and reducing gorse regeneration (i.e. Balneaves, et al., 1982; Balneaves, et al., 1976; Rockell, 1966; Valentine, 1966; Zabkiewicz, et al., 1978). However, the use of fire in planted forests has declined over time mainly due to environmental concerns (Robertson, 1998), hence many of the studies on the environmental effects of fire use in planted forests are dated.

Burning logging residues often resulted in a substantial reduction in organic matter and associated nutrient reserves. On the West coast of the South Island, burning beech forest residues removed most of the litter layer with higher quantities of organic matter consumed in the more intense burns. The highest nutrient losses were those nutrients consumed by fire (N 66%, P 35%, S 51%) (Goh, et al., 1991; Phillips, et al., 1985). Highest burn temperatures were recorded in the litter layer and areas of high intensity burns, with temperatures often exceeding 640°C (Goh, et al., 1991; Phillips, et al., 1985). Nitrification increased in the first 2-3 months after the burn, and two years after the burn nutritional content of the organic matter in the unharvested forest was generally higher than the burnt sites. However, around 80-90% of the nutrients from decomposing litter and ash in the burnt sites were retained in the humus layer.

Figure 51: Burning *Pinus radiata* harvest residue in preparation for planting

Burning of logging slash from five sites in planted forests around New Zealand (four in *P. radiata*, one in *P. contorta*) showed similar results, with around 60% of the total organic matter and its carbon content lost to the atmosphere (Robertson, 1998). These losses were primarily from the duff layer and above ground material. Robertson (1998) estimated the annual carbon loss from burning logging slash at approximately 10 300 tonnes, a small component of the 1995 estimate from New Zealand's planted forest estate of 143 Mt C. The results of Australian studies into the potential nutrient losses from burning *P. radiata* harvesting slash also highlighted the loss of organic matter and nutrients through burning, particularly the more intense, hotter burns, which have the potential to affect site productivity particularly in infertile soils (Flinn, et al., 1979; Woods, 1980). While fertilisers can replace nutrient losses, replacing organic matter is more problematic (Flinn, et al., 1979). Build-up of logging slash after harvest is a potential environmental risk, particularly around logging landings where there is a risk of landings collapsing. However, burning to remove this material can also pose risks from fires escaping into the forest estate. A survey by Hall (1998) showed that burning was a secondary option to removing excess logging residue by machine even though burning was a cheaper option.

Assessing the effects of burning logging slash on catchment hydrology and water quality is more difficult as the effects of forest removal often overwhelm the effects of fire. In the Reefton area on the west coast of the South Island, fire was used to remove logging residue from harvesting indigenous forests to facilitate the establishment of exotic planted forests. Clear-felling and burning of beech forest in small catchments significantly increased water yield by 75-100% in the first 19 months after burning. Most of the increase in water yield (60-65%) was a result of the reduced interception of rainfall through the removal of the forest canopy, with 60% of the increased run-off exported during high flow events. Peak flows also increased following clear-felling and burning (Pearce, et al., 1980). While harvesting and roading activities can contribute sediment and short-term pulses of nutrients to waterways, burning can provide an additional contribution to the post-harvest nutrient pulse along with elevated sediment concentrations from ash run-off into waterways (O'Loughlin, 1979; Pearce, et al., 1980).

There is a lack of serotiny in wilding pines in New Zealand. In the past, burning has been a limited option for the control of wilding pines in New Zealand (Ledgard, 2004). Nevertheless, there has been renewed interest in its use in the South Island high country, particularly in combination with pre-treatments using chemicals desiccants (Fig. 52). However, there is an information gap on the environmental impacts of the use of fire to control wilding pines.

Figure 52: Experimental research using fire to control wilding pines, Twizel (2016)

Fire as a management tool in conservation land

Historically, fires provided an infrequent contribution to natural ecosystem processes in New Zealand. As a result, few indigenous species are naturally adapted to fire (Allen, et al., 1996; Basher, et al., 1990; Bond, et al., 2004; Perry, et al., 2014). Some species such as *Chinochloa rigida*, manuka, kanuka (*Kunzea ericoides*) and *Dracopyllum* spp. display enhanced flowering, seeding and germination following a fire, and plants with wind-dispersed seeds can take advantage of recently burnt nearby sites. More commonly many re-sprout from plant bases (*Chionochloa* spp., matagouri, *Cassinia* spp.) or bulbs (lillies and orchids) (Allen, et al., 1996; Basher, et al., 1990; Singers, et al., 2014). However, there is the potential to use fire as a management tool for the conservation and maintenance of protected areas in New Zealand. Potential applications include preventing natural succession to maintain particular ecosystems of interest, weed control, protecting and enhancing habitat for rare and endangered species and reducing build-up of fuel loadings and associated risks of wild fires. There is divided opinion on the use of fire in conservation land, particularly with the risks of controlled burns evolving into wild fires, creating conditions favourable to weed establishment and contributing to ecosystem degradation (Allen, et al., 1996; Hicks, et al., 2001; McQueen, et al., 2000; Miller, 1993; Perry, et al., 2014; Silvester, et al., 2009).

Figure 53: Burning in the Awarua wetland, Southland, New Zealand

In many areas of New Zealand, tussock and shrubland communities and some wetland communities, if left undisturbed, will naturally progress toward a forested state. In some instances there may be advantages in preserving representative areas of wetland, tussock grassland and early successional shrubland and forest land communities. For example, Calder et al. (1992) noted that in the Flagstaff Scenic Reserve established near Dunedin in 1975*, Leptospermum scoparium* was starting to replace *Chionochloa* dominated tussock grasslands. The author's recommended controlled burning every 14-20 years to maintain the tussock grassland communities and reduce the risk of accidental fires. Miller (1993) suggested that the pakahi wetlands on the South Islands west coast were likely to revert back to forest in the absence of fire. Rogers and Leathwick (1994) also commented on the potential of fire to maintain representative areas of tussock grassland in the central North Island currently predicted to succeed to shrublands within 30-50 years of burning and re-establish forests within 200-300 years.

There is limited information on the use of fire as a management tool in wetlands (Fig. 53). Norton and DeLange (2003) used experimental burns to assess the effectiveness of fire in enhancing habitat for the critically endangered orchid (*Corybas carsei*) in the Whangamarino wetland. The carefully controlled cool burns removed surface vegetation but left the underlying peat layer intact. The increased surface exposure increased surface radiation and daytime soil temperatures for over 4 years after the burn. *C. carsei* declined in the controlled unburnt plots but increased in abundance in the burnt plots in the first 4 years after burning. Overall plant species richness also increased in the post-fire period with recovery strongly influenced by the life history and morphological traits of plants in the burnt plots. In addition to *C. carsei*, three other nationally threatened or declining species benefitted from the burns. In contrast, Johnson's (2005) review on the effects of fire in scrub and wetlands in the lower South Island concluded that fire did not provide any benefits to conservation values, ecological processes or species protection and that the key management option was through fire prevention.

Fire has also been suggested as a potential management tool for the on-going retention and maintenance of red tussock grasslands, an iconic feature of the Tongariro National Park (Silvester, et al., 2009). Smale & Fitzgerald (2004) provide one of the few New Zealand trials on this topic. They tested a range of treatments, including fire, as potential tools for maintaining monoao (*Dracophyllum subulatum*) shrublands in the central North Island. While monoao cover declined following controlled burning, burning was effective at initiating seedling establishment, albeit at a much lower rate than hotter wildfire or controlled burns.

There is a lack of information on the environmental impacts of fire on riparian areas in New Zealand. The position of riparian areas as corridors through the wider landscape, where they provide an interface between adjacent aquatic and terrestrial ecosystems, means that these areas often contain unique ecosystems, with high diversity values. International literature highlights the vulnerability of these systems to fire (Baillie, et al., 2008) and it would be advantageous to under research in this area in New Zealand.

Waihopai Controlled Burn, 2013. Photo Courtesy of Scion

Key findings

Fire is considered a useful tool in rural New Zealand. However, there are growing concerns around its use. This study provides an insight into who thinks what around the risks and benefits of using fire as a land management tool. The findings from this research have been presented at several conferences and workshops to interested stakeholders. **The results of this work have established the importance of the use of fire in the rural sector. In recognition of the degree of use and benefits to the rural sector in New Zealand, it is important to ensure fire is used safely and effectively to reduce the current level of risk.**

History

The current use of fire in New Zealand as a land management tool, has been shaped by past use of fire, a practice that has an extensive and lasting impact on today's landscape. Prior to human arrival (≈ 730 years BP), 85-90% of New Zealand was covered in forest. Before human arrival, fires were infrequent, mainly started by lightning strikes or volcanic activity. As a result, New Zealand vegetation had little natural resistance to this type of disturbance, with few species adapted to burning. With the arrival of Polynesians (around 730 years ago), about a third of the native forest cover was lost (approx. 6.7 million ha). Fire was heavily relied on as a land management tool to clear pathways, establish village sites, maintain bracken fern beds, hunt for game, clear and cultivate land for crops such as taro and kumera, and pest control. Fire use continued with the arrival of Europeans (around 180 years ago), and was used widely throughout the North and South Islands, primarily for converting native vegetation into agriculture. By the end of the 1950s only 25% remained (approx. 5 million ha). Over last 100 years, concerns have grown regarding the loss of native vegetation, soil erosion and pasture degradation. As a result, a number of Acts and regulations have been established to control the use of fire as a land management tool in New Zealand.

Environmental impacts

The impact of using prescribed fire on receiving environments was largely determined by the severity of the fire, vegetation type and site conditions on the day of burning. Burning under hot, dry conditions had the greatest impact on terrestrial plants, insect communities and soil fertility, and subsequent recovery rates. Research (mainly confined to tussock grasslands and scrub) clearly identifies the benefits of carrying out lighter burns under cool moist conditions in order to mitigate potential impacts on terrestrial receiving environments. While there is a reasonable body of scientific information on the effects of prescribed burning in tussock grasslands, elsewhere available up-to-date scientific research is limited. In particular, there is limited information on the effects of prescribed burning on hydrology, and a lack of information for water quality, and freshwater biodiversity. Scientific information on the effects of prescribed burning on terrestrial ecosystems is also limited for land uses outside of tussock grasslands such as agriculture, horticulture and forestry. The use of fire as a tool on conservation land remains open to debate. Future research investment into these areas would provide a greater understanding of the environmental risks and benefits associated with the use of fire in rural areas. This information would assist in the development of best burning practices that minimise environmental risk to terrestrial and freshwater ecosystems.

Smoke plume prediction models

Currently, there are no smoke plume modelling tool available to end users in New Zealand. The benefits of having such a tool includes:

- Enhancing fire management decision-making around deployment of resources and evacuations,
- Warning the public of smoke health effects and / or poor transportation corridor visibility (roads and airports), and
- Reducing smoke nuisance from prescribed burns.

Smoke plume modelling is based on first principal physics, and therefore any one of the models can be used anywhere in the world without alteration. The BlueSky Modelling Framework allows for real time modelling of smoke dispersion, using satellite data. Originally developed by the US Forest Service, and is in use worldwide (Canada, USA, South Korea, Portugal and Australia).

The case study experience of implementing the BlueSky Smoke Modelling Framework tool during wildfires and experimental burns were used to draw conclusions on the best operational smoke model and tool output for New Zealand. The future directions is to develop a real-time smoke modelling tool and training for prescribed fire users to reduce the risk of smoke becoming a nuisance to neighbours.

The BlueSky Framework is the best suited system for implementing operational smoke dispersion modelling with the puff or particle model imbedded with the Framework invoked. This system already has built in output models that generate tools for end users to access, such as the Google Earth mapping of plumes. The system also provides web services, which allows for custom tools that can be developed based on New Zealand operational needs (scoping for this is outside the current programme).

Modifications of the BlueSky Framework for the New Zealand fire environment are minor in expenditure compared to the overall development and refinement of the Framework to date. The two limitations listed above can be overcome with funding, trust, and resources. Existing datasets (i.e. Guide to New Zealand Fuels) can be incorporated into the Framework to modify it for the New Zealand environment. The benefits of smoke modelling were demonstrated during the Wairau valley burn (see quote above) and the need for smoke nuisance modelling has surfaced from the National survey.

National survey

Our comprehensive survey identified that 54% of the respondents were using fire. Fire was used across the country for a variety of reasons, debris burns or vegetative rubbish removal (small piles) being the major use. Land managers believed fire was a good option compared to the general rural populace. Land managers also perceived a lower level of risk from burning compared to rural fire officers. From a range of 34 statements that represent people's attitudinal beliefs around the use of fire, we identified five key beliefs:

1. Benefits of fire use,
2. Smoke impacts of fire use,
3. Tradition of fire as a tool,
4. Regulations and liabilities,
5. Knowledge loss from changing land use.

Significant differences were found between:

- Genders,
- Different stake holder types, (rural fire officers, land managers, rural populace)
- Land management sectors,
- Regional locations,
- Size of the land being managed.

But found no significant differences in beliefs across each of the five factors for the different age groups.

Males agree more than females on the benefits of fire use, whereas **females** were more concerned on the impacts of smoke and the loss of knowledge. **Users** of fire agreed more on that fire was a traditional tool. Whereas, **non-users** of fire agreed more on the impacts fire has as a smoke nuisance and also there is a loss of knowledge on fire practises.

Land managers felt that regulations were a constraint to using fire more than the rural populace, and agreed more with the statements concerning fire being a traditional tool than either rural fire officers or the rural populace. Land managers were much less likely to agree with the statements concerning the impacts of smoke than either rural fire officers or the rural populace. **Rural fire officers** were also in greater agreement with the benefit of fire as a tool than either the rural populace or land managers.

Land managers with smaller land areas (<40 ha) were in greater agreement with statements concerning smoke impacts compared to managers with land greater than 800ha. Those managing smaller lands agreed more on the benefits of fire as a tool compared to those managing greater areas of land.

Interestingly, amongst the five attitudinal constructs, only smoke had a significant effect on a survey respondents' choice regarding the questionnaire item "Is fire a good option for managing land". A respondent's likelihood to opt "yes" decreased with their smoke impacts attitudinal score. In other words, the more a respondent agreed that smoke was negative, the less likely they were to believe that fire is a good option.

There was a varied response between rural fire officers and land managers about the environmental impacts of fires. Both fire officers and land managers agreed on the negative impacts on air quality. Whereas, they both saw the positive impacts for woody weed removal and fire acting as a cost effective tool. However, there are a number of actions where there is disagreement between fire officers and land managers on best practise to avoid escapes. It is unclear if it is because there is lack of understanding or scientific information or best practise guidelines being available. This area of disagreement could be a reason for the accidental escapes, injuries and deaths being reported. These areas of misconceptions highlight the need for further research, especially comparing reality with perceptions, or "myth busting", by identifying differences in perceived risks and benefits (from the online survey), and marry with facts (from a literature review). Currently there are no training courses, detailed guidelines or protocols to facilitate the safe and effective use of fire as a land management tool in New Zealand, without compromising the integrity of the air and land.

Recommendations for future research

Building on from the Fire as a Land Management Tool programme, two further research projects will be established:

Mythbusting

In order to provide a base of evidence for the societal, sectoral, and political concerns regarding the use of fire as a land management tool, the results in the survey database, along with a review of literature including recent media articles, will be used to identify the range of viewpoints for and against fire use and the drivers behind major concerns regarding the use of rural fire. This review will be compared against the known evidence concerning the ecological impacts and risk factors from the use of fire in the management of rural land, to determine where 'myths' exist for rural burning practices. The quantitative data will enable us to establish for instance, perceptions that are incorrect but held by a majority versus those that are correct, yet held by only a minority. Similarly, it can identify practises of high/low risk that are commonly undertaken, versus those practices that are scarcely used. The findings of this research can assist the relevant stakeholders in the development of best practices, by identifying key misconceptions.

Knowledge exchange and extension services

The outcomes of the Fire as a Land Management Tool programme, in conjunction with Mythbusting conclusions will be provided as a means for the Reductionist Working Group to develop best practice guidelines for rural sector. While NZ has some guidelines, there is little depth in terms of how to implement these in practice. Australia and USA have more in-depth implementation outlines in their guides, which could be workshopped here to upskill the fire using community. This should also allow the guideline recommendations to be taken further into guides that can implement practical solutions on the ground. This knowledge needs to be customised to NZ cultural rural practice and environment. A series of workshops to develop NZ guides and upskill the RF community is recommended, including demonstrations for training and upskilling of fire users. These might involve the education of fire users around best burning practises (i.e. dry vs wet fuels), or running Burn camps or training courses to support landowners or managers in understanding how to use fire safely and effectively

Other recommended future research directions

Based on the findings raised around the benefits and risks of using fire, further research is required to investigate:

- the impacts of burning on terrestrial (outside of tussock grasslands) and freshwater ecosystems and the development of best burning practices that minimise environmental risk to those environments
- post fire recovery studies, and
- what are the consequences of not burning, i.e. economic impacts, which is more harmful to the environment (chemicals vs mechanical)
- development of burning prescriptions (seasonal conditions, fire behaviour, etc.) for different vegetation types

We recommend building on previous Scion research (Dunningham, et al., 2015) to extend from the identification of risks towards development of innovative mechanisms that support transformative change in rural fire user practices through enhanced understanding of the risk environment and the ability to act appropriately (i.e. take control of the risk rather than react to it). This will require to further understand use of fire by farmers and rural landowners, perceptions of fire risk and views on existing and appropriate future communication strategies. It will identify major practice change barriers, drivers and intervention points arising from identified risks in using fire as a land management tool, and marry information and communication and technology (ICT) mechanisms to build community resilience.

There remains a need for scoping new technologies, or converging technologies towards building greater awareness of fire use danger or allowing better individual preparedness or ability to adapt to any environmental changes that occur during a burn that could increase risk in a community. We recommend an investigation into the use of ICT technologies and devices in enabling land managers to become more resilient to fire risks and impacts. This will require also exploring how these technologies might be married to provide mechanisms/tools for fire users that build preparedness and allow them to control the risk environment.

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Waihopai Controlled Burn preparation, 2013. Photo Courtesy of Scion

Appendix A

14 Perceptions of rural fire officers from pilot study interviews	**34 Items used in questionnaire based on the pilot viewpoints**
Prescribed burns are necessary to control fuel loadings	There are no practical alternatives to burning in the development of high country grazing Prescribed burns are required to control fuel loadings Reducing fuel loads decreases the risk of wildfires Lack of regular burning in the high country increases fuel loadings Prescribed burning reduces the risk of wildfire
Fire is of the past, a danger, and should be phased out in rural land management	Using fire for rural land management should be phased out Fire is a traditional rural land management tool Direct drilling negates the need to burn
Using fire brings risk of re-ignition at a later date	There needs to be more information on how to burn safely and effectively for land management operations There needs to be tighter controls on how fire is used in the rural sector
Fire is still the best option for us, and an essential tool	Burning is an essential rural land management tool The majority of land owners still want to use prescribed burning Burning is the most cost-effective solution for vegetation management
There are ecological and biodiversity impacts from the use of fire	Fire is an environmentally friendly land management option
The increasing fire risk is due to greater numbers of boundary neighbours and human presence in the area	Newcomers to the district have not been adequately inducted about the safe use of fire Having a greater number of boundary neighbours increases the risk of fire escaping across boundaries It is riskier to conduct a burn now than it was 10 years ago
Loss of fire as a tool will lead to weeds and woody infestations	Lack of regular burning in the high country will increase wilding infestation
Regulations make it difficult for rural land managers to use fire	Current regulations and liabilities make it hard to conduct a burn Fire Authorities are reluctant to let us burn DoC don’t believe in using fire in the landscape
Fire has impacts on soil	Fire can take away nutrients from the soil Burning crop residue stops the buildup of soil pathogens
The ‘rural code’ of local fire knowledge around prescribed burning practice has decreased over time	The level of knowledge in the rural community concerning good burning practice has decreased in the past 10 years I feel confident of my ability to manage a prescribed burn Conducting a high country burn is stressful
Safe fire practice is tied to different weather conditions	Climate change means New Zealand is at increased risk of fire escape
There are various farm management practice actions one can take that prevent fires getting out of control	I plan to increase the amount of prescribed burning on my property I plan to decrease the amount of prescribed burning on my property
Fire helps regenerate seeds, including weed seeds	Prescribed burning is an effective method to induce desirable vegetation Fire can help to regenerate vegetation
Urban dwellers have a negative view of rural fire use	The smoke from burning causes health issues The smoke from burning causes traffic hazards The smoke from burning causes nuisance

Appendix B

List of outputs of the program:

Obj. 3 – Use of Fire as a Land Management Tool

	Report number
Clifford, V R; Baillie, B R; Bayne, K M; Lowe, S; Pearce, H G. 2011. Benefits and Risks of Using Fire as a Rural Land Management Tool – Funding application. New Zealand Fire Service Commission Contestable Research Fund	47220 and 47221
Clifford, V R; Pearce, H G; Baillie, B R; Lowe, S; Bayne, K M 2011. Work Plan for Research theme 1.3 Using Fire as a Rural Land Management Tool.	48041
Bayne, KM. 2011 INFFER Workshop on Fire as a Land Management Tool. Minutes of Meeting held at Alexandra, 16-18 Nov 2011	48743
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