New Zealand Fire Service Research Report

Development of an integrated framework to assess after fire economic impacts

Scion

2016

Estimating the total economic cost of wildfires is critical for justifying the investment in rural fire management activity measures (Reduction, Readiness, Response and Recovery) undertaken to mitigate the economic losses incurred during a wildfire event and the consequences suffered by society.

Scion has developed a wildfire impacts economic assessment framework focused on after fire impacts. The framework was developed as a first step to identify critical categories in an after fire economic impact assessment, existing data sources, information gaps and methodologies to gather or estimate missing data.

The authors suggest the following future research avenues:

- Test the availability and usefulness of the various datasets suggested in this report using case studies for individual wildfire events and at the national level.
- Integrate the proposed NZFSC fire incidence reporting system with the after fire cost framework developed in this report and spatial data available for pre-suppression and suppression costs.
- Gather data for indirect tangible and intangible impacts (i.e. business disruptions, environmental, and mental and physical health) following the procedures identified in this report.
- Development of a classification of conservation land for valuation purposes jointly with the Department of Conservation to justify the values of protected conservation areas in the medium to long-term future.

New Zealand Fire Service Commission Research Report Number 151

ISBN Number (978-1-92-728714-9)

ISSN Number 1178-3648

CLIENT REPORT (Confidential)
Development of an integrated framework to assess after-fire economic impacts

Juan J. Monge, E. R. (Lisa) Langer, Sandra J. Velarde and H. Grant Pearce

www.scionresearch.com

REPORT INFORMATION SHEET

REPORT TITLE	DEVELOPMENT OF AN INTEGRATED FRAMEWORK TO ASSESS AFTER-FIRE ECONOMIC IMPACTS
AUTHORS	JUAN J. MONGE, E. R. (LISA) LANGER, SANDRA J. VELARDE AND H. GRANT PEARCE
CLIENT	NEW ZEALAND FIRE SERVICE COMMISSION (NZFSC)
SCION CONTRACT NO:	QT-4393
SCION CLIENT REPORT NO.	22714
SIDNEY OUTPUT NO.	57382
SIGNED OFF BY	RICHARD PARKER
DATE	APRIL 2016
CONFIDENTIALITY REQUIREMENT	CONFIDENTIAL (FOR CLIENT USE ONLY)
INTELLECTUAL PROPERTY	© NEW ZEALAND FOREST RESEARCH INSTITUTE LIMITED ALL RIGHTS RESERVED. UNLESS PERMITTED BY CONTRACT OR LAW, NO PART OF THIS WORK MAY BE REPRODUCED, STORED OR COPIED IN ANY FORM OR BY ANY MEANS WITHOUT THE EXPRESS PERMISSION OF THE NEW ZEALAND FOREST RESEARCH INSTITUTE LIMITED (TRADING AS SCION).

Executive summary

The problem

Estimating the total economic cost of wildfires is critical for justifying the investment in rural fire management activity measures (Reduction, Readiness, Response and Recovery) undertaken to mitigate the economic losses incurred during a wildfire event and the consequences suffered by society.

The New Zealand Fire Service Commission (NZFSC) has identified the need for an updated and comprehensive assessment of the total costs of wildfires in New Zealand. Due to upcoming structural and legislative changes proposed for New Zealand fire services, the sponsoring agency elected to switch the focus from a comprehensive cost assessment to one focused only on after-fire costs. This decision is also in line with a major knowledge gap identified in the literature review performed under milestone 2 of the project regarding the importance of quantifying after-fire costs due to the significance of their contribution to total fire costs.

Scion has been contracted under the Contestable Research Fund to address this by developing a wildfire impacts economic assessment framework focused on after-fire impacts using existing published loss assessment protocols. Scion researchers have addressed the limitations encountered by Business and Economic Research Limited (BERL; Wu, et al., 2009) by identifying alternatives to quantify the tangible and intangible after-fire impacts in New Zealand.

Key Results

The framework developed in this report describes the ideal methodology identified from the literature review to assess after-fire costs and is based on frameworks generated for other major natural hazards or disasters. Using time and space as the driving characteristics of the framework, after-fire costs were divided into tangible/intangible and direct/indirect impacts. A group of private industry and government stakeholders was involved in developing the framework by providing feedback regarding data categories. Such feedback has been incorporated into the framework.

To estimate a final after-fire cost, quantities or incidences per individual impacts are needed as well as their respective values or costs. From previous studies and existing data, it has been identified that incidence and values for human lives, injuries, productive potential, infrastructure, carbon emissions, carbon sequestration, erosion and sedimentation are available to an extent that could be considered adequate to arrive at a potential estimate in the short term.

Summary of data availability and assessment method per after-fire cost item.

After-fire cost item	Data availability	Assessment method
Human lives and injures	Yes	Averaging
Productive stock	Yes	Averaging or synthetic
Infrastructure	Yes	Averaging or synthetic
Physical health	Partially	Synthetic or survey
Business disruptions	No	Synthetic or survey
Mental health	No	Surveys
Environmental		
Carbon emissions and sequest.	Yes	Averaging or synthetic
Erosion and sedimentation	Yes	Synthetic
Recreation and tourism	Partially	Synthetic and surveys
Biodiversity	Partially	Synthetic and surveys

As listed in the table above, major and partial data gaps have been identified for certain indirect and intangible impacts. Although valuation data is partially available for environmental and physical health impacts, there is no known incidence data that relates values to wildfire events and intensities to such impacts. In New Zealand there is absolutely no valuation data for mental health impacts and business disruptions resulting from wildfires. Such impacts could be measured by performing surveys of the people directly affected or synthetically using complex economic and fire simulation models.

It is worth emphasising the trade-off between the cost of obtaining the data and the benefits derived from such information. This report is in part aimed at providing the reader an idea of the magnitude of the economic impacts exerted by fire events through time after their occurrence. Among the benefits of measuring such impacts in detail is the ability to systematically link, following the appropriate theoretical foundations, pre-suppression and suppression investments to after-fire economic impacts, to the extent of analysing “what if” scenarios under various circumstances (e.g. climate change).

Implications

The framework was developed as a first step to identify critical categories in an after-fire economic impact assessment, existing data sources, information gaps and methodologies to gather or estimate missing data. The next step would be to develop and constantly update a database comprising data for the various components of the framework. The framework has been developed in such a way that the database could then be used across any spatiotemporal scale – national, regional or individual wildfire event – to address issues such as emergency management, policy-making, and investment decisions on suppression and pre-suppression alternatives.

An aggregation scheme has been suggested to integrate the spatial component of the after-fire cost framework with the land use/cover databases that will be used in the proposed NZFSC fire incidence reporting system. Hence, the framework could be used to undertake both: (1) a high-level national assessment of after-fire impacts using readily available data, and (2) more in-depth case-by-case assessments that would require further data gathering and complex fire and economic modelling. The major knowledge gap currently limiting the completion of a potential national assessment is the lack of values data for conservation lands, i.e. biodiversity and, to a lesser extent, recreational use and tourism.

Recommendations

The authors of this framework suggest the Commission the following future research avenues:

- Test the availability and usefulness of the various datasets suggested in this report using case studies for individual wildfire events and at the national level. As a first step, a test using easily available information would be a good starting point for the Commission to provide an educated estimate of annual after-fire costs and to measure progress.
- Integrate the proposed NZFSC fire incidence reporting system with the after-fire cost framework developed in this report and spatial data available for pre-suppression and suppression costs.
- Gather data for indirect tangible and intangible impacts (i.e. business disruptions, environmental, and mental and physical health) following the procedures identified in this report. A good starting point would be to rely on experts’ opinions if the cost of obtaining such information, through in-depth surveys or complex modelling, outweighs its benefits.
- Development of a classification of conservation land for valuation purposes jointly with the Department of Conservation to justify the values of protected conservation areas in the medium to long-term future.

Development of an integrated framework to assess after-fire economic impacts

Juan J. Monge, E. R. (Lisa) Langer, Sandra J. Velarde and H. Grant Pearce

Scion

April 2016

Table of Contents

Introduction

Estimating the total economic cost of wildfires is critical for justifying the investment in rural fire management activity measures (Reduction, Readiness, Response and Recovery) to mitigate the economic losses incurred during a wildfire event and the consequences suffered by society. The avoided economic losses are considered to be the benefits from investments in mitigation actions. Historical records of such actions are a key resource when undertaking a cost–benefit analysis of past, current and future (potential) mitigation actions. However, such records are not always readily available for a variety of reasons. Issues include confidentiality, aggregated figure budgets, lack of (or incomplete) records and inconsistencies in the types of data reported.

The organisation Business and Economic Research Limited (BERL) has undertaken three studies to date (BERL, 1987; Goodchild, et al., 2005; Wu, et al., 2009) to estimate the economic costs of wildfires in New Zealand. The authors categorised costs depending on the timing of occurrence (pre-suppression, suppression and after-fire) and estimated the total cost of wildfires in New Zealand. However, they encountered several data limitations, including accessibility to necessary data, and concluded that a robust data-collection framework was needed to undertake future wildfire research[1]. BERL suggested that “to establish a data collection framework … [the New Zealand Fire Service Commission (NZFSC)] would need to undertake five steps” (Wu, et al., 2009):

1. Identify all the cost components that best represent New Zealand’s total cost, including pre-suppression, suppression, and after fire costs, of wildfires.
2. Establish the uses of this data, including primary and alternative uses as the data may be useful for research projects other than wildfires/fires.
3. Identify data sources (i.e. which organisation collects what data).
4. Develop a database that is available to key stakeholder organisations.
5. Install checks and balances, including data integrity, auditing and revision procedures for the database.

The NZFSC has identified the need for an updated and comprehensive assessment of the costs of wildfires in New Zealand. Scion has been contracted under the Contestable Research Fund to address this by developing an integrated economic-cost framework using existing published cost-estimation protocols. Scion researchers are addressing the limitations encountered by BERL by identifying alternative data sources to enable quantification of the tangible and intangible after-fire impacts in New Zealand. Hence, out of the five steps suggested by BERL, Scion has addressed steps 1 and 3 for after-fire costs.

Literature review

As a preceding milestone to the framework development, a literature review was undertaken by analysing more than 70 papers on the economic costs of fires and wildfires (Velarde, et al., 2015). Key stakeholders were also consulted to validate cost-data categories and available data sources (Langer, et al., 2015; Velarde, et al., 2015)[2]. Below is an extract of the key review findings:

[1] Among the most important data and methodological limitations listed by the authors were the: lack of cost data from major forest management groups due to confidentiality and aggregation issues; lack of recreation and environmental impacts; and lack of business disruption impacts.

[2] Copies of these previous milestone reports are available upon request. A summary of the stakeholder feedback is included as Appendix 1 to this report.

- The literature review revealed a variety of approaches and terminology used to assess the cost of fires. However, few studies were found that estimate cross-sectoral impacts of fire;

- There is a lack of information concerning the complexity of wildfires as an economic and social problem (Lueck, et al., 2015), and the need for multi-disciplinary management strategies and policies to deal with them given conflicting goals in wildfire management (Coghlan, 2004);

- The majority of studies in the published literature focused on certain aspects of fire costs (e.g. operations, health, ecosystem services, etc.), and only a very limited number of studies evaluated the total costs of fires at a country level, e.g. Australia and the USA (Ashe, et al., 2009; Hall, 2014, respectively), or internationally (Chuvieco, et al., 2014; González Cabán, 2013). The scarce literature developed in Australia and the USA is in part a reflection of the significance of fire as a natural hazard in those nations. Most papers focused on pre-suppression and suppression activities (Milne, et al., 2014) although some did consider after-fire impacts;

- Major gaps found in the literature were: 1) the inter-relationships among different cost-data categories, as well as the institutional arrangements in place for fire-management decision making and how they affect cost structures; 2) long term after-fire costs; and 3) environmental impacts such as ecosystem service losses due to wildfires;

- Only a few examples connect wildfires to wider community economic impacts, for example, impacts on labour and employment (Davis, et al., 2014). There is an urgent need to fill this gap since fire management covers a wide range of stakeholders, e.g. landowners, public and private organisations, and interest groups (Guild, et al., 2010);

- Frameworks generated for other types of disaster were considered a useful starting point to build the cost framework for wildfires (e.g. impact indicators and measurement units for natural disasters and fire emergencies; Stephenson, 2010).

Revised scope to after-fire costs

The Department of Internal Affairs announced in November 2015 that the New Zealand Government has agreed to merge the 52 rural fire authorities, the National Rural Fire Authority (NRFA) and New Zealand Fire Service (NZFS) into one unified fire-services organisation. Due to these structural and legislative changes, it was decided in discussion with the project sponsor (Rob Goldring, NRFA) to focus this study on after-fire costs only as, according to Wu, et al. (2009), the pre-suppression and suppression data sources are already partially available and have the potential to change significantly in the short to medium term as a result of this Fire Services Review. This decision is also in line with a major knowledge gap identified in the aforementioned literature review regarding the measurement of after-fire costs. Hence, the development of this framework aims to address this new institutional direction and knowledge gap.

The framework describes the ideal methodology identified from the literature review to assess after-fire costs and is based on frameworks generated for other major natural hazards or disasters (Handmer, et al., 2002; Stephenson, 2010). Using time and space as the driving characteristics of the framework, after-fire costs were divided into tangible/ intangible and direct/indirect impacts. A group of private industry and government stakeholders was involved in developing the framework by providing feedback regarding data categories. Such feedback has been incorporated into the framework.

According to Wu, et al. (2009) and international literature on wildfire economics (Donovan, et al., 2003; Mendes, 2010), the “cost plus net value change” (C+NVC) model provides a suitable theoretical foundation for wildfire economics. The objective sought by the NZFSC can be interpreted as a minimisation problem in the following manner:

$$\text{minimise} \sum_{c} cost_c + nvc$$

where c is a set that includes pre-suppression and suppression costs, $cost$ represents the absolute costs, and nvc denotes the net value changes in the economy due to wildfire-related damages. Besides negative impacts, such net value changes could include positive benefits from fires such as short-term increases in grass growth/productivity as a result of ash fertiliser effects. However, due to the focus on after-fire costs, such net value changes will be treated as net losses (i.e. net of benefits) in this framework. Hence, the net total after-fire costs estimated using this framework represent the last variable in the previous mathematical expression (nvc).

A graphical representation of the framework is summarised through the hierarchical chart in Figure 1 with space and time dimensions. The space dimension was included in the framework to consider the parallel project being undertaken by NZFS/NRFA to develop a wildfire risk incidence layer. The next sections present in detail the data, sources and methodologies needed to create a spatial dataset, populate a concept matrix and estimate a total annual after-fire cost figure.

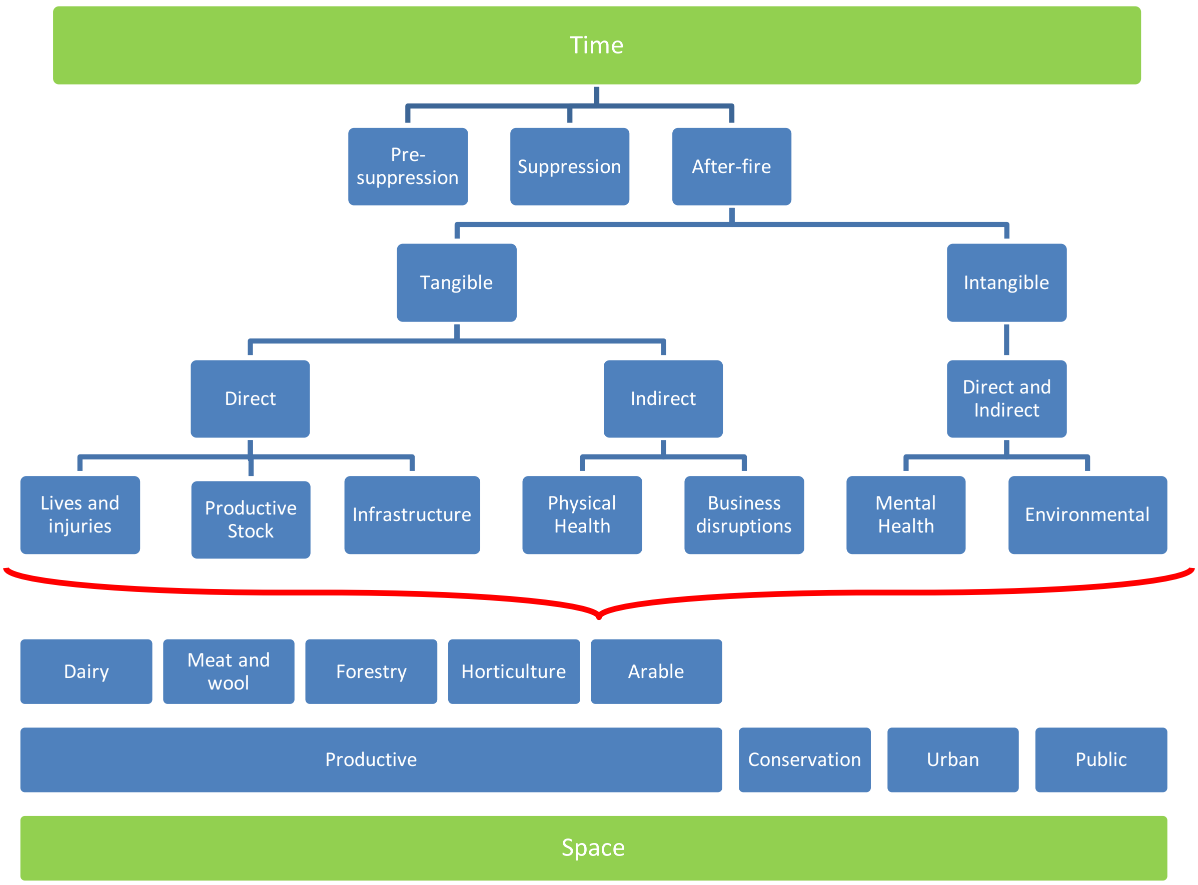

Figure 1. Hierarchical representation of an after-fire economic-assessment framework.

Spatiotemporal considerations

While assessment of economic losses from wildfire can be coarsely estimated at a national level (e.g. from national areas burnt for different vegetation types and average values for different land uses), more detailed regional assessments are preferable. According to Handmer, et al. (2002) and Stephenson (2010), it is of utmost importance to limit an after-fire loss assessment to a specific region and time horizon. This is due to economic accounting reasons considering resilience time and regional economic transfers. For example, a specific firm might reach full production capacity within the time horizon specified (e.g. 3 years), in which case the losses would involve the transaction costs incurred in the recovery process. An example regarding space limits could be represented by the activity gained by business B due to the activity lost by business A due to wildfire. If both businesses are located within the region in question, the losses suffered by business A are not considered in the total after-fire loss since they are just an economic transfer from business A to B.

Time and space delimitations will depend on the use of the framework and data availability. Potential spatial delimitations in New Zealand could consider political divisions such as district and regional councils or even smaller regions depending on the use of the framework. If the aim is to measure instant and direct impacts, a small region and hours might be enough to assess civilian, productive, infrastructure and environmental losses. However, to account for indirect impacts, political divisions are suggested due to the availability of statistical records for regional economic activity from Statistics New Zealand. Stephenson (2010) suggested an interval of 6–12 months to measure indirect and intangible impacts. However, certain long-term impacts (e.g. mental health) might take considerably longer to recover from.

The main space categories included in the framework and considered representative in New Zealand are: productive, conservation, urban and public. The *productive* space includes all the sectors that are considered primary by the Situation and Outlook Annual Reports published by the Ministry for Primary Industries (e.g. MPI, 2014). Such sectors include pasture-dependent sectors (e.g. dairy and drystock), forestry, horticulture (e.g. apples, pears, kiwifruit, vegetables and viticulture) and arable (e.g. grains and seeds). The *conservation* space includes all the land managed by the Department of Conservation (DOC) including environmental services such as conservation, biodiversity, natural heritage, recreation, etc. The *public* space includes parks managed by district and regional councils as well as other conservation and recreational areas in addition to roads, bridges, etc. The *urban* space in this report specifically consists of the rural-urban interface at risk from wildfire, rather than urban centres. The latter would entail a completely different framework considering the valuation and resilience of multi-story buildings among other specific components. The urban space includes primary sector processing industries (e.g. dairy plants and sawmills) since many of the operations are in rural areas.

According to Handmer, et al. (2002), a proper loss assessment divides impacts into two main categories depending on time of occurrence and proximity of the people, stock or structures affected: *direct* and *indirect*. The former are due to direct contact with the wildfire event, while the latter are a consequence of the direct impacts. Considering the time dimension, the direct effects will happen almost instantly after the event while the indirect effects can be assessed under medium- and long-term time horizons. The two previous broad categories, direct and indirect, can be subdivided into two additional categories depending on their monetary recognition in the economy: *tangible* and *intangible*. According to Stephenson (2010), intangibles are “items that are not normally bought or sold and for which therefore no agreement on their monetary value exists”. Tangibles, on the other hand, are “items normally bought or sold and that are therefore easy to assess in monetary terms". Handmer, et al. (2002) suggested grouping the direct and indirect intangible impacts into one group since these pose the greatest challenge to quantify.

Broad assessment methods

According to Handmer, et al. (2002), the following categories represent the broad literature on loss assessment methods:

Averaging

Also known as the "rapid assessment method", this assigns an average loss value to different property types estimated from historical events. It measures potential losses. This is the cheapest method but depends on availability of historical records. This is the method used by Hall (2014), Ashe, et al. (2009) and Wu, et al. (2009) to estimate the total cost of fires in the U.S., Australia and New Zealand, respectively. Average costs could be developed for different land uses/covers on a per-hectare basis following this method. For example, on average, a building of a certain size might have been found to be damaged to a value of $20,000 based on estimates from previous fires. Another hypothetical example would be that the average historical profit lost per hectare for a dairy farm is $1,000.

Synthetic

This uses more intricate computer modelling of losses using stage-damage curves[3]. These curves essentially represent the relationship between wildfire intensity and magnitude of economic loss. Depending on the speed of the fire and biomass burnt, the wildfire intensity will change and will inflict different levels of economic losses. Hence, different cost factors can be developed for different wildfire intensities and scales. Such curves can be estimated either:

- Synthetically: by inventorying groups of assets (i.e. furniture, goods and structures in a building), developing repairs costs and classifying properties depending on loss susceptibility, or
- Historically: by assessing post-event losses for different wildfire intensities.

The synthetic assessment method measures potential losses. This is a data-intensive and expensive method, and requires considerable modelling expertise. Fire growth models such as the Canadian wildland fire growth model Prometheus can be used to simulate wildfire scale, and complex economic models to simulate indirect effects. A hypothetical example could be the damage inflicted on a building depending on the scale and intensity of wildfire: $15,000 for light fires, $20,000 for medium fires and $25,000 for intensive fires.

Survey

Surveys can be performed after an event has happened to collect a sample of data from individuals affected which can then be generalised to a region. Sampling and survey design are critical to this method. Since they measure actual losses, these reflect specific circumstances and prevention measures that were undertaken before the specific event.

[3] In New Zealand, the Natural Hazards Research Platform and Resilience to Nature's National Science Challenge use the terminology "fragility functions". These are included within their RiskScape model for earthquakes and floods, which is maintained by the National Institute of Water and Atmospheric Research (NIWA, 2015).

Hence, care is needed when generalising to other regions under different preventative circumstances. Surveys should be performed when there is no historic data or when the impacts are indirect and/or intangible. Surveys are the most appropriate alternative for estimating intangible environmental losses such as biodiversity, recreation and other ecosystem services.

Examples of elicitation methods to assess intangible losses are the ‘revealed’ and ‘stated preferences’ approaches. The former is based on the observed behaviour followed by individuals when making choices. The most common approach is the travel method which, for example, estimates the cost of travelling to and time spent in a national park to estimate a recreational value per visitor. The latter is based on elicitations through the simulation of a market and includes methods such as contingent valuation and choice experiments and the concept of “willingness to pay”.

When primary data collection is not feasible in a specific context (e.g. national park or local economy), the benefit-transfer methodology is suitable for estimating non-market values for the context in question by adapting estimates from similar contexts. Such methodology uses ancillary (i.e. surrogate) information, such as regional economic indicators (e.g. wages) or terrain characteristics (e.g. slope), to transfer previously elicited values using either revealed or stated preferences in other similar contexts. This methodology is useful when there are budget or time constraints to perform a survey and an initial non-market value is needed.

A combination of the previously listed methods was used in this framework depending on historical data availability, time and budget constraints. Table 3 at the end of this report (page 23) summarises the methods suggested for each impact category.

Assessment scope

Due to different interpretations and expectations of the after-fire cost framework, it is worthwhile clarifying what will be included in the economic framework as opposed to relying on existing assumptions of what it should include. The following bullet points summarise differing interpretations:

- Economic versus financial loss assessment. The former relates to the economic losses in a region including all economic, social and environmental agents. The latter relates to the losses to a specific individual, business or industry. For example, intangible losses (such as biodiversity) are a social concern and not necessarily a business’s concern. This framework addresses economic losses only.

- Economic losses in a defined region are counted only if there are no subsequent gains in the region (e.g. business activity picked by other industries). Hence, insurance is not an economic loss since it is a money transfer in the regional economy (from insurer to insuree). It is considered a benefit if the insurance payment comes from outside the region of interest. If the assessment is performed at the national level then such economic losses would be suffered mainly by exporters since other exporting nations will be able to pick up the lost export opportunities.

- Economic versus insurance loss assessment. The former deals with market values considering the concept of depreciation. The latter deals with full replacement costs. In some instances, the market value may be half of the replacement cost. Hence, insurance loss assessments overestimate after-fire loss assessments. This framework considers economic loss assessments only.

- Double counting losses for fixed assets (e.g. machinery, stock or land). Either the market value of the lost asset or subsequent lost profit should be considered, not both. This holds since the market value of the asset is a function of the value of its productive potential (i.e. profits). Hence, by assessing lost profitability, the lost market value is also being considered. This framework considers lost profitability only.

- Profits versus revenue losses. Lost profits should be considered since revenues are just part of the picture. A specific business is benefited by the avoided input costs. This framework considers lost profits.

Types of impact

The various impacts of a wildfire can be categorised in various ways. Using the framework illustrated in Figure 1, impacts are divided in to tangible and intangible ones, with further layers of subdivision. Each of these categories will be summarised below.

Tangible impacts

Tangible impacts are divided in to two sub-categories: direct and indirect.

Direct tangible impacts: Human lives and injuries

This category includes firefighters as well as civilians. Depending on the intensity and scale of a wildfire, the injuries suffered by a human being from wildfire can range from minor injuries to death. The cost of human lives lost or injured during a wildfire event can be estimated in two steps. The first step consists of obtaining an inventory of human lives lost or injured per wildfire event. For example, inventories of firefighters' deaths and injuries have been developed by the NZFS and NRFA and are updated on an annual basis, while inventories of civilians could be obtained from the Ministry of Health or Accident Compensation Corporation (ACC). According to Wu, et al. (2009), the Ministry of Health does keep records of hospitalisations due to "exposure to uncontrolled fire, not in building and structure". The second step consists on calculating the cost of human lives lost or injured in monetary terms.

The Ministry of Transport (MOT) publishes an annual report on the "social cost of road crashes and injuries". This publication reports what is known as the value of statistical life (VOSL), which is estimated using a willingness-to-pay valuation technique that expresses pain and suffering from loss (in dollar terms) of life or life quality to the injured and to their families (MOT, 2014). As well as the VOSL, the Ministry of Transport also estimates the cost of minor and serious injuries by considering permanent disability, loss of output (temporary disability) and medical expenses[4]. The current 2014 figures are the following:

- Fatal: $3,950,000 per injury
- Serious: $472,800 per injury
- Minor: $20,800 per injury

Such values could be updated annually, multiplied by the inventory numbers from different wildfire events, and summed to get a total economic loss for human lives and injuries for different regions or nationally.

[4] The Ministry of Transport also includes vehicle damage, as well as legal and court expenses, but this information has been excluded from the framework as it is irrelevant.

Direct tangible impacts: Productive stock

This category includes lost productive potential from primary industries due to wildfire events. As previously stated, the consideration of lost profits is sufficient for a loss assessment since it is equivalent to estimating the lost value of fixed assets such as land, stock, machinery, etc. and avoids double counting. Hence, the per-hectare profits[5] should be included in the framework in the following manner:

$$totprodloss = \sum_i \sum_l discprodloss_{l,i}$$

$$discprodloss_{l,i} = \sum_t {profloss_{l,i,t}}\Big/{(1 + disc_l)^t}$$

$$profloss_{l,i,t} = lossfct_{l,i,t} * prof_{l,t} * ha_{l,i}$$

$$lossfct_{l,i,t} = f(i, t, l)$$

where l is a set representing different productive land uses, i different wildfire intensities, t represents time period, $totprodloss$ total discounted value of productivity lost, $disc$ discount rate, $discprodloss$ discounted value of productivity lost, $profloss$ annual profits lost, $lossfct$ loss factor, $prof$ per-hectare profits and ha hectares affected.

The loss factor is equivalent to a stage-damage curve and is a function of wildfire intensity, time and land use. This loss factor can change through time to reflect different degrees of resiliency across land uses and wildfire intensities. The discount rate differs by land use since it should reflect the opportunity cost of lost productivity.

Similar to stage-damage curves, the loss factor can be estimated from historical wildfire events, or synthetically produced by considering different types of biomass burnt (e.g. pasture, forest, orchards, etc.). Details of the number and area of affected hectares for wildfire events can be obtained from the NZFS's fire incident reporting system (Station Management System, SMS)[6], or inventories updated annually by the NRFA from data supplied by rural fire authorities (NRFA Annual Returns). Synthetic estimates can be derived using simulation software such as, Prometheus (Tymstra, et al., 2010), which has been adapted for use in New Zealand (Scion, 2011) using fuel types obtained from the Land Cover Database (LCDB) (Thompson et al., 2003). The discount rates for different land uses can be directly elicited from the farm or forest owners affected by a specific wildfire event. Otherwise, the best approximation would be the rate of return obtained from different enterprises before the wildfire event.

The per-hectare profits for different land uses and regions can be found in the following sources of information:

- Horticulture and arable: The Ministry of Agriculture and Forestry (MAF, now MPI) maintained representative models for the main horticulture and arable land enterprises in New Zealand until 2012[7]. These estimates could be used as a starting point to assess productivity lost. The last comprehensive report was published in September 2011 (MAF, 2011). Different individual reports can be obtained for the 2012 season with their respective Microsoft Excel files from the MPI website (MPI, 2015a, 2015c).

---

[5] Such profits should be estimates before taxes.
[6] The NZFS and NRFA have a project currently underway to develop an improved rural fire incident reporting system within SMS that will potentially provide a map drawing tool through which fire perimeters can be drawn manually or added from GPS track files directly onto GIS land use layers (such as the LCDB or Agribase).
[7] These were: pipfruit models for Hawke's Bay and Nelson; a kiwifruit model for Bay of Plenty; viticulture models for Hawke's Bay and Marlborough; an arable model for Canterbury; and seven apiculture models.

- Dairy: Each year Dairy NZ publishes an economic outlook of a representative set of farms across different regions and ownership types in New Zealand (DairyNZ, 2015). The ownership types are owner-operators and 50:50 sharemilkers. The eight regions covered are Northland, Waikato, Bay of Plenty, Taranaki, Lower North Island, West Coast-Tasman, Marlborough-Canterbury and Otago-Southland.

- Meat and wool: Beef and Lamb New Zealand publishes an annual economic outlook of representative farms across different regions, classes and productivity quintiles (Beef + Lamb New Zealand, 2015). There are nine farm classes spread over five regions. The regions are:
  - Northern North Island: Northland, Waikato, Bay of Plenty
  - Eastern North Island: Gisborne, Hawke's Bay, Wairarapa
  - Western North Island: Taranaki and Manawatu
  - Northern-Central South Island: Marlborough, Nelson, Canterbury
  - Southern South Island: Otago, Southland.

  The farm classes represent common relationships among terrain, stocking units and management type. The classes are:
  - South Island: High country, hill country, and intensive finishing.
  - North Island: High country, hill country, finishing, breeding, intensive finishing and mixed finishing.

- Forestry: Scion has recently developed a spatial-economic model known as the Forest Investment Framework (FIF). This model generates a geospatial information systems (GIS) layer of profits as a function of forestry yields, costs and timber prices (Harrison, et al., 2012). However, FIF does not consider the spatial distribution of different forest-age classes. Such age-class information could be obtained by surveying forest owners affected by a specific wildfire event. The FIF uses cost data obtained from AgriHQ (previously Agrifax) and log-price data from MPI. Profitability estimation outputs from FIF (a spatial layer indicating $/ha) are obtained by running the model. The FIF model would need to be run on a case-by-case basis by contracting Scion.

  Good alternative sources of information to FIF are AgriHQ for production costs and prices (AgriHQ, 2015), and MPI's yield tables published annually in the National Exotic Forest Description (NEFD) for different regions, silvicultural regimes and log grades. The NEFD is published annually by MPI (MPI, 2015b).

For example, Figure 2 shows the spatial distribution of different land uses affected by different fire intensities. Such a spatial distribution is the hypothetical representation of a proper GIS database such as Agribase (AssureQuality, 2016) or the LCDB (Thompson, et al., 2003). Such GIS databases contain information on land cover, land use, and area among other things[8]. The profits for each land use type have been obtained from the aforementioned databases and are the following ones:

- $3,050/ha/yr for an average dairy farm in the Waikato region (DairyNZ, 2015);
- $2,758/ha/yr for forestry representing Kaingaroa Forest's 2015 profits[9] (Boot, 2015);
- $600/ha/yr for an intensive finishing sheep farm in Waikato (Beef + Lamb New Zealand, 2015).

---

[8] LCDB contains information on land cover whereas Agribase contains information on land use.

[9] Such hypothetical example includes the profits earned by a representative forest owner and would be different for other forests conditioned on forest size and location among other factors. Such profits have been annualised considering a sustainable forest that has reached a steady state regarding annual harvest yield. In other words, the profits have been divided by the predominant rotation age in the Central North Island – 28 years. The downstream profits earned by the transportation and manufacturing sectors are not included in the reported figure since they are treated as "business disruptions" in this framework, which are covered in the indirect tangible impacts section.

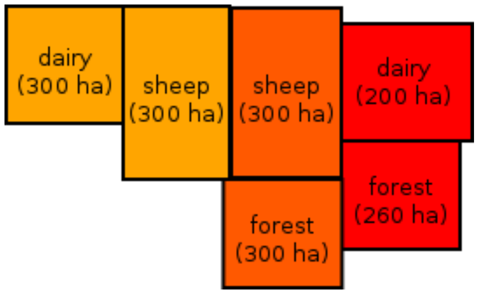

Figure 2. Hypothetical representation of a land-use spatial layer affected by intensive fires (red colour), intermediate fires (dark orange colour), and light fires (light orange colour).

Table 1. Hypothetical annual loss factors by fire intensity for a 5-year horizon.

Years	Light fire	Interm. fire	Intense fire
0	50%	70%	100%
1	40%	60%	90%
2	30%	50%	80%
3	20%	40%	70%
4	10%	30%	60%
5	0%	20%	50%

Table 2. Hypothetical losses in a dairy farm due to a wildfire event for a 5-year horizon.

Years	Loss of profit ($)		Discounted loss ($)	
	Light fire	Intense fire	Light fire	Intense fire
0	457,500	610,000	457,500	610,000
1	366,000	549,000	351,923	527,885
2	274,500	488,000	253,791	451,183
3	183,000	427,000	162,686	379,601
4	91,500	366,000	78,215	312,858
5	0	305,000	0	250,688
Subtotal			1,304,115	2,532,216
Total			3,836,330	

Table 1 lists the loss factors ($lossfct$), which differ by fire intensity. Resiliency is represented by the reduction of the loss factor through time. The areas affected are listed in Figure 1. Hence the detailed example for a dairy farm is listed in Table 2. Two dairy farms have been affected by different fire intensity levels: light fire affected a 300-hectare dairy farm whereas an intense fire affected a 200-ha farm. Assuming a discount rate (i.e. opportunity cost) of 4% and a 5-year time horizon, the discounted profit loss for a light fire for year 1 is calculated as following:

$$profloss_{l=dairy,i=light,t=1} = (40\%) * (\$3{,}050/ha/yr) * (300ha) = \$366{,}000/yr$$

$$discprodloss_{l=dairy,i=light,t=1} = \frac{\$366{,}000/yr}{(1+4\%)^1} = \$351{,}923/yr$$

Hence, the total loss for both dairy farms considering a 5-year time horizon would be about $4 million. Considering the profits, areas and loss factors of the other two sheep farms and two forests, the total productivity loss in the hypothetical fire example would be approximately $9.6 million and estimated as follows:

$$totprodloss = discprodloss_{l=dairy} + discprodloss_{l=forestry} + discprodloss_{l=sheep}$$

$$totprodloss = \$3{,}836{,}330 + \$5{,}058{,}152 + \$709{,}360 = \$9{,}603{,}843$$

The hypothetical example of a fire event affecting different land uses at different intensities showcases the combination of GIS databases and economic data obtained from the aforementioned data sources. Such calculation already includes resilient capacities for different land-uses, farms and fire intensities. All calculations have been discounted to the present to consider the time dimension. The loss factors can also be obtained from more detailed farm or forest-level calculators such as Farmax (Bryant, et al., 2010) and FIF.

Direct tangible impacts: Infrastructure

The framework would consider three main infrastructure categories: private, public and conservation. As previously stated, an economic loss assessment considers depreciated market values rather than replacement costs. According to the Bureau of Transport Economics (BTE, 2001), “unless the asset is close to the beginning of its expected life, the insurance payout [i.e. replacement cost] will significantly overstate the economic value of the loss”. Hence, following the economic loss assessment used in this framework and under the assumption that the asset will be replaced at constant time intervals, the present value of perpetual replacement expenditures can be represented by $expense$ (BTE, 2001):

$$expense_b = mktval_b * \left[\frac{(1 + disc_b)^{life_b}}{(1 + disc_b)^{life_b} - 1}\right]$$

where b is a set representing different assets, $life$ is the asset’s lifetime, $disc$ is the discount rate and $mktval$ is the market value of the asset. Hence, the economic loss resulting from a disaster can be represented by $totassetloss$:

$$totassetloss = \sum_b expense_b * \left[1 - \frac{1}{(1 + disc_b)^{life_b * frc_b}}\right]$$

where frc represents the fraction of the asset’s lifetime left if the wildfire had not happened. Hence, in essence, the economic loss is the fraction (or frc) of total expenses brought forward.

Following the previous example of a dairy farm, if the replacement cost of a milking facility is $100,000 (or $mktval$), its lifetime is 30 years (or $life$) and the discount rate (or $disc$) is 4%. Without any wildfire events, the present value of perpetual replacement outlays happening every 30 years is $144,575. If the wildfire event happened in year 20 (or two thirds into the facility’s lifetime), then the present value of the future expenses would be brought forward by 10 years (or a third of the facility’s lifetime). Hence, the total economic loss would be:

$$expense_{b=facility} = \$100{,}000 * \left[\frac{(1 + 4\%)^{30}}{(1 + 4\%)^{30} - 1}\right] = \$144{,}575$$

$$totassetloss = \$144,575 * \left[1 - \frac{1}{(1+0.04)^{30*0.3}}\right] = \$46,905$$

The lifetime and discount rates of different infrastructure types can be obtained through a survey after a fire event from the asset owners affected. The market values can be obtained from the following sources:

- Private: This category includes commercial, industrial and residential buildings. According to one of the most recent earthquake risk assessment studies performed for Christchurch, the market value information for properties and buildings can be obtained from local councils (Brabhaharan, et al., 2005). Such information used to be maintained by the Government Valuation Department. However, after the Rating Valuation Act of 1998, such information was transferred to local councils. Such information is generally available at either property or mesh block levels. If this information was not available from local councils, a good alternative would be Quotable Value (QV, 2015). Currently, the RiskScape model uses valuation data from QV. QV holds similar information as councils and would provide it in a timely manner. Additional information such as building structure, age and number of storeys can be readily obtained from such databases.

- Public: This category includes lifeline networks such as roads, water supply, telecommunications and electricity. If a private company owns the infrastructures, then they should be included in the previous category. According to Brabhaharan, et al. (2005), such information can be obtained either from local councils, or the Road Assessment and Maintenance Management (RAMM, 2015).

- Conservation: According to the 2014 review of DOC by State Services Commission, the Treasury and the Department of the Prime Minister and Cabinet, DOC manages $5.4 billion in capital assets of which 9% are DOC-owned assets such as tracks, huts and structures (DOC, 2014). Such values can be directly obtained from DOC on a case-by-case basis.

Hence, if the infrastructure was damaged or lost in the 200-ha dairy farm of the aforementioned hypothetical example, the total tangible direct loss attributed to infrastructure and productivity potential would be approximately $2.6 million obtained from adding infrastructure ($46,905) and productivity ($2.5 million) loss. If a life was lost in the 200-ha dairy farm under an intense fire, the total tangible direct loss would be approximately $6.5 million obtained in the following manner:

$$total\ tangible\ and\ direct\ loss = totassetloss + totprodloss + lifeloss$$

$$total\ tangible\ and\ direct\ loss = \$46,905 + \$2,532,216 + \$3,950,000 = \$6,529,121$$

Indirect tangible impacts: Physical health

The difference between this category and the 'lives and injuries' category outlined above is that here fire is not considered to directly cause health impacts and their symptoms are, in some cases, not identified instantly. The main indirect tangible health impacts of wildfires considered in the literature are respiratory illnesses (e.g. asthma and bronchitis) suffered by people affected by smoke in areas surrounding the fire site. However, according to Finlay, et al. (2012), cardiovascular, ophthalmic and psychiatric problems can also result from the smoke produced by wildfires. The symptoms of these health effects might take time to identify, unlike burn injuries suffered by people directly in contact with the fire that are identified instantly.

The methods most commonly used in the literature to value fire-related health impacts have been the cost of illness (COI) (Bauen, et al., 2013) and damage functions (or dose-response functions) (Richardson, et al., 2012). Similar to the method used to value injuries, the COI includes “expenditures on medical care and medications, the opportunity cost of time spent in obtaining medical care, and lost wages from not being able to work” (Richardson, et al., 2012). The damage function relates exposures to a specific pollutant, health outcomes and associated costs.

A good starting point to estimate the COI is the report on “the impact of respiratory disease in New Zealand” (Barnard, et al., 2015). This report estimates the cost of serious respiratory diseases to the New Zealand economy based on the costs of pharmaceuticals, hospitalisation, mortality data, visits to a doctor, adult prescriptions, days off school/work, emergency department visits and years lost due to disability. A per-capita figure could be estimated from this publication. Due to the main rural scope of this framework, it is worth including the business costs related to sole operators’ (e.g. farm managers and primary sector contractors) poor physical health, as a result of a fire event, which may affect the productivity of the operators’ business operations due to lower stock performance, reduced production volumes and a lower return.

To relate such per-capita costs to the damage levels from specific fire events, a damage function could be developed from studies undertaken in New Zealand regarding health effects due to domestic fires (i.e. woodburners, etc.). According to Kuschel, et al. (2012), “domestic fires dominate the health impacts associated with anthropogenic air pollution across New Zealand”. Although the health effects from domestic fires (e.g. low-level and long-lasting exposure) are quite different than the ones caused by wildfires (high-level and acute exposure), they are a starting point to estimate health effects. The damage function could then be applied to the people exposed to the smoke produced by specific fire events. Otherwise, data could be obtained on hospitalisations due to respiratory illnesses directly from the hospitals close to a specific fire site.

However, COI and damage functions ignore factors such as the “investments of time or money in taking preventive actions to decrease exposure, and the disutility associated with symptoms or lost leisure” (Richardson, et al., 2012). Hence, according to Richardson, et al. (2012), “the theoretically correct measure of this cost is the individual willingness to pay to avoid this damage because it will include all costs individuals face when exposed to fire smoke”.

The willingness-to-pay values can be estimated from market data on wage risk trade-offs or from surveys eliciting such trade-offs after specific fire events (Rittmaster, et al., 2006). An alternative procedure would be to use transfer functions with the willingness-to-pay values previously estimated in other countries (e.g. Australia or Canada) adjusted to the local economy by a per-capita income differential (de Mendonça, et al., 2004).

Indirect tangible impacts: Business disruptions

According to impact-assessment studies on wildfires or natural hazards in the literature, most business disruptions are difficult to identify and measure due to the detailed information required (e.g. business and household surveys) and the large time span over which different wildfires occurred (Ashe, et al., 2009; Hall, 2014; Handmer, et al., 2002; Stephenson, 2010). There are currently no studies on the indirect impacts from business disruptions due to wildfires in New Zealand nor any historical data available from which to estimate average annual costs. If there were historical data then it would be possible to estimate and attribute a multiplier to the direct effects measured on a per-hectares basis.[10] However, this is a major knowledge gap that needs to be filled in order to accurately estimate total after-fire costs.

Fire-cost assessments such as those published by Ashe, et al. (2009) and Hall (2014) used a combination of surveys and the 'averaging' assessment approach. Ashe, et al. (2009) used information from the U.K. to arrive at an estimate of indirect fire losses for Australia. Hall (2014) used historical data to estimate indirect impacts in the U.S. as percentages of direct impacts. He apportioned costs as follows: 65% for manufacturing and industrial properties; 25% for public, educational, institutional, store and office properties; 10% for residential, storage and special-structure properties; and 0% for vehicle and outdoor fires. Alternatively, Handmer, et al. (2002) and Stephenson (2010) suggested running focus groups or surveys with industry experts to arrive at acceptable indirect impacts due to business disruptions.

The approaches suggested and followed by major assessment frameworks are useful as a first option when budget and time constraints are critical. However, a synthetic and more robust alternative for assessing indirect impacts from business disruptions uses complex regional economic models based on relevant literature for natural hazards. Such economic models are broadly known as integrated assessment models and include Social Accounting Matrices (SAMs) (Munasinghe, et al., 2010), Input-Output (I-O) and Computable General Equilibrium (CGE) models. Such models have been considered essential for estimating indirect effects, because "they focus on flows, can measure community resilience, and because it is nearly impossible to cover and sort out the many linkages in a regional economy of any significant size through direct data collection" (Rose, et al., 2002).

The essential usefulness of such approaches is the implicit connectivity of different sectors in the economy representing links along the value chain. All sectors produce commodities by employing labour and using inputs/capital produced in the region. Hence, a wildfire event would affect the production capacity of different sectors and, subsequently, the labour and capital demands would be reflected in job and investment losses. Furthermore, wildfires can also affect lifelines such as energy and transportation networks by indirectly affecting sectors that highly depend on them. Combinations of downtime, sector composition and sector resiliency are the key considerations used to estimate losses stemming from the curtailment of utilities or transport services due to the damage to lifeline networks arising from natural hazards such as wildfire events (Rose, et al., 2002). Lost business opportunities is another important aspect to consider since it can exert tangible impacts upon future profits, employment and regional gross domestic product. A good example would be exporting industries, where overseas or domestic competitors may achieve significant productivity improvements while the affected businesses are in a rebuilding phase.

In the case of New Zealand, such models represent the economy in a stylised manner through a matrix that can be readily obtained from Statistics New Zealand for the entire country. A key challenge is to reduce these national matrices to just those regions affected by wildfire events. Currently, Market Economics Ltd is one of the few entities in the country that develops regional matrices (Zhang, et al., 2008). In fact, Market Economics Ltd has been included in the Resilience to Nature's Challenges National Science Challenge to measure indirect impacts from business disruptions caused by earthquakes and floods (although not wildfires) using CGE models jointly with the RiskScape model developed and maintained by the National Institute of Water and Atmospheric Research (NIWA, 2015).

[10] A multiplier is the factor of proportionality that measures how much indirect costs (e.g. manufacturing potential and employment lost) change in response to a change in direct costs (i.e. immediate and medium-term after-fire costs).

Hence, a robust alternative to estimating business disruptions due to wildfires in New Zealand would be to simulate wildfire event scenarios and assess indirect economic effects with a basic regional I-O model. Recent major wildfires could be simulated using fire-growth simulation software, such as Prometheus. The direct after-fire impacts (i.e. profit losses) on different land-uses (e.g. pasture, horticulture and forest) would be estimated from the fire perimeters generated by Prometheus and using the data sources previously listed (e.g. LCDB, Agribase, etc.). The regional I-O model would assess the business disruption impacts (e.g. employment, tax generation, consumption, etc.) suffered by industries such as transportation and manufacturing. The environmental impacts reflected in changes in recreational demands would also be measured and included in the regional I-O model. The model would be based on regional I-O tables or SAMs developed by following the procedures described in Zhang, et al. (2008) for New Zealand and Monge, et al. (2014) for the U.S.

Intangible impacts

The direct and indirect effects of intangible impacts are combined.

Direct and Indirect intangible impacts: Mental health

Beyond direct injuries and physical health impacts, the mental health effects caused by wildfires are often extensive and long lasting. Like physical health impacts, mental health impacts are considered indirect since they are not a direct result of wildfires and their symptoms are often identified long after the wildfire event. Health impacts should not be confined to an individual, but include entire families (even extended ones) since they can be impacted by the poor health of an individual. Due to their long-term duration and lack of assessment methods, such impacts are generally ignored in loss assessments of natural hazards. Among the most common symptoms suffered by individuals who have experienced wildfires are the stress-related ones (e.g. post-traumatic stress disorder), depression and schizophrenia (Jenkins, et al., 2009). Due to the rural scope of this framework, it is worth including the business costs related to sole operators' (e.g. farm managers and primary sector contractors) poor mental health, as a result of a fire event, which may affect the productivity of the operators' business operations.

Post-traumatic stress disorder (PTSD) is a good example for wildfires since it describes a range of mental and physical problems that can follow a threatening or distressing event (e.g. wildfire) (Ferry, et al., 2012). According to the Diagnostic and Statistical Manual of Mental Disorders criteria (American Psychiatric Association, 1994), the four broad symptoms for PTSD are: (1) re-experiencing the traumatic event, (2) avoiding things that re-trigger event memories, (3) numbing of responsiveness, and (4) hyper-vigilance symptoms.

A good starting point to value the losses from PTSD and other mental disorders would be a report assessing the economic burden of such disorders to society, similar to the ones developed for respiratory illnesses (e.g. asthma). There are economic studies that relate traumatic events or natural hazards to PTSD in the literature. For example, Ferry, et al. (2012) estimated the economic burden of PTSD in Northern Ireland due to the civil war. Knowlton, et al. (2011) estimated the economic burden of PSTD due to climate-change-induced hurricanes in the U.S. among other things. Greenberg, et al. (1999) estimated the economic burden of anxiety disorders in the 1990s and identified that PTSD has the highest rate of service use among mental disorders.

However, there are no studies in New Zealand or Australia that assess the economic burden of PTSD to society (Australian Centre for Posttraumatic Mental Health, 2007). There is one study that measures the economic cost of traumatic brain injury (TBI) in New

Zealand (Te Ao, et al., 2014). Although TBI is unlikely to be caused by wildfires, the methodology followed and datasets used would be a good starting point to develop an assessment for PTSD and other mental disorders in New Zealand.

Te Ao, et al. (2014) followed the same method used in the studies undertaken for PTSD in other countries with a slight modification. The authors estimated the cost of illness (COI) per person and then multiplied such estimates by an incidence and prevalence value in New Zealand. COI assessments of mental disorders include direct (e.g. service visits and medication costs) and indirect costs (e.g. productivity losses and presenteeism). They also estimated hospitalisation costs based on hospital reimbursements from the Ministry of Health. The cost of community and home support was approximated by the cost per hour per therapist and number of visits to therapists (i.e. nurses, psychologists and social workers). The lifetime healthcare costs occurring each year were discounted and summed with the first-year costs. The value of lost employment up to age 65 years was estimated for adults employed previous to the injury. Cost of productivity was estimated using reported loss of income combined with Statistics NZ data on average weekly earnings per occupation categories.

A similar methodology to the one used by Te Ao, et al. (2014) could be used for the long-term mental health impacts from wildfires in New Zealand. This implies estimating the COI per person for a specific illness (e.g. PTSD) and combining such values with the incidence of mental illnesses due to wildfires. The incidence could be estimated by gathering hospitalisations in hospitals near the fire event after a certain number of months since it might take some time before symptoms are identified and affected individuals present themselves.

Direct and Indirect intangible impacts: Environmental

A wide range of environmental impacts can occur after a wildfire. Four of these (carbon emissions and sequestration, erosion and sedimentation, recreation and tourism, and biodiversity) are discussed in more detail below.

Carbon emissions and sequestration

The carbon emissions generated during and after a wildfire event are an externality suffered by society. Hence, according to de Mendonça, et al. (2004), the economic cost should be acknowledged by considering either the avoided damage (i.e. mitigation benefits) or the mitigation costs.

Avoided damage (i.e. mitigation benefit) is defined as the difference between various emission scenarios in terms of wellbeing. In the case of New Zealand, the studies by Takatsuka, et al. (2009) and Baskaran, et al. (2009) could be a good starting point since they measured the willingness to pay for a proposed programme that would guarantee a reduction in greenhouse gas (GHG) emissions. The latter study estimated that people would be willing to pay between $60 and $97/household/year for emissions reductions of 20% and 50%, respectively. The former study estimated a range of $8 and $15/household/year for reductions of 10% and 30% in Canterbury, respectively.

The alternative method is to value emissions using the mitigation cost (or carbon offset price). This approach has been used internationally by different mechanisms of the Kyoto Protocol and nationally by the Emissions Trading Scheme (Beets, et al., 2009)[11]. Since

[11] International carbon prices are a controversial issue since the mitigation cost is higher for affluent countries such as New Zealand. For example, allowing for the purchase and surrendering of international Kyoto carbon units under the New Zealand ETS caused carbon prices to fall drastically from $25/unit in 2008 to $2/unit in 2013.

New Zealand has decided to take its next emissions reduction commitment (2013-2020) under the United Nations Framework Convention on Climate Change (UNFCCC) rather than the Kyoto Protocol, emissions from fires are not considered national liabilities. However, emissions are still an externality suffered by society. Hence, the current carbon price of $9 per New Zealand unit (CommTrade, 2015) is a good approximation of the value of emissions from fire.

According to de Mendonça, et al. (2004), the quantity of emissions produced by a wildfire depends on the area affected, biomass type and quantity, and rate of biomass lost (i.e. combustion factor). The NRFA maintains a database of annual wildfire area estimates (Anderson, et al., 2008) divided into grassland, scrub and forest. These subcategories are used to obtain biomass type and quantity as a basis for reporting emissions from wildfires in the national greenhouse gas inventory (MFE, 2015).

Although NRFA maintains separate wildfire area estimates for planted and natural forests, no age categories have been published to date. Hence, a good starting point to estimate forest biomass quantity would be to use the national mean ages estimated by Wakelin (2011) for pre-1990 and post-1989 planted forests using the Land Use Carbon Analysis System (LUCAS) annual planting area data and yield table. Wakelin (2011) used the mean biomass content of 145 tonnes of carbon per hectare, estimated by Beets, et al. (2009), for natural pre-1990 forests. He also used the Intergovernmental Panel on Climate Change's (IPCC) default assumption that 45% of above-ground biomass is lost or oxidised in forest fires. Such loss estimates could be improved by using synthetic stage-damage curves from wildfire simulation software (e.g. Prometheus) for different fire intensities, if the fire intensity was recorded or estimated. Another potential starting point to measure annual emissions from forests would be Holdaway, et al. (2014).

Similar to the concept of opportunity cost, lost carbon sequestration potential from a wildfire should also be accounted for in an after-fire assessment. If the forest was completely lost to a wildfire and instantly reforested, then no loss of sequestration potential should be considered since the new forest is likely to sequester carbon at a rate equal to or higher than the rate previously anticipated. However, if the forest was partially damaged and not instantly harvested (for salvage timber) or reforested, the lost potential from the land not sequestering carbon should be considered. The lost sequestration potential could be estimated from yield tables modelled spatially using FIF. The valuation methodology would be similar to the valuation of emissions where a carbon price is assigned according to the mitigation cost principle.

The biomass quantity and loss rate for arable and grassland can be obtained from the latest national greenhouse inventory (MFE, 2015). For arable land, the report lists the parameters used to estimate the quantity of nitrous oxide released under the "field burning of agricultural residues" chapter. Such estimates were developed by the New Zealand Crown Research Institute Plant and Food (Thomas, et al., 2011) and are a close approximate to the emissions from a wildfire. For grassland, the average biomass quantities per hectare are listed in Table 6.1.3 under the "Land Use, Land-Use Change and Forestry (LULUCF)" chapter. The default loss rate for grassland of 86% was established by the IPCC for tropical savannah (IPCC, 2006). However, New Zealand uses country-specific factors when calculating emissions from grassland fires in both scrub (i.e. grassland with wood biomass) and grassland. For grassland, these factors include the live-to-dead biomass ratio and the assumptions that 100% and 80% of aboveground dead and live biomass are consumed by fire, respectively (Wakelin and Pearce, 2011; Wakelin, personal communication, 2015).

Erosion and sedimentation

According to Stephenson (2010), the erosion caused by the removal of vegetation from a wildfire is an indirect and intangible impact that should be considered in an environmental loss assessment. Since there are currently no figures or records in New Zealand of the erosion caused by wildfires, synthetic estimates could be obtained using the New Zealand Empirical Erosion Model (NZEEM) developed by Dymond, et al. (2010). According to Barry, et al. (2014), a GIS layer of disturbed erosion rates could be developed using FIF and NZEEM by comparing erosion rates under forested and bare (i.e. disturbed) land.

The losses caused by wildfire-caused erosion could be valued using a group of pivotal valuation studies in New Zealand. Krausse, et al. (2001) estimated that the national economic cost of soil erosion and sedimentation was approximately $126 million per year. The authors concluded that the erosion costs from on- and off-site impacts were $76 million and $27 million per year, respectively. Dymond, et al. (2012) then allowed for inflation and used the total cost estimated in Krausse, et al. (2001), and the annual estimate of eroded soil exported to the sea of 200 million tonnes by Dymond, et al. (2010), to arrive at an erosion cost of $1 per tonne. Barry, et al. (2014) estimated a cost of $6.5 per tonne by eliciting the avoided costs of flood damage and water treatment from regional and city councils in New Zealand.

Recreation and tourism

The recreational activities enjoyed by international and domestic tourists in New Zealand take place mainly in national parks and tracks where access is free. Nevertheless, such parks and tracks hold an immeasurable value to the nation since they generate direct income to concessionaires (walking track companies, guides, water-taxis, etc.) plus indirect income to the businesses (e.g. airlines, shops, backpackers, etc.) that depend on the tourism generated by such public amenities. Although access to these parks and tracks is free and is not measured directly by a monetary value, there are non-market valuation methods that either consider the tangential expenditures incurred by tourists (i.e. travel cost method) or the willingness to pay to enjoy certain recreational characteristics (i.e. contingent valuation)[12]. Hence, their inclusion into an after-fire cost framework is critical since they would measure the losses experienced by a regional economy due to wildfires.

To assess the economic cost of wildfires to the tourism industry, a good starting point is to use the 2015–2021 projections of the number of international visitors and expenditure per visitor published by the Ministry of Business, Innovation and Employment (MBIE, 2015c). This report projects total expenditures, number of visitors, total visit days, expenditures per day, and average length of stay for visitors from different parts of the world. The International Visitor Survey (IVS) and Domestic Travel Survey (DTS) also published by MBIE (2015a, 2015b) could be used to localise the tourism expenditure figures in the 2015-2021 projections to specific regions in New Zealand. However, non-market valuation figures would be needed to relate regional tourism estimates to outdoor, nature-based recreational activities in specific parks and trails. A good starting point to gather national and international value estimates using various non-market valuation methods would be the Lincoln Ecosystem Services Valuation Database (Lincoln University, 2015) and the Environmental Valuation Reference Inventory (EVRI, 2015), respectively. The former provides a list of more than 850 valuation studies performed in New Zealand from which values have been standardised temporally and spatially to U.S. Dollars per hectare per year values. The latter is a benefits transfer global database supported by environmental entities from Canada, New Zealand, U.S., Australia, Mexico, France and the U.K. The EVRI database was "designed specifically to help economists evaluate the quality of the information about the study site(s) and to match the studies with current policy sites" (EVRI, 2015).

[12] Some tracks charge for the use of huts and campsites, e.g. Routeburn and Abel Tasman tracks.

A subset of the studies listed in the previous two databases has been undertaken in representative conservation parks in New Zealand and could be directly used in wildfire loss assessment exercises. However, to relate the loss of recreation and tourism amenities to specific wildfire events and intensities, a set of surveys should be performed for representative conservation areas recently affected by fires. Other characteristics should be percentage of viewshed (i.e. area visible from a location) burned, intensity of wildfire, time since event, viewing distance and trails affected. The literature in the strategic development of such surveys is extensive (e.g. Loomis, et al., 2010; Venn, et al., 2011). Such information would help to identify the sites that would have a measurable effect on tourism since not all of the sites affected by fire events would impact tourism.

A potential methodology to make such elicited non-market values spatially explicit would be to correlate them to geographical and economic characteristics in the region or parks in question, resulting in a GIS layer (Baerenklau, et al., 2010; Eade, et al., 1996). Such a GIS layer could then be transferred to other parks with similar geographical characteristics using transfer value functions. The economic characteristics in the region (e.g. per-capita income levels) could be adjusted to reflect the region in question. This approach would save money by performing surveys in representative parks and using GIS modelling to map such values in other parks.

Biodiversity

In contrast to the values that visitors assign to the environmental services directly enjoyed (or used) in conservation areas, there are also benefits that non-visitors receive from the knowledge that a natural environment, habitat or species is protected for current and future generations. Such benefits are known as bequest, existence or passive use values. Non-market valuation techniques such as contingent valuation and choice modelling have been widely used to value the existence of such environmental services (Loomis, et al., 2010). Biodiversity is therefore a special case that needs to be considered in an after-fire loss assessment.

Biodiversity enhancement or conservation can be expressed through a wide array of specific goals such as ecological integrity, biodiversity persistence, human prosperity or ecosystem services (Overton, et al., 2015). However, according to Lee, et al. (2005), New Zealand's biodiversity strategy goal can be fully represented by the concept of ecological integrity, which can be further specified in three concepts: species occupancy, environmental representation, and native dominance. In an attempt to operationalise the concept of ecological integrity, Overton, et al. (2015) developed the Vital Sites framework that uses the concepts of significance and benefit of management to spatially identify sites where conservation actions result in the largest gains to achieve ecological integrity.

Significance is a useful concept to rank different species and sites according to their marginal contribution to a conservation goal. To measure site significance, Vital Sites uses two different models to assess: (1) species significance using the concept of species occupancy; and (2) environment significance according to the presence of indigenous vegetation. Benefit of management is defined as the marginal contribution of different actions to conservation goals, which in a wildfire context could be pre-suppression and suppression actions. To estimate benefit of management, the authors consider future expected biodiversity losses (i.e. vulnerability) due to pressures with and without conservation actions. In an after-fire context, the concept of vulnerability in Vital Sites could be used to apply a wildfire pressure to different sites where wildfire events either have occurred or will likely occur in the future to measure the extent of losses.

However, a monetary metric would be necessary to report overall economic after-fire losses. Non-market valuation would be necessary for the most important species at representative DOC sites. Such species and sites could be chosen according to the significance metric used by Vital Sites. A good starting point to obtain values for native species in New Zealand would be the Lincoln Ecosystem Services Valuation Database (Lincoln University, 2015). A subset of those studies deals with biodiversity and ecosystem services. If such estimates are not available for the high ranking species, then performing a survey would be necessary for representative DOC sites that either have a high wildfire incidence or have recently had a wildfire event. Such elicited values would then be applied to the biodiversity inventories used or generated by Vital Sites.

Summary of data availability and assessment feasibility

As is the case for other natural hazards, direct and indirect after-fire impacts are an extremely important component of the total cost of wildfires. A framework for assessing the after-fire economic impacts of wildfires in New Zealand has therefore been developed, based on frameworks generated for other major natural hazards or disasters. The ideal methodologies to assess these after-fire costs have also been identified from relevant national and international literature and described in some detail. A summary of the availability of data for use in both current and potential assessment methods for the different after-fire cost categories in New Zealand is presented in Table 3. A matrix representation of the final product of a populated after-fire cost dataset is shown in Table 5. To estimate a final after-fire cost, quantities or incidences per individual impacts are needed as well as their respective values or costs.

From previous studies and existing data, it has been identified that incidence and values information for human lives, injuries, productive potential, infrastructure, carbon emissions, carbon sequestration, erosion and sedimentation are available to an extent that could be considered sufficient to arrive at a potential estimate in the short term.

Table 3. Summary of data availability and assessment method per after-fire cost item.

After-fire cost item	Data availability	Assessment method
Human lives and injures	Yes	Averaging
Productive stock	Yes	Averaging or synthetic
Infrastructure	Yes	Averaging or synthetic
Physical health	Partially	Synthetic or survey
Business disruptions	No	Synthetic or survey
Mental health	No	Surveys
Environmental		
Carbon emissions and sequest.	Yes	Averaging or synthetic
Erosion and sedimentation	Yes	Synthetic
Recreation and tourism	Partially	Synthetic and surveys
Biodiversity	Partially	Synthetic and surveys

Valuation data are partially available for the following environmental intangibles: recreation, tourism and biodiversity. Such data are available through compiled datasets of non-market values and national statistics. However, there are no incidence data that relate values to wildfire events and intensities for these intangibles. Hence, it is highly recommended that such data be gathered through surveys or synthetically using modelling software (e.g. Vital Sites and Prometheus) in critical areas. A surveying method would be to gather a panel of subject experts in these elements and elicit representative or ballpark estimates. The decision to gather such data depends on the extent of impacts of different wildfire events on intangible and environmental factors.

Regarding health effects, there are no incidence or valuation data for New Zealand wildfire events to the best of our knowledge. A few alternatives have been suggested in this report on how to gather such data (e.g. surveys and hospitalisation records) and good starting points to value physical health effects are available through national reports and statistics for other causes. It is also highly recommended that such data for wildfires be gathered if mental health impacts are considered critical to a specific after-fire loss assessment. A panel of experts would again be a relatively cheaper and simpler alternative given the scope of the context of rural fire in New Zealand.

There are no data or previous studies for business disruptions due to wildfires in New Zealand. Such indirect impacts have been considered critical components of after-fire economic impact assessments in the U.S. concluding that, in certain instances, they are even higher than direct impacts. Such impacts could be measured by performing surveys with experts or synthetically using complex economic (e.g. IO, SAM or CGE) and fire simulation models (e.g. Prometheus). A panel of experts would also be a relatively cheaper and simpler alternative to elicit representative estimates.

Integration with incidence reporting system

As previously stated, data availability for certain after-fire costs items is readily available to different extents (Table 3). For example, productive potential, carbon and erosion data can be obtained in a spatially explicit format (e.g. GIS layers) by gathering the data directly from public sources or using third-party software (e.g. FIF and Prometheus). Such spatial disaggregation would fit perfectly into the parallel spatial projects which have been undertaken by the NZFSC on fire incidence reporting system (Figure 3) and Wildfire Prone Areas (Pearce, et al., 2014). The fire incidence reporting system will rely on widely available land-use databases such as LCDB v4.

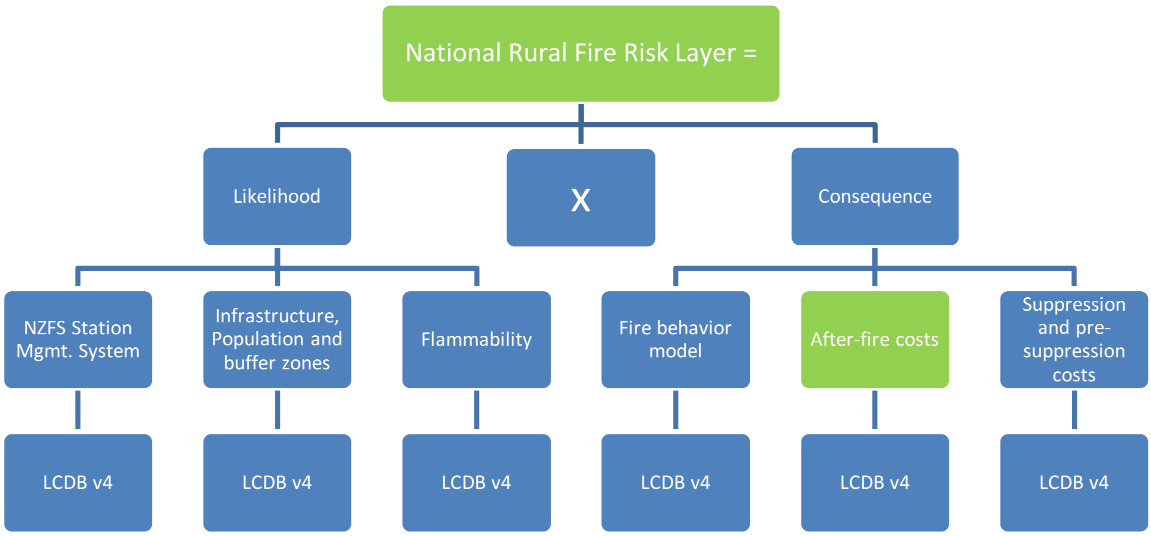

Figure 3. Hierarchical representation of the national rural fire risk layer.
Source: Rob Goldring, NZFSC.

Table 4 lists a potential aggregation scheme that could be used to integrate the after-fire cost framework and the fire incidence reporting system using two widely applied GIS databases: LCDB v4 and Agribase. The last column of Table 4 lists the land-use categories used in the after-fire cost framework (Figure 1) whereas the first column lists the LCDB categories on which the fire incidence reporting system will be based upon. Hence, overlaying LCDB and Agribase would result in a spatial disaggregation similar to the one proposed in the after-fire cost framework. The LCDB provides maps of land cover including 71 different classes (first column of Table 4). Agribase provides land-use maps including 46 categories (second column of Table 4). Hence, LCDB and Agribase complement each other since, by overlaying both databases, a more detailed land-use map can be obtained. For example, LCDB identifies the areas with pastureland and Agribase would divide such pasturelands into dairy, meat or wool. On the other hand, Agribase might show that a farm is 100% dairy when in reality the farm might contain portions of shrubs, native and exotic forests. The latter would be identified by overlaying the LCDB over Agribase.

Table 4. Land-use aggregation scheme combining LCDB v4 and Agribase.

Land Cover Database (LCDB) v4	Agribase	Land-use category
Depleted tussock, high producing exotic, and low producing grassland	Dairy milk production, dairy dry stock rearing, and grazing other people's stock	Dairy
	Beef cattle farming, sheep farming, and mixed sheep and beef farming	Meat and wool
Exotic forest, harvested forest, and deciduous hardwoods	Forestry	Forestry
Orchard, vineyard, mānuka and/or kānuka*, and other perennial crops	Avocados, berryfruit, squash, stonefruit, nursery, vegetable, viticulture, citrus, cut flower, kiwifruit, nuts, other fruits, other plants, pipfruit, and other orchards	Horticulture
Short-rotation cropland	Arable cropping, maize, hay fodder, herbs, and seed crops	Arable
Built-up area, Urban parkland/open space, transport infrastructure	Lifestyle properties, tourism, honey, horses, deer, kennels, ostrich, emu, piggeries, aquaculture, poultry, goat, zoological gardens, miscellaneous animal types and land uses	Urban/rural, public and others
Indigenous forest, mānuka and/or kānuka*, fernland, flaxland, gorse, broom, broadleaved indigenous, matagouri, grey scrub, and scrubland	Native forest blocks, not farmed (idle), unspecified	Conservation

* Mānuka and kānuka could be considered intensive horticultural crops if the landowner's objective is the production of honey or oil. If the objective is conservation, then the area in question should be categorised as conservation land.

For the purposes of after-fire impact assessments, the aggregation of conservation land into one land-use category is considered to be coarse. The ideal scenario would be to have a systematic classification of conservation land that would easily allow the assignation of environmental values from non-market valuation databases (e.g. Lincoln Ecosystem Services Valuation Database) to different categories the same way profits have been assigned to different productive land uses. Although DOC has developed a classification based on managerial objectives rather than valuation objectives (i.e. benefits to society), such ideal conservation land classification is non-existent in New Zealand to the best of our knowledge.[13]

[13] Such DOC classification includes includes areas of natural heritage or public conservation such as national parks, areas of recreational opportunities such as recreational hunting areas, camping areas and walking tracks, and areas of historic heritage.

Potential uses of framework

The economic costs of wildfire framework presented here was developed as a first step to identify critical categories in an after-fire economic impact assessment, existing data sources, information gaps and methodologies to gather or estimate missing data. The next step would be to develop surveys, stage-damage curves and calibrate synthetic models to generate missing data. A final step would be to create and populate a database using the different methodologies and data sources presented in this report.

The final product developed from following the framework (i.e. populated database) could then be used across any spatiotemporal scale, would not have any expiry date and should include as much quantitative data as possible. Among the potential uses of the populated database would be:

- Emergency management: develop appropriate wildfire responses based on improved information on the impacts of wildfires such as deaths, injuries, damaged infrastructure and loss of productive potential. Hence, valuing the total cost of wildfires would enable better comparison of the importance of wildfire with other natural hazards.

- Policy-making: improve resilience capacity to long-term consequences by recording better data for indirect and intangible impacts. The framework would not only be important in identifying trends through time (e.g. climate change) but it would also be a practical gauge of "business and community vulnerability, improving recovery decisions, establishing a basis for federal aid, and informing insurers of their liability" (Rose, et al., 2002).

- Investment decisions: ensure these are made using pre-suppression and suppression alternatives that justify avoided after-fire costs. Better information on the true costs of wildfires would identify rural fire's value proposition, i.e. what it is worth to the community, in terms of values lost, vis-a-vis values potentially saved for the level of investment in rural fire. Identification of the areas of greatest potential costs would also enable decisions to be made on where to best allocate limited resources, i.e. where could we get our best "bang for the buck" in terms of investment in rural fire.

Recommendations for future research

As previously stated, BERL suggested to follow five steps to establish a data collection framework (Wu, et al., 2009). The development of this framework has addressed steps 1 and 3 for after-fire costs. Hence, as initially suggested in the proposal submitted to the NZFSC Contestable Research Fund round, the authors of this framework suggest that the Commission addresses the rest of BERL's steps (i.e. 2, 4 and 5), as well as the gaps identified in this study, by testing the proposed after-fire cost framework at a national, regional and individual wildfire event scale. The authors suggest the Commission the following future research avenues:

- Test the availability and usefulness of the various datasets suggested in this report using case studies for individual wildfire events and at the national level. Such case studies should include representative landscapes and parties affected in frequent fire events in New Zealand. Such testing would help to assess the applicability (primary and alternative) of the after-fire cost framework. As a first step, a test using easily available information would be a good starting point for the Commission to provide an educated estimate of annual after-fire costs and to measure progress.

- Integrate the proposed NZFSC fire incidence reporting system with the after-fire cost framework developed in this report and spatial data available for pre-suppression and suppression costs. Such integration would link the capture of spatial fire perimeters directly to land cover/land use data layers (LCDB and Agribase) and economic figures. However, more detailed information also needs to be captured in SMS on known fire damages (and suppression costs) for every wildfire incident.

- Gather data for indirect tangible and intangible impacts (i.e. business disruptions, environmental, and mental and physical health) following the procedures identified in this report. As previously mentioned, a good starting point would be to rely on experts' if the cost of obtaining such information through in-depth surveys or complex modelling outweighs its benefits. If the benefits outweigh the costs then the data of such impacts should be generated in more detail either through in-depth surveys or complex modelling (i.e. Prometheus and Input-Output models).

- Foreseeing that a classification of land under conservation management will be of outmost importance to the NZFSC to justify the values of protected conservation areas in the medium to long-term future, one of the recommendations from this study would be to pursue the development of such a classification jointly with DOC and the derivation of values associated with these conservation land-use classes, e.g. for biodiversity, recreational and tourism use, etc.

Table 5. Matrix representation of the framework to estimate after-fire costs.

TIME/IMPACT				SPACE							
				Productive					Conservation	Urban	Public
IMPACT	ITEM	YEARS	STAGE-DAMAGE	Dairy	Meat and wool	Forestry	Horticulture	Arable			
Tangible and Direct	Human lives										
	Civilians										
	Fire fighters										
	Stock (profits)										
	Infrastructure										
	Private										
	Commercial										
	Industrial										
	Residential										
	Public										
	Conservation										
Tangible and Indirect	Physical health										
	Business disruption										
	Output										
	Employment										
	Capital										
	Regional GDP										
Intangible Direct and Indirect	Mental health										
	Environmental										
	Erosion and sediment										
	Biodiversity										
	Recreation & tourism										
	Carbon emissions										
	Carbon sequest										
Discount rate (consider opportunity costs of land uses)											
Discounted total after-fire costs											

Acknowledgements

We thank the New Zealand Fire Service Commission (NZFSC) for funding this work, and Rob Goldring (NRFA) in particular for guiding the development of the project and framework. We would like to thank Lynsey Moore and Sierra De la Croix (Scion) for assisting with the initial literature search, Steve Wakelin (Scion) for providing guidance regarding carbon emissions, Ruth Falshaw (Scion) for editing the draft final report, and John Foley (Marlborough/Kaikoura Rural Wildfire Authority) for use of the cover photograph. In addition, thanks are extended to Alf Kirk (on contract to NZFS), Rob Goldring and Kevin O'Connor (NRFA) for reviewing this final project report.

References

AgriHQ. (2015). *AgriHQ Data*. Retrieved 2015, from https://agrihq.co.nz/data

American Psychiatric Association. (1994). *Diagnostic and Statistical Manual of Mental Disorders*. (4th ed.). Washington DC.

Anderson, S. A., Doherty, J. J., & Pearce, H. G. (2008). Wildfires in New Zealand from 1991 to 2007. *New Zealand Journal of Forestry, 53*(3), 19-22.

Ashe, B., McAneney, K., & Pitman, A. (2009). Total cost of fire in Australia. *Journal of Risk Research, 12*(2), 121-136.

AssureQuality. (2016). Agribase Database. Retrieved 2016, from https://searchagribase.asurequality.com

Australian Centre for Posttraumatic Mental Health. (2007). *Australian Guidelines for the Treatment of Adults with Acute Stress Disorder and Posttraumatic Stress Disorder.* Melbourne, Victoria.

Baerenklau, K. A., González-Cabán, A., Paez, C., & Chavez, E. (2010). Spatial allocation of forest recreation value. *Journal of Forest Economics, 16*(2), 113-126.

Barnard, L. T., Baker, M., Pierse, N., & Zhang, J. (2015). *The Impact of Respiratory Disease in New Zealand: 2014 Update.* Wellington: The Asthma Foundation.

Barry, L. E., Yao, R. T., Harrison, D. R., Paragahawewa, U. H., & Pannell, D. J. (2014). Enhancing ecosystem services through afforestation: How policy can help. *Land Use Policy, 39*, 135-145.

Baskaran, R., Cullen, R., & Colombo, S. (2009). Estimating values of environmental impacts of dairy farming in New Zealand. *New Zealand Journal of Agricultural Research, 52*(4), 377-389.

Bauen, A., Chase, A., Chudziak, C., Ouwens, J. D., Denvir, B., Owen, N., Ripken, R., van den Berg, M., & Vuille, F. (2013). A harmonised auto-fuel biofuel roadmap for the EU to 2030.

Beef + Lamb New Zealand. *Benchmark Your Farm - Sheep & Beef FArm Quintile Analysis*. Retrieved 2015, from http://www.beeflambnz.com/information/on-farm-data-and-industry-production/benchmarking-data/

Beets, P. N., Kimberley, M. O., Gouldring, C. J., Garret, L. G., Oliver, G. R., & Paul, T. (2009). *Natural Forest Plot Data Analysis: Carbon Stock Analyses and Re-measurement Strategy.* Scion Contract Report 42782, prepared for the Ministry for the Environment. Rotorua: New Zealand Forest Research Institute Limited (Scion).

BERL. (1987). *Economics of Fire Control Expenditure.* Wellington: Project commissioned by the New Zealand Forest Service.

Boot, S. (2015). Kaingaroa Timberlands profit rescued by foreign exchange. *Scoop Business*, from http://www.scoop.co.nz/stories/BU1512/S00623/kaingaroa-timberlands-profit-rescued-by-foreign-exchange.htm

Brabhaharan, P., Davey, R., O'Riley, F., & Wiles, L. (2005). *Review of Risk Assessment Methodologies and Development of a Draft Risk Assessment Methodology for Christchurch.* In Prentice, D. (Ed.) Earthquake Risk Assessment Study. Report No. U04/108. Christchurch: OPUS International Consultants.

Bryant, J. R., Ogle, G., Marshall, P. R., Glassey, C. B., Lancaster, J. A. S., Garcia, S. C., & Holmes, C. W. (2010). Description and evaluation of the Farmax Dairy Pro decision support model. *New Zealand Journal of Agricultural Research, 53*(1), 13-28.

BTE. (2001). *Economic Cost of Natural Disasters in Australia.* Report 103. Bureau of Transport Economics.

Chuvieco, E., Martínez, S., Román, M. V., Hantson, S., & Pettinari, M. L. (2014). Integration of ecological and socio-economic factors to assess global vulnerability to wildfire. *Global Ecology and Biogeography, 23*(2), 245-258. doi:10.1111/geb.12095

Coghlan, B. J. (2004). The human health impact of the 2001–2002 “Black Christmas” bushfires in New South Wales, Australia: an alternative multidisciplinary strategy. *Journal of Rural and Remote Environmental Health, 3*(1), 18-28.

CommTrade. *Carbon*. Retrieved 2015, from https://www.commtrade.co.nz

DairyNZ. (2015). *DairyNZ Economic Survey 2013-14.* Hamilton: DairyNZ.
Davis, E. J., Moseley, C., Nielsen-Pincus, M., & Jakes, P. J. (2014). The community economic impacts of large wildfires: A case study from Trinity County, California. *Society and Natural Resources, 27*(9), 983-993. doi:10.1080/08941920.2014.905812
de Mendonça, M. J. C., Vera Diaz, M. d. C., Nepstad, D., Seroa da Motta, R., Alencar, A., Gomes, J. C., & Ortiz, R. A. (2004). The economic cost of the use of fire in the Amazon. *Ecological Economics, 49*(1), 89-105.
DOC. (2014). *Review of the Department of Conservation (DOC).* Wellington: Department of Conservation.
Donovan, G. H., & Rideout, D. B. (2003). A reformulation of the Cost Plus Net Value Change (C+NVC) model of wildfire economics. *Forest Science, 49*(2), 318-323.
Dymond, J. R., Ausseil, A.-G. E., Ekanayake, J. C., & Kirschbaum, M. U. (2012). Tradeoffs between soil, water, and carbon – a national scale analysis from New Zealand. *Journal of Environmental Management, 95*(1), 124-131.
Dymond, J. R., Betts, H. D., & Schierlitz, C. S. (2010). An erosion model for evaluating regional land-use scenarios. *Environmental Modelling & Software, 25*(3), 289-298.
Eade, J. D., & Moran, D. (1996). Spatial economic valuation: benefits transfer using geographical information systems. *Journal of Environmental management, 48*(2), 97-110.
EVRI. (2015). *Environmental Valuation Reference Inventory*. Retrieved 2015, from https://www.evri.ca/Global/HomeAnonymous.aspx
Ferry, F., Bolton, D., Bunting, B., O'Neill, S., Murphy, S., & Devine, B. (2012). *The Economic Impact of Post Traumatic Stress Disorder in Northern Ireland. A report on the direct and indirect health economic costs of post traumatic stress disorder and the specific impact of conflict in Northern Ireland.* Bamford Centre for Mental Health and Wellbeing and the Northern Ireland Centre for Trauma and Transformation.
Finlay, S. E., Moffat, A., Gazzard, R., Baker, D., & Murray, V. (2012). Health impacts of wildfires. *PLoS Currents, 4*, e4f959951cce959952c.
González Cabán, A. (2013). The Economic Dimension of Wildland Fire. In Goldammer, J. G. (Ed.), *Vegetation Fires and Global Change – Challenges for Concerted International Action. A White Paper directed to the United Nations and International Organizations* (pp. 229-237). Freiberg: Global Fire Monitoring Center (GFMC). Kessel Publishing House.
Goodchild, M., Sanderson, K., Leung-Wai, J., & Ganesh, N. (2005). *The Cost of Managing the Risk of Fire in New Zealand.* New Zealand Fire Service Commission Research Report No. 53. Wellington: New Zealand Fire Service Commission.
Greenberg, P. E., Sisitsky, T., Kessler, R. C., Finkelstein, S. N., Berndt, E. R., Davidson, J. R., Ballenger, J. C., & Fyer, A. J. (1999). The economic burden of anxiety disorders in the 1990s. *Journal of Clinical Psychiatry, 60*(7), 427-435.
Guild, D., & Dudfield, M. (2010). A history of fire in the forest and rural landscape in New Zealand - Part 2, post 1830 influences, and implications for future fire management. *New Zealand Journal of Forestry, 54*(4), 31-38.
Hall, J. R. (2014). *The Total Cost of Fire in the United States*. Quincy, MA: National Fire Protection Association.
Handmer, J., Read, C., & Percovich, O. (2002). *Disaster Loss Assessment Guidelines.* Australian Emergency Manuals Series. Canberra: Emergency Management Australia.
Harrison, D. R., Barry, L. E., Palmer, D. J., Kimberley, M. O., Turner, J. A., Hock, B. A., & Hall, P. (2012). *Developing a Forest Investment Finder for New Zealand.* Future Forest Research. ES015. Rotorua: New Zealand Forest Research Institute Limited (Scion).
Holdaway, R. J., Mason, N. W. H., Easdale, T., Dymond, J., Betts, H., Wakelin, S. J., & Moore, J. R. (2014). Annual carbon emissions associated with natural disturbance in New Zealand's natural and planted forests. Ministry for Primary Industries, Wellington. MPI Technical Paper No. 2014/08. 73 p. [Scion Client Report 19637]
IPCC. (2006). Generic Methodologies Applicable to Multiple Land-Use Categories. In *2006 IPCC Guidelines for National Greenhouse Gas Inventories*. Geneva: Intergovernmental Panel on Climate Change.

Jenkins, J. L., Hsu, E. B., Sauer, L. M., Hsieh, Y.-H., & Kirsch, T. D. (2009). Prevalence of unmet health care needs and description of health care-seeking behavior among displaced people after the 2007 California wildfires. *Disaster Medicine and Public Health Preparedness, 3* (SupplementS1), S24-S28.

Knowlton, K., Rotkin-Ellman, M., Geballe, L., Max, W., & Solomon, G. M. (2011). Six climate change-related events in the United States accounted for about $14 billion in lost lives and health costs. *Health Affairs, 30*(11), 2167-2176.

Krausse, M. K., Alexander, R. R., & Eastwood, C. R. (2001). *Muddied waters: Estimating the national economic cost of soil erosion and sedimentation in New Zealand*. Lincoln: Landcare Research.

Kuschel, G., Metcalfe, J., Wilton, E., Guria, J., Hales, S., Rolfe, K., & Woodward, A. (2012). *Summary Report.* Updated Health and Air Pollution in New Zealand Study: Health Research Council of New Zealand, Ministry of Transport, Ministry for the Environment and New Zealand Transport Agency.

Langer, L., Pearce, H. G., Monge, J. J., & Velarde, S. J. (2015). *Milestone 1: The Economic Cost of Wildfires - Project Inception.* Report to the New Zealand Fire Service Commission. Rotorua: New Zealand Forest Research Institute Limited (Scion).

Lee, W., McGlone, M., & Wright, E. (2005). Biodiversity inventory and monitoring: a review of national and international systems and a proposed framework for future biodiversity monitoring by the Department of Conservation. *Landcare Research Contract Report LC0405/122 (unpublished)*. Lincoln: Landcare Research.

Lincoln University. *The New Zealand Non-Market Valuation Database*. Retrieved 2015, from http://www2.lincoln.ac.nz/nonmarketvaluation/

Loomis, J., & González-Cabán, A. (2010). Forest Service use of nonmarket valuation in fire economics: Past, present, and future. *Journal of Forestry, 108*(8), 389-396.

Lueck, D., & Yoder, J. (2015). The economic foundations of firefighting organizations and institutions. *Journal of Forestry, 113*(3), 291-297. doi:10.5849/jof.14-050

MAF. (2011). *Horticulture and Arable Overview.* Wellington: Ministry of Agriculture and Forestry.

Majorhazi, K., & Hansford, A. (2011). *New Zealand Wildfire Threat Analysis - Workbook Documentation (Version 3.1, November 2011).* Wellington: National Rural Fire Authority.

MBIE.(2015a). *Domestic Travel Survey*. Retrieved 2015, from http://www.mbie.govt.nz/info-services/sectors-industries/tourism/tourism-research-data/domestic-travel-survey

MBIE.(2015b). *International Visitor Survey*. Retrieved 2015, from http://www.mbie.govt.nz/info-services/sectors-industries/tourism/tourism-research-data/ivs

MBIE. (2015c). *New Zealand Tourism Forecasts 2015-2021.* Wellington: Ministry of Business, Innovation and Employment.

Mendes, I. (2010). A theoretical economic model for choosing efficient wildfire suppression strategies. *Forest Policy and Economics, 12*(5), 323-329.

MFE. (2015). *New Zealand's Greenhouse Gas Inventory 1990-2013.* Wellington: Ministry for the Environment.

Monge, J. J., Bryant, H. L., & Anderson, D. P. (2014). Development of regional social accounting matrices with detailed agricultural land rent data and improved value-added components for the USA. *Economic Systems Research, 26*(4), 486-510.

MOT. (2014). *Social Cost of Road Crashes and Injuries 2014 Update.* Wellington: Ministry of Transport.

MPI. (2014). *Situation and Outlook for Primary Industries.* Wellington: Ministry for Primary Industries.

MPI. (2015a). *Horticultural Monitoring Statistics From 2011 and 2012*. Retrieved 2015, from https://www.mpi.govt.nz/news-and-resources/statistics-and-forecasting/agriculture/horticulture-and-arable-monitoring/

MPI. (2015b). *National Exotic Forest Description as at 1 April 2014.* Wellington: Ministry for Primary Industries.

MPI. (2015c). *Pastoral Monitoring Data from 2012*. Retrieved 2015, from https://www.mpi.govt.nz/news-and-resources/statistics-and-forecasting/agriculture/pastoral-monitoring/

Munasinghe, P. C., & Khanal, S. K. (2010). Biomass-derived syngas fermentation into biofuels: Opportunities and challenges. *Bioresource Technology, 101*(13), 5013-5022. doi:http://dx.doi.org/10.1016/j.biortech.2009.12.098

NIWA. (2015). *RiskScape*. Retrieved 2015, from https://riskscape.niwa.co.nz

Overton, J. M., Walker, S., Price, R., Stephens, R., Henson, S., Earl, R., & Wright, E. (2015). Vital sites and actions: an integrated framework for prioritizing conservation actions and reporting achievement. *Diversity and Distributions, 21*(6), 654-664.

Pearce, H. G., Langer, E. R., Harrison, D. R., & Hart, M. (2014). Describing Wildfire Prone Areas in the New Zealand context. New Zealand Fire Service Commission Research Report No. 134. Wellington: New Zealand Fire Service Commission.

QV. (2015). *Valuations*. Retrieved 2015, from https://www.qv.co.nz/valuations/choosing-a-valuation

RAMM. (2015). *Road Assessment and Maintenance Management*. Retrieved 2015, from http://www.ramm.com

Richardson, L. A., Champ, P. A., & Loomis, J. B. (2012). The hidden cost of wildfires: Economic valuation of health effects of wildfire smoke exposure in Southern California. *Journal of Forest Economics, 18*(1), 14-35.

Rittmaster, R., Adamowicz, W. L., Amiro, B., & Pelletier, R. T. (2006). Economic analysis of health effects from forest fires. *Canadian Journal of Forest Research, 36*(4), 868-877.

Rose, A., & Lim, D. (2002). Business interruption losses from natural hazards: conceptual and methodological issues in the case of the Northridge earthquake. *Global Environmental Change Part B: Environmental Hazards, 4*(1), 1-14.

Scion (2011). Prometheus - Canadian Wildland Fire Growth Simulation Model: New Zealand User Manual for version 5.2.3. Scion Client Report 18673. Christchurch: Scion, Rural Fire Research Group.

Stephenson, C. (2010). *Impact Frameworks for natural disasters and fire emergencies.* Melbourne: RMIT University and Bushfire CRC.

Takatsuka, Y., Cullen, R., Wilson, M., & Wratten, S. (2009). Using stated preference techniques to value four key ecosystem services on New Zealand arable land. *International Journal of Agricultural Sustainability, 7*(4), 279-291.

Te Ao, B., Brown, P., Tobias, M., Ameratunga, S., Barker-Collo, S., Theadom, A., McPherson, K., Starkey, N., Dowell, A., Jones, K., & Feigin, V. L. (2014). Cost of traumatic brain injury in New Zealand: Evidence from a population-based study. *Neurology, 83*(18), 1645-1652.

Thomas, S., Hume, E., Fraser, T., & Curtin, D. (2011). *Factors and Activity Data to Estimate Nitrous Oxide Emissions from Cropping Systems, and Stubble and Tussock Burning.* Report No. 2012/16 prepared for the Ministry of Agriculture and Forestry. Wellington: Plant and Food Research.

Thompson, S., Gruner, I., & Gapare, N. (2003). New Zealand Land Cover Database; Version 2: illustrated guide to target classes. Wellington: Ministry for the Environment.

Tymstra, C., Bryce, R., Wotton, B., Taylor, S., & Armitage, O. (2010). *Development and structure of Prometheus: the Canadian wildland fire growth simulation Model*. Vol 417. Edmonton: Natural Resources Canada, Northern Forestry Centre.

Velarde, S. J., & Monge, J. J. (2015). *Milestone 2: The Economic Cost of Wildfires - Draft Literature Review.* Scion Client Report (NZFSC) No. 22478. Rotorua: New Zealand Forest Research Institute Limited (Scion).

Venn, T. J., & Calkin, D. E. (2011). Accommodating non-market values in evaluation of wildfire management in the United States: Challenges and opportunities. *International Journal of Wildland Fire, 20*(3), 327-339. doi:10.1071/WF09095

Wakelin, S. J. (2011). *Apportioning Wildfire Emissions to Forest Sub-Categories in the National Greenhouse Gas Inventory.* Scion Client Report (MfE) No. 18682. Rotorua: New Zealand Forest Research Institute Limited (Scion).

Wakelin, S. J. (2015). Grassland carbon emissions from wildfires. Personal communication via email.

Wakelin, S. J., Pearce, H. G. (2011). Improving LULUCF non-CO2 emission estimates in New Zealand's National Greenhouse Gas Inventory. Scion Client Report No. 18318 prepared for the Ministry for the Environment).

Wu, J., Kaliyati, W., & Sanderson, K. (2009). *The Economic Cost of Wildifres.* New Zealand Fire Service Commission Research Report No. 99. Wellington: New Zealand Fire Service Commission.

Zhang, Y., McDonald, G., Nixon, P., & Smith, N. (2008). *Development of a Regional Social Accounting Framework for New Zealand.* NZCEE Research Monograph Series. 15. Takapuna: New Zealand Centre for Ecological Economics.

Appendix 1.

Summary of stakeholder feedback on cost-data categories and available data sources

A. Stakeholders approached for feedback

Organisation	Representative	Position
National Rural Fire Authority	Rob Goldring	Manager Rural Fire, Auckland
Enlarged Rural Fire District Chairperson & Principal Rural Fire Officer Executive Group	Rob Hands	Principal Rural Fire Officer, South Canterbury Rural Fire District, Timaru District Council, Timaru
Marlborough Kaikoura Rural Fire Authority	Richard McNamara	Principal Rural Fire Officer, Marlborough Kaikoura Rural Fire Authority, Blenheim
Christchurch City Council	Darrin Woods	Principal Rural Fire Officer, Christchurch
Department of Conservation	Bryan Jensen	National Fire Manager Operations, Wellington
Department of Conservation	Elaine Wright	Planning, Monitoring and Reporting Manager, Science and Policy Group, Christchurch
Department of Conservation	Alistair Drake	Business Accountant, Kaikaute Pakihi, Corporate Services Group, Whangarei
Ministry for Primary Industries	Parnell Trost	Senior Analyst, Resource Policy Directorate, Dunedin
Ministry for the Environment	Nigel Searles	Senior Analyst, Wellington
New Zealand Forest Owners Association	Glen Mackie	Technical Manager, Wellington
Federated Farmers of New Zealand	Anders Crofoot	National Vice-President, Castle Point
Federated Farmers of New Zealand	Nick Hanson	General Policy Advisor, Wellington
Beef and Lamb New Zealand	Rob Gibson	Senior Agricultural Analyst, Beef and Lamb NZ, Wellington.
Forest Protection Services	Kevin Ihaka	Managing Director FPS Forestry, Forest Protection Services, Whangarei. (No response)
Timberlands Ltd.	Colin Maunder	Forest Risk Manager, Timberlands Ltd., Rotorua (No response).

B. Stakeholder feedback on fire cost-data categories

Category 1: Pre-suppression costs

Sub-category	Level	Cost factors	Indicators	Methods	Data source
Administration	_	NRFA – Administrative costs	Admin costs	Direct cost	NRFA – Yes FOA – No, but could obtain from selected members MKRFD – no response provided MPI – No DOC - Yes (could be derived)
Prevention	_	NRFA – Education activities for prevention FOA - Signage	Education programs costs	Direct cost	NRFA – Yes FOA – No, but could obtain from selected members MKRFD – Yes MPI – No DOC - Yes (could be derived)
Preparedness	Risk reduction costs	NZFS - Protection measures in buildings, fences NZFS - Safety regulations and compliance (e.g. evacuation schemes, trial evacuations) Insurance services Corridors, including roads and fire breaks and electricity transmission Fuel treatments (prescribed fire)	Building protection costs Compliance cost Insurance costs Corridor building and maintenance	Direct cost Opportunity cost Monte Carlo simulations of welfare changes	NRFA - Yes (NZFS) FOA – No, but could obtain from selected members MKRFD – No MPI – No DOC - No
Preparedness	Level of protection analysis	NRFA – Existing investment e.g. investment planning tools NRFA – Research e.g. to improve fire danger rating system MPI - Research to assess the level and extent of wild fire risk under predicted climate change conditions	Tools costs Research projects cost	Direct cost	NRFA - Yes Scion & Contestable Research Fund FOA – No, but could obtain from selected members MKRFD – Yes MPI – No DOC - Yes
Preparedness	Resource-location allocation	Pre-existing infrastructure Allocated funding Existing resources *e.g. Location of processing facilities*→ e.g. costs of prescribed fires including livestock management related to fires	forest / land owner fire protection costs	Direct cost	NRFA – No FOA – No, but could obtain from selected members MKRFD – No MPI - Yes - Location of Facilities: Details of operators, businesses and persons that are registered, recognised, approved or listed under laws administered by MPI, plus list of 'export approved premises' and 'exporters register', Food Safety section, MPI website. Location details on industry association sites: e.g. Meat processing: Beef+Lamb, Dairy processing: Dairy Companies Association of NZ and Forest Industry Engineering Association DOC - Yes

Preparedness	Readiness	Available resources e.g. reticulated water supply system Cost of having resources 'active' Contribution of suppression to reducing loss		Direct cost	NRFA - Yes NIMTs and response teams. FOA – No, but could obtain from selected members MKRFD – Partly MPI – No DOC - Possibly some data, but not comprehensive FOA - Training costs FOA - Restrictions to areas for work or recreational use
Preparedness	Detection	Pre-existing detection infrastructure Cost of fire detection alternatives Efficacy of fire detection alternatives (e.g. time to detection) Pre-existing detection infrastructure Potential impacts due to delayed detection Cost of false alarms		Direct cost	NRFA - Yes Publicity campaign FOA – No, but could obtain from selected members MKRFD – No MPI – No DOC - No

Category 2: Suppression costs

Sub-category	Level	Cost factors	Indicators	Methods	Data source
Response (also called: direct extinguishment, fire emergency services)	Dispatch	Resource costs		Direct cost	NRFA - Yes NIMT Program FOA – No, but could obtain from selected members MKRFD – Yes MPI – No DOC - Yes
	Travel	Resource travel rates		Direct cost	NRFA – Yes FOA – No, but could obtain from selected members MKRFD – Yes MPI - No DOC - Yes
	Suppre-ssion work	Resource types and constraints Fuels		Direct cost	NRFA – Yes FOA – No, but could obtain from selected members MKRFD – Yes MPI - No DOC - Yes
		Avoided fuel treatment cost (this cost item is a benefit in a CBA)	Fuel management costs under different programs Impacts Multipliers Wood utilisation rates	Avoided cost	NRFA – No FOA – No, but could obtain from selected members MKRFD – No MPI – No DOC - No
		Fire suppression strategies	Cost per hectare or daily cost	Direct cost	NRFA - Yes (RFFF & Exotic forest Costs) FOA – No, but could obtain from selected members MKRFD – Partly MPI - No DOC - Yes
		Fire intensity level (FIL)	Ecosystem resilience Fire severity (fire behaviour, fuel model, topography)	Algorithm integrating socio-economic assessment, resilience and fire severity	NRFA - Yes (WTA) FOA – No, but could obtain from selected members MKRFD – Partly MPI - No DOC – Yes – some data
Indirect containment of fire spread		E.g. Containment of large wildfires	Containment probability	Generalised linear mixed model	NRFA - Yes NIMT Program FOA – No, but could obtain from selected members MKRFD – Partly MPI - No DOC - No

Category 3: After-fire costs (also 'recovery and consequence')

Sub-category	Level	Cost factors	Indicators	Methods	Data source
IMMEDIATE COSTS					
Immediate	Non-market values	Human deaths due to burns and smoke inhalation	Annual average mortality Value of statistical life (VoSL)	Direct cost Contingent valuation to establish VoSL	NRFA - Yes (Statistic numbers, but not costs) FOA – No, but could obtain from selected members MKRFD – Yes MPI – No DOC - Yes
Immediate	Non-market values	Human injuries e.g. fire fighters	Injury mechanism, diagnosis and body part 'exposure to fire and smoke injuries'	Logistic regression	NRFA - Yes (Statistic numbers, but not costs) FOA – No, but could obtain from selected members MKRFD – Yes MPI - No (try ACC or WorkSafe NZ) DOC - Yes
Immediate	Market values	Reduction in forage availability	Burned grasses	Direct cost	NRFA – No FOA – No, but could obtain from selected members MKRFD – No MPI – see next row DOC - No
Immediate	Market values	Loss of output, e.g. Livestock losses Lost animal-unit months of forage		Direct cost	NRFA – Yes FOA – No, but could obtain from selected members MKRFD – No MPI - Sheep and beef data from national Beef+Lamb NZ survey and produce farm models for different classes of land for five groups of regions (including per stock unit and hectare costs/revenue, which could be applied to burnt areas to gauge extent of economic loss). Regular MPI monitoring reports for viticulture, arable, dairy, horticulture and sheep and beef - solid base for assessing lost production. DOC - No
Immediate	Market values	Building/Property damage, structure losses e.g. fencing (farmers & other land owners), boardwalks/bridges, etc.	Number $ value of buildings	Direct cost Difference in market value	NRFA – Yes FOA – No, but could obtain from selected members MKRFD – No MPI - No DOC - No

Immediate	Non-market values	Use values: protecting homes	Programme to reduce area burnt and number of houses burnt	Stated preference: Contingent Valuation	NRFA – No FOA – No but could obtain from selected members MKRFD – Partly MPI - No DOC - No
Immediate	Market values	MfE - Wildfire emissions carbon cost to Government	New Zealand's National Greenhouse Gas Inventory and carbon unit price	Direct cost	MfE - Yes
MEDIUM TERM COSTS					
Medium term	Non-market values	Indirect injury costs, e.g. Human health impacts due to smoke	Annual average mortality		NRFA – No FOA – No but could obtain from selected members MKRFD – No MPI – No. DOC - No
Medium term	Non-market values	Economic risk of post fire debris flow		Spatial analysis, damage cost, estimate probabilities	NRFA – No FOA – No, but could obtain from selected members MKRFD – No MPI - No. DOC - No
Medium term	Non-market values	Community impacts of wildfire		Mixed: Difference-in-difference regression model, In-depth interviews, direct costs fire suppression	NRFA – No FOA – No but could obtain from selected members MKRFD – No MPI - No. DOC - No
LONG TERM COSTS					
Long term	Non-market values	MfE - Wildfire emissions contribution to New Zealand's greenhouse gas emissions	New Zealand's National Greenhouse Gas Inventory		MfE - Yes

Category 3: After fire costs (also 'recovery and consequence') - Continuation

Sub-category	Level	Cost factors	Indicators	Methods	Data source
Medium term	Non-market values	Access to recreational facilities	Price of access the site (proxy) Area affected	Travel Cost Method, Contingent Valuation	NRFA – No FOA – No, but could obtain from selected members MKRFD – No MPI – No DOC - No
Medium term	Non-market values	Damage to natural resources and heritage sites Passive values: Loss of wildlife Existence and bequest values e.g. habitat value ('passive' use), FOA - Medium term loss of biodiversity	Program to reduce the amount of old-growth burned critical habitat units	Contingent Valuation	NRFA - Yes (Annual Return & KPI's) FOA – No, but could obtain from selected members MKRFD – No MPI - No DOC - Yes
Medium term	Non-market values	Use values: protecting homes	Programme to reduce area burnt and number of houses burnt	Contingent Valuation: Willingness to pay Visual representation/virtual reality, e.g. simulation models*	NRFA - Yes (FireSmart) FOA – No, but could obtain from selected members MKRFD – Partly MPI - No DOC - No
Medium term	Non-market values	Use values: hiking and mountain biking	Visits to area after wildfire	Travel cost	NRFA - No (WTA rating) FOA – No, but could obtain from selected members MKRFD – No MPI - No DOC - Yes
Medium term	Non-market values	Secondary effects: Increased runoff, erosion, flooding, sedimentation, vulnerability to invasive weeds		Valuation of values-at-risk (VAR)	NRFA – No FOA – No, but could obtain from selected members MKRFD – No MPI - No DOC - No
Medium term	Market values	Rehabilitation/recovery costs			NRFA – No FOA – No, but could obtain from selected members MKRFD – No MPI - No DOC - No
Medium term	Market values	Salvaging biomass from wildfire burnt areas (benefit in a cost benefit analysis)	Biomass salvaged Procurement cost Hauling distance	Direct cost	NRFA – No MPI - No FOA – No, but could obtain from selected members MKRFD – No MPI - No DOC - No

Medium to long term	Market values	Business interruption MPI - Lost production from primary sector activities (the farm modelling data could be used to extrapolate losses until properties return to full production)	Percentage change in: i) production per economic sector, ii) sub-national	Computable General Equilibrium model	NRFA – No FOA – No, but could obtain from selected members MKRFD – No MPI - No DOC - No
LONG TERM COSTS					
Long term	Non-market values	Psychological or behavioural impacts			NRFA – No FOA – No, but could obtain from selected members MKRFD – No MPI - No DOC - No
Long term	Non-market values	Climate change effects on ecosystem services – including fire probability, fire severity, baseline ecosystem services scenarios		Veg. type as proxy of ecosystem services bundle	NRFA - Yes Contestable Research Fund FOA – No but could obtain from selected members MKRFD – No MPI – Yes. Contracted projects, mainly with Scion: e.g.: *'Improved estimates of the effect of climate change on NZ fire danger'* *'The effect of climate change on New Zealand's planted forests'* DOC - No
Long term	Non-market values	Different fire risk and management factors E.g. risk characterisation and risk assessment		Multi-attribute stated preference surveys (risk, loss and cost) Probabilistic modelling	NRFA – No FOA – No, but could obtain from selected members MKRFD – No MPI - No DOC - No
Long term	Market values	Impacts of fuel reduction programs	Impacts Multipliers Wood utilisation rates	Input-Out analysis Social Accounting Matrix (SAM) multipliers	NRFA – No FOA – No, but could obtain from selected members MKRFD – No MPI - No DOC - No
Long term	Market values	Regional economic impacts		Linear Programming-SAM Computable General Equilibrium models (CGE)	NRFA – No FOA – No, but could obtain from selected members MKRFD – No MPI - No DOC - No