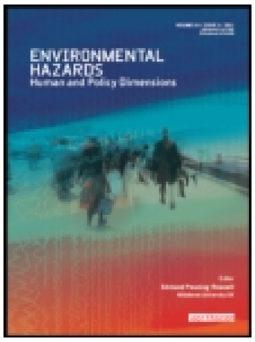

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Estimating the economic, social and environmental impacts of wildfires in Australia

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Wildfires often result in widespread destruction and damage to a range of economic, social and environmental assets and functions. This article presents an economic loss assessment framework which has not only been developed to value these assets, but more importantly addresses the fundamental economic principles commonly lacking in other frameworks. Five severe south-eastern Australian wildfires were used as case studies to examine the utility of the framework. The impact and cost data collected as part of this framework provide valuable information for a range of applications, such as measuring the efficacy of government response and recovery arrangements and programmes, shaping policies and providing businesses with disaster information on which they can make decisions. Some areas requiring further research were identified. These included the need to develop consistent values for estimating environmental impacts, in the form of ecosystem service values for south-eastern Australia, and a standardized survey format for valuing a range of indirect economic and social impacts.

Keywords: Australia; economic cost; economic loss assessment; loss framework; wildfire

1. Introduction

Fire is a familiar sight in many Australian natural environments, being a necessary element (under the most appropriate fire regime) for the ongoing survival of ecological communities within them (Burrows, 2008; Flint & Fagg, 2007). In some cases, however, wildfires cannot be controlled in time and impact negatively on a diverse range of economic, social and environmental assets and values.

A framework that estimates the costs of these impacts is an important analytical tool, providing an in-depth understanding of the extent of these impacts that can be used by a range of governmental and non-governmental organizations. Governments at all levels have a strong interest in the impacts and costs resulting from wildfires for several reasons. These include the need to measure the efficacy of disaster mitigation strategies, preparedness plans and recovery programmes (Office of the Emergency Services Commissioner (OESC), 2008). Policy makers not only rely on accurate disaster data for policy development, but also require it for much broader issues. These include insurance and reinsurance programmes for homeowners claiming losses related to wildfires (Commission on Geosciences, Environment, and Resources, 1999), and the development of building codes in fire-prone areas (Building Commission, 2010). Outside of the government, insurers and business owners have a

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commercial interest in accurate wildfire data, while researchers and practitioners in disaster loss estimation would benefit from a standardized data set that further improves frameworks and models dedicated to estimating the impacts and costs. This, in turn, would inform governments' future strategies related to wildfires (Commission on Geosciences, Environment, and Resources, 1999).

Even though a large range of frameworks and models are used to assess the impacts and costs of wildfires, many of these contain limitations. Handmer, Abrahams, Betts, and Dawson (2005) draw attention to a number of these limitations, including that they focus on measurement issues only ignoring the broader process of loss assessment, generally do not consider data quality, often overlook intangibles such as social and environmental impacts and are concerned with national economies rather than state or local/regional economies.

An economic loss assessment framework has been developed to address these deficiencies and is presented in this paper, and is called the Socio-Economic Impact Assessment Model for Emergencies (SEIA-Model) explained below. This model was originally developed in response to the Victorian Ministerial Taskforce on Bushfire Recovery's (2007) recommendation that a socioeconomic assessment be conducted in regions affected by the 2006/07 Great Divide Fires (described in Section 5) and after future events to gauge the Victorian Government's recovery response and the changes that often occur after major natural disasters (OESC, 2008). The model drew on previous work, including the Disaster Loss Assessment Guidelines (Handmer, Read, & Percovich, 2002) and the Handbook for Estimating the Socio-economic and Environmental Effects of Disasters (Economic Commission for Latin America and the Caribbean (ECLAC), 2003). It was then tested on the Victorian Shire of Wellington after the 2006/07 Great Divide Fires. To test the validity of the SEIA-Model across a much larger scale, the costs of five severe south-eastern Australian wildfires have been estimated, with the results being presented in this paper.

All costs are in Australian dollars brought to 2009 values using the Reserve Bank of Australia's (online) Inflation Calculator using the Consumer Price Index (CPI). Any foreign currency amounts have been converted to Australian dollars using the average exchange rate for the year the cost was incurred.

The next section outlines the terminology used in this paper. Section 3 then examines why a framework based on economics is important for measuring the impacts and costs of wildfires and how the SEIA-Model achieves this. A brief overview of the five fires being studied is detailed in Section 4. Section 5 applies the SEIA-Model methodology for the fires, while Section 6 sets out the costs of the five fires studied. This is then followed by a discussion where the costs are analysed. Future research needs and the conclusion follow in Section 8.

2. Terminology used in this paper

To ensure that there is common understanding of the terminology used throughout this paper, some key terms are defined in Table 1.

Cost is another term associated with natural disasters and emergencies, being defined by Emergency Management Australia (EMA) (1998, p. 26) as direct and indirect, involving any negative impact, including money, time, labour, disruption, goodwill, political and intangible losses'. For the purposes of this paper, however, cost refers to the dollar value of something, and can either be a negative (e.g. cost of a destroyed house) or positive (e.g. insurance payments) value.

Table 1. Terminology used in this paper.

Term	Description
Impact	Is the broadest term and includes both market-based (i.e. tangible) and non-market (i.e. intangible) effects Individual impacts can be either negative or positive (Commission on Geosciences, Environment, and Resources, 1999)
Direct impact	Impacts that result from direct contact with the event (Parker, Green, & Thompson, 1987; van der Veen, 2004)
Indirect impact	Impacts that arise as a consequence of the impacts of the event (Parker et al., 1987; van der Veen, 2004) For example, disruption to the flow of goods and services in and out of the affected area
Tangible impact	Items that are normally bought or sold and that are therefore easy to assess in monetary terms (Handmer et al., 2002)
Intangible impact	Items that are not normally bought or sold (Handmer et al., 2002)
Economic impact	The word economic has two meanings in this paper. In the field of economics, the word economics refers to the study of the economy as a whole and measures all losses and benefits to that economy (Handmer et al., 2002). In this sense, all impacts, including environmental and social impacts, are included, regardless of whether they can be valued in monetary terms or not. In the context of the 'triple bottom line' approach (Suggett & Goodsir, 2002), economic refers to the impacts on tangible assets, both direct and indirect. When reading this paper, economic means impacts to the whole economy when used in reference to an economic loss assessment, whereas it refers to tangible impacts when used in all other cases
Social impact	Impacts relating to people, such as health (e.g. fatality, injury, mental health) (Middelmann, 2007) and items or places of personal (e.g. memorabilia) or cultural (e.g. heritage buildings or sacred sites) significance. It also includes impacts to the broader 'social fabric' of the community (Middelmann, 2007). This is considered an intangible impact
Environmental impact	Impacts on the natural environment, including assets such as the soil, water, air, fauna, flora, habitat and flows such as ecosystem services. This is considered an intangible impact
Loss	In economic terms, loss is a measure of the impact on a specific economy. It is taken as being equal to the resources lost in the area of analysis as a consequence of the disaster. The resources can be expressed in time, money or other measure for specific intangible losses (Handmer et al., 2002)
Benefit	Any benefit the economy receives as a result of the disaster, such as government aid (e.g. recovery packages) and insurance payouts (Handmer et al., 2002). These are usually measured in terms of the money flowing across the spatial boundary of the selected economy into the assessment area. Flows such as government aid within a defined economy would usually be viewed as transfers. Enhanced business activity is another potential benefit. Benefits may also be environmental or social

3. Why use an economic loss assessment?

The information produced from a framework that measures the impacts, losses and benefits of a wildfire will influence the outcome of many important management and policy decisions. It is therefore crucial that the framework providing this information is transparent and uncomplicated, and produces accurate, comprehensive and consistent results.

Economic loss assessments comply with the above conditions, essentially adding up all the losses and benefits resulting from the event and finding the net cost (i.e. losses minus benefits). Including the benefits to a community after a wildfire or any natural disaster may sound strange; however, this is a fundamental part of any economic loss assessment. It is especially important when measuring the impacts on a small scale (i.e. regionally or smaller), as the money flowing into an economy partially offsets the losses flowing out of it (Handmer et al., 2002; New York City Partnership and Chamber of Commerce, 2001).

Another key feature of an economic loss assessment is that it places geographical and temporal boundaries around the assessment. Apart from giving the assessor clear boundaries in which to work, it is critically important when measuring indirect effects (Commission on Geosciences, Environment, and Resources, 1999; European Commission, 1999). The geographical boundary enables the flow of goods and services (and the costs of these) to be accounted for and identifies what is a loss, benefit or transfer. Losses can be viewed as the loss of goods and services within the assessment boundary (e.g. crops, buildings and loss of business), while the benefits can be measured by the flow of goods and services (including money) into the assessment area. The exchange of goods, services or money wholly within the assessment boundary (i.e. does not move across the boundary) is considered a transfer effect and not an economic loss or benefit to the assessment area (Handmer et al., 2002).

Losses and benefits attributed to a wildfire will change depending on the size of the assessment boundaries. That is, in many cases losses at a local level will 'disappear' at a state or national level because losses to the local economy will be compensated by increased productivity in other regions, thereby producing no net loss (Merz, Elmer, & Thieken, 2010). Therefore, assessing the local economy actually affected by the wildfire will produce meaningful results specific to that economy, where the effects of mitigation strategies and policies can be most effectively measured. Handmer et al. (2002) recommend that a loss assessment be conducted at least 6 months after the event. This is to ensure that indirect and intangible impacts not immediately obvious are accounted for. For example, the trauma and other psychological impacts felt by those in the community will not be known until well after the fire has stopped burning and people have to rebuild their lives. Conversely, losses resulting from some products and services may be recovered to some degree over the months and years after an event, such as timber salvage operations.

An economic loss assessment measures the impact of an event on the economy of the area selected for analysis and not individual businesses (ECLAC, 2003). A financial assessment is undertaken when a business wants to assess the impact of the event on their own profits, and does not consider impacts directly unrelated to their business, such as most intangible losses, disruption to the wider economy and impacts to residential and government sectors (Handmer, 2003).

Direct economic losses are comparatively easy to measure and cost, as they are readily bought and sold in existing markets. As part of assessing direct economic losses, the depreciated (or market) value of the asset is used rather than the replacement value (Read Sturgess and Associates, 2000) which more accurately reflects the actual value of the lost asset. Indirect economic losses are harder to value, as they are a consequence of the event and can be more difficult to measure and confirm (Rose & Lim, 2002). Social and environmental impacts, on the other hand, are very difficult to value financially, as generally no market exists to accommodate them (Bureau of Transport Economics (BTE), 2001). Where possible, economic loss assessments place a dollar value on such impacts, thereby enabling them to contribute to the net cost. Several methods have been developed to try and estimate the value of these non-market impacts. Refer to Morrison (2011) for an examination of these techniques. In many cases, however, the most valuable items that a person possesses cannot be valued in monetary terms (i.e. personal documents, family photos and other memorabilia), but are included in an economic loss assessment as qualitative data.

Several other methods exist for estimating the costs of wildfires; however, these are not considered suitable for several reasons. Insurance losses are typically seen as indicative of disaster losses, but insurance is in the hands of part of the private sector and is not interested in the impact of the disaster on economies. It is interested in claims against insurers. Insurance is usually only partial; not everyone is covered and many assets, such as those held by government, and activities are normally uninsured or only partly covered. Furthermore, household insurance usually replaces lost items with new ones (new for old), resulting in a much higher value for such items than what was originally destroyed or damaged (Handmer, 2003).

Another approach excluded from selection was general equilibrium modelling, which attempts to estimate the impact of an event on a specified economy. It does this by modelling the impact on the total economic flows of goods and services. This approach would appear to make sense in disaster loss assessment when it is concerned with the impact of an event on an economy. However, there are a number of reasons as to why this approach is not widely used in disaster loss assessment. A good model of the economy is needed, which in turn requires very detailed data on all sectors and how they respond to different impacts. Such models exist at national and state levels but at these levels most disasters have very small impacts. At local levels the impacts may be large but the models tend to be relatively simple due to the limitations of data, cost and expertise. The models also require specialist expertise to develop and run, and for all these reasons were considered inapplicable in this study with its emphasis on robust approaches that can run with limited data at a wide range of scales.

Another wildfire model, called the Cost plus Net Value Change (C + NVC) model (Donovan & Rideout, 2003), focuses on the best use of suppression resources, although it can be applied to other fire risk management strategies. It does not put benefits against costs, but seeks to find the smallest total of costs plus loss. The standard measure of mitigation, that of losses avoided, is not used and there is no attempt to calculate the losses avoided by the suppression measure under assessment. The advantage of the approach is that data on losses avoided are not needed, and it can be seen as a measure of the sensitivity of losses to changes in the amount spent on suppression. However, in addition to focusing only on the economics of fire management, another major disadvantage from an economic point of view is that it does not directly examine the return on investment – other than in a comparative sense with alternative suppression measures.

4. Methodology as used in the SEIA-Model

The SEIA-Model contains eight steps that are set out below. The actions taken to fulfil these steps in a fire emergency and for the fires reported in this paper are shown subsequently.

1. Description of the emergency to establish its operational response requirements and geographical and temporal details.

It is within this step that general details of the event(s) are researched. This includes information such as significant fire dates (e.g. start and finish dates, days of significant fire behaviour), important fire suppression activities, fatalities and injuries, health impacts, overview of the main assets destroyed and impacts on businesses and households. Basic information is provided in Section 5 of this article.

For this study, the geographical boundary in which the impact of each wildfire event was assessed was within the local government areas (LGAs) that were burnt to some extent. This ensured that as well as accounting for direct destruction and damage, indirect impacts in the areas surrounding the fire were also included. By using the LGAs as the assessment boundary, statistical data relating to each LGA could be easily tracked. While this boundary may be convenient for some things, state government agencies and other organizations all have their own regional boundary lines, which meant that impact data gathered from these sources needed to be, as best as possible, aligned with LGA boundaries.

Information was collected from the day the fires began to 2 years after the fire was declared safe. This allowed indirect impacts to be sufficiently accounted for, as they may only become known months after the event.

2. Baseline profile of the assessment area to describe its:

(i) Economic and social activity
(ii) Assets that may be affected by the emergency – identifying assets within the impacted area, using GIS data
(iii) Community wellbeing.

Mapping the social and economic status of an area prior to the event occurring is a critical step, as it emphasizes the importance of the economic, social and environmental context on the way that losses and benefits are valued. This step will typically contain information on the study areas demographics (e.g. population, age, gender, employment status and income) and main economic sectors. It would also contain information on a range of assets located within the study area, such as significant public buildings and infrastructure, cultural and heritage listed objects and sites, and environmentally sensitive areas, including populations of endangered flora and fauna.

Given that presenting baseline profiles for all of the five fires studied in this paper would be very lengthy, the information has not been included.

3. Identification and assessment of direct tangible and intangible losses, damage and costs from the emergency including:

Tangible costs

(i) Residential, business and industry premises, stock and contents
(ii) Infrastructure
(iii) Agricultural/timber/stock/crops.

Intangible costs

(i) Death and injury
(ii) Health and psychological impacts
(iii) Culture and heritage loss and damage
(iv) Loss of memorabilia and environmental loss and damage.

Data for steps three, four and five were collected from primary sources where possible, such as from relevant government agencies and other organizations. Other sources were also used, such as inquiries, books and reports. Collecting data for the 1983 Ash Wednesday Fires (fires discussed in Section 5) proved relatively difficult, as government agencies or other organizations that were approached had very little information on these fires. Therefore, impacts and costs were largely sourced from the literature. The Royal Commission's interim report was used when collecting impact information for the 2009 Black Saturday Fires (Teague, McLeod, & Pascoe, 2009) instead of the final report (released 31 July 2010) because the current analysis was completed before the Commission's final report was released. This means that the minor changes made to some impact information when the Commission's final report was released (e.g. number of housed destroyed increased for the Delburn Fire (i.e. one of the single fires making up the Black Saturday Fires) in the final report) were not included in the current analysis and therefore final costs.

Residential, business and industry premises, stock and contents, infrastructure and park assets were valued according to the following formula: 'X' per cent of the replacement cost (i.e. depreciated value) or cost of repairs if damaged multiplied by the number of assets destroyed or damaged. The percentage value ranged from 85 per cent for residential, commercial, agricultural and park buildings to 50 per cent for many park structures (e.g. tables and seats, park signage). Agricultural livestock and feed were valued according to their market value at the time of the fire, apart from pasture, in which the cost of restoration was used. For crop and timber losses, the market price at the time of the fire less input costs avoided was used.

While many social impacts could not be quantified, two social impacts that are often valued statistically are loss of life and injuries. The value of a statistical life is $3.7 million according to the Australian Government's Office of Best Practice Regulation (OBPR) and is an 'estimate of the financial value society places on reducing the average number of deaths by one' (OBPR, 2009, p. 1). Injuries were valued using the human capital approach, whereby people are viewed as a labour source and the (average) 'value to society of preventing an injury is the saving in potential output or productive capacity' (BTE, 2001, p. 129). The values used were $439,000 for a serious injury and $14,700 for a minor injury (BTE, 2001).

Health impacts, psychological impacts, culture and heritage loss and damage and loss of memorabilia are not quantified in the SEIA-Model framework. Instead, household surveys distributed at some point after the fire (i.e. not immediately after) are recommended as the best method of collecting these qualitative data.

When the SEIA-Model was first tested using the Shire of Wellington, the contingent valuation method was used to value the environmental impacts. This involves surveying a number of people to understand their maximum willingness to pay for a particular good or service (Mogas, Riera, & Bennett, 2006), in this case the environmental importance of three areas within the boundary of the 2006/07 Great Divide Fires (OESC, 2008). Given that surveying people who lived through the fires as far back as the 1983 Ash Wednesday Fires was unrealistic, it was decided to value the impact of the fires on the environment in terms of the ecosystem services the environment provides humans, such as water supply, nutrient cycling, climate regulation and recreation. Estimating these services in a common unit (i.e. currency) is a practical method for use in policy decision making, as it allows the services provided by the ecosystem to be compared with economic services and manufactured capital (Costanza et al., 1997). If these ecosystem services are not valued in dollar terms, then TEEB (2009) advocates that the overall value of these services in terms of their weighting in policy decisions is grossly underestimated.

The framework used in Costanza et al. (1997) was used to estimate environmental impacts in this study because it provided a single value per hectare per year lost for each type of biome, e.g. forest, grasslands, thereby allowing consistency and comparability across the separate fires studied. This approach does have some critical limitations (Pagiola, von Ritter, & Bishop, 2004); however, another study that specifically reflects a range of Australian ecosystem service values could not be found. Two of these ecosystem services did not contribute to the final ecosystem service cost used in this assessment, being Food Production and Raw Materials, as the costs associated with these were accounted for in the loss of agricultural crops and timber. Note that production of some foods, such as honey, dependent on native vegetation may be unaccounted for. Conversely, the values given to Recreation and Cultural ecosystem services were used to measure the loss to tourism and cultural heritage values. The biomes of forest, swamps/floodplains, grasslands (which includes pasture) and cropland were singled out for use in this assessment. Environmental impacts were valued at 70 per cent of the first year cost per hectare. The value of 70 per cent was used based on studies measuring the proportion of burnt vs. unburnt areas and vegetation defoliation when burnt during previous Australian bushfires (Hammill & Bradstock, 2009; Lindenmayer & McCarthy, 2002; Williams et al., 2008). The scope of this loss assessment was to account for bushfire impacts over 2 years; however, since vegetation re-grows, an estimate on what proportion of each ecosystem service is 'restored' by the second year cannot be given with any degree of confidence at present. Regeneration is dependent on a range of factors including fire intensity and post-fire weather conditions – for example, an ongoing drought will slow down regeneration.

In some cases, the total dollar amount lost for an entire group of assets was given in the relevant literature, with no break-down of the impacts to specific assets (e.g. number of lookouts destroyed, kilometres of tracks damaged). This was especially evident when gathering information for the 1983 Ash Wednesday Fires. For example, the total loss to the Forests Commission Victoria, who at the time managed parks, reserves and forestry (timber) operations, was given for park and reserve assets (e.g. signage, roads, tracks, etc.) and the loss in timber production to the State.

4. Identification and assessment of indirect costs including:

(i) Business disruption losses and benefits
(ii) Disruption to transport networks
(iii) Disruption to essential service provision
(iv) Disruption to public services
(v) Disruption to households
(vi) Costs of emergency response and relief to the regional area.

Identifying indirect costs can be difficult, as detailed business or household surveys are the best ways to obtain information on which calculations can be made. As with environmental impacts, much of this information could not be collected by surveys due to the large time span over which the different fires occurred. Indirect costs collected across the five fires were the cost of emergency response (e.g. fire suppression) and smoke taint on viticulture crops.

5. Identify and assess the benefits to the area of analysis of:

(i) Insurance payments
(ii) Payments by governments
(iii) Recovery and restoration programmes
(iv) Economic activity generated from within the assessed district.

These were sourced for the Insurance Council of Australia and various government reports. The amount received from donations was also included in this study, as donations were seen as a benefit to those affected just like money received from insurance agencies or the government.

6. Quantification (and qualification) of costs and benefits.

This was conducted throughout the data gathering phase in steps three, four and five.

7. The comparison of costs and benefits with and without the wildfire to establish net socio-economic impact.

The net economic loss was found by adding up all the (quantitative) losses and then the benefits and subtracting the benefits from the losses.

8. Analysis of costs and benefits considering community sustainability and future emergency mitigation and preparedness strategies.

The analysis is presented in Sections 6 and 7.

5. Brief overview of the five severe south-eastern Australian wildfires being valued

The five fires chosen to test the framework were the 1983 Ash Wednesday Fires, 2003 Alpine and Canberra Fires, 2005/06 Grampians Fires, 2006/ 07 Great Divide Fires and 2009 Black Saturday Fires. They were selected because they are significant in south-eastern Australia's fire history, causing widespread destruction that led to numerous economic, social and environmental

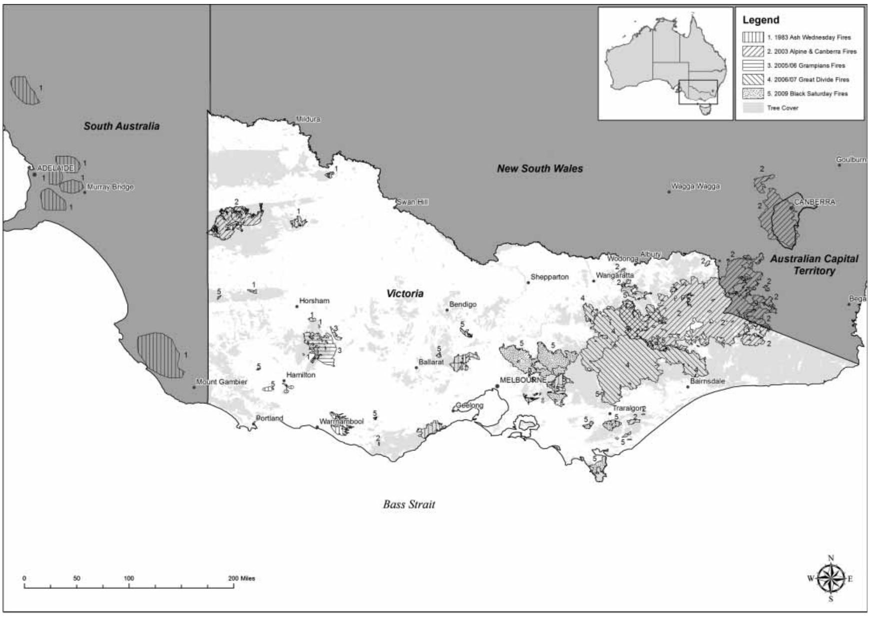

Figure 1. Areas burnt by each fire (DSE, 2010a).

impacts. Each fire is made up from 2 (2005/06 Grampians Fires) to 12 (2009 Black Saturday Fires) separate fires that burnt around the same time period and required emergency management personnel to manage these and sometimes other fires that were not included under the overall fire name simultaneously. A map outlining the area in which these fires occurred is shown in Figure 1.

The weather leading up to each of the fires being studied was generally similar, being characterized by prolonged drought and below average to record low rainfalls in the months or weeks leading up to the fires (Rawson, Billing, & Duncan, 1983; Sullivan, 2004; Teague et al., 2009). This was further compounded by days of extreme heat (typically above 40°C) and low relative humidity (as low as 5 per cent) in the days just before and during the fires (Karoly, 2009; Oliver, Britton, & James, 1984). While fighting the fires, changing wind conditions, large amounts of spotting (where embers burnt at the fire front are carried on air currents up to kilometres ahead of the main fire to create new fires) and in many cases rugged and difficult terrain made containing these fires extremely difficult (Fleming, Fletcher, Sietsma, Tiddy, & van der Peet, 2007). The fires started in a number of ways, including lighting strikes, powerlines arcing or power poles falling to the ground, malicious circumstances or by accident (e.g. campfires, cigarette butts). In some cases, the cause was not determined. Table 2 provides basic details on each fire's final area and the date they were first reported as spreading, when they were fully contained within a boundary and the date the responsible fire agency declared them safe (i.e. completely or very close to being extinguished). Table 3 highlights some of the impacts they caused. The information in these tables was collated from published and unpublished sources. They are displayed to give an idea of the impacts and should not be viewed as the final values. It is recommended that where possible, impact data be drawn from primary rather than secondary sources.

Some of the data in Table 3 have been extrapolated from the information available in other literature (especially for the Ash Wednesday Fires). Furthermore, some of the values may not include impacts from all the separate fires that make up the five fires discussed in this article.

Table 2. The total area burnt and timeframe for each fire.

Fire area and status	1983 Ash Wednesday	2003 Alpine and Canberra	2005/06 Grampians	2006/07 Great Divide	2009 Black Saturday
Total area (hectare)	387,615	1,838,063	142,885	1,113,251	388,261
Going	16 February 1983	7 January 2003	31 December 2005	1 December 2006	29 January 2009[a]
Contained	21 February 1983	7 March 2003	2 February 2006	7 February 2007	14 March 2009
Safe	Unknown	30 April 2003	1 May 2006	2 May 2007	15 May 2009

[a]The Black Saturday Fires were named after Saturday, 7 February 2009, the day when a majority of the individual fires began.
Source: DSE (2010b).

Table 3. Summary of the major impacts caused by each fire.

Asset type destroyed or damaged	1983 Ash Wednesday	2003 Alpine and Canberra	2005/06 Grampians	2006/07 Great Divide	2009 Black Saturday
Fatalities	75	5	2	1	173
Major injuries	133	52	Minimal	Minimal	130
Minor injuries	2543	338	Minimal	Minimal	670
Homes	2475	844	77	51	2298
Agricultural buildings	1499	343	307	213	1411
Fencing (kilometres)	18,939	3757	2244	1436	8618
Sheep	266,651	13,185	58,636	71	4449
Cattle	18,453	3859	160	907	3673
Pasture (hectares)	153,381	Unknown	39,246	11,778	65,065
Softwood plantation timber (hectares)	22,810	18,697	Minimal	3622	12,416
Native forest on public land (hectares)	106,155	1,376,900	91,860	1,008,274	269,030

Note: All dates for the 1983 Ash Wednesday and 2003 Alpine and Canberra Fires, which burnt across state borders (Figure 1), are for those parts of the fires burning within the state of Victoria.

6. Results and analysis of the costs

The losses, benefits and net costs for each fire are shown in Table 4. The labels given in this table are arranged slightly differently to those in the methodology section to firstly highlight the impact on specific sectors, and to display only those asset types that could be valued in terms of dollars for this study.

Using the SEIA-Model, the 2003 Alpine and Canberra Fires were shown to be the most costly in terms of their net loss value, followed by the 2006/07 Great Divide Fires. These high losses can be attributed to the large areas they burnt in mostly forested landscapes. In addition, the 2003 Alpine and Canberra Fires burnt 87,000 ha of merchantable timber in Victorian state forests, of which 2190 ha was salvaged (Theobald & Lawlor, 2006), almost 2000 ha of plantation timber in Victoria (Wareing & Flinn, 2003a, 2003b) and 16,770 ha of softwood plantations in the Australian Capital Territory (Bushfire Recovery Taskforce, 2003). Together, these resulted in losses of $1.494 billion dollars. The 1983 Ash Wednesday and 2009 Black Saturday Fires were the third and fourth most costly fires, respectively, producing similar net losses, reflecting the many similarities between the two fires. These include that the total areas shown for each

Table 4. Total quantified losses, total benefits and net loss for each fire (rounded to the nearest $'000,000) (their percentage value relative to the total loss or total benefit value is shown in parentheses).

Cost category	1983 Ash Wednesday	Ash 2003 Alpine and Canberra	2005/06 Grampians	2006/07 Great Divide	2009 Black Saturday
Residential buildings and contents	629 (35)	154 (4)	15(3)	14(1)	623 (21)
Commercial, industrial and public buildings and contents	34 (2)	5 (0)	0 (0)	0 (0)	38 (1)
Park buildings, contents and infrastructure	120 (7)	35 (1)	11 (2)	29 (1)	34 (1)
Public infrastructure (including utilities and roads)	1 (0)	93 (3)	0 (0)	0 (0)	7 (0)
Agriculture (including stock, feed, crops, buildings and fencing)	341 (19)	66 (2)	64 (14)	169 (8)	733 (25)
Timber (including native forest and plantation)	126 (7)	1494 (41)	0 (0)	705 (32)	80 (3)
Emergency response operations	15(1)	137 (4)	37 (8)	181 (8)	344 (12)
Fatalities and injuries	375 (21)	46 (1)	7 (2)	4 (0)	714 (24)
Environment	165 (9)	1629 (45)	321 (71)	1116 (50)	366 (12)
Total losses	1807	3659	455	***2216***	2939
Government aid and programmes	48 (8)	164 (27)	12 (29)	147 (83)	517 (26)
Donations	98 (16)	12(2)	0 (0)[a]	0 (0)[b]	389 (19)
Insurance	465 (76)	434 (71)	29 (71)	31 (17)	1092 (55)
Total benefits	611	610	41	178	1998
Net loss	1196	3049	414	2038	942

Note: Values may not add up to the totals due to rounding. All values are in AU$2009.
[a]Donations totalled $217,417, but were not included due to rounding.
[b]Donations totalled $356,872, but were not included due to rounding.

fire are the result of many separate fires burning on the Wednesday and Saturday from which the fire names are derived. In addition, these fires devastated rural townships, resulting in high fatalities, injuries and residential and agricultural losses. The 2005/06 Grampians Fires produced the least net loss, being attributed to its relatively small size and limited impact on urban or township areas.

While the 2003 Alpine and Canberra Fires were the costliest fires in terms of net loss, Table 5 highlights both the total loss and net loss of each fire per hectare, which greatly alters the way in which the costs can be interpreted. By displaying the total loss per hectare in addition to the net

Table 5. Total loss and net loss of each fire per hectare.

Comparison measurement	1983 Ash Wednesday	2003 Alpine and Canberra	2005/06 Grampians	2006/07 Great Divide	2009 Black Saturday
Total loss per hectare ($) Net loss per hectare ($)	4,662 3,086	1,991 1,659	3,184 2,899	1,991 1,831	7,570 2,425

loss per hectare, the results illustrate that accounting for the benefits the community receives can go some way to offsetting the financial losses. Having said that, intangible losses such as the emotional trauma of living through a severe wildfire or losing a loved one could not be compensated for with financial assistance. The most expensive fire in terms of total loss per hectare were the 2009 Black Saturday Fires, almost doubling the 1983 Ash Wednesday Fires cost. The high total loss values for these fires can be attributed to the large housing, agricultural and social (i.e. fatalities and injuries) losses in a relatively small area. The 2005/06 Grampians Fires contained the next highest total cost per hectare, which burnt a much smaller area than all the other fires predominantly through forested areas. The 2003 Alpine and Canberra and the 2006/07 Great Divide Fires had the lowest cost per hectare. Although the timber and environmental losses were very large for both, the total size of the 2003 Alpine and Canberra and the 2006/07 Great Divide Fires meant that the cost per hectare was spread across a much larger area. When the area burnt is then divided by the net loss, the most noticeable difference was seen for the 2009 Black Saturday Fires, being reduced by 68 per cent; to the third highest net loss per hectare. This was due to the large amount of financial assistance received from all three benefit types (i.e. government aid, donations and insurance) relative to the other fires. The 1983 Ash Wednesday Fires produced the next highest change, with the loss per hectare being reduced by 34 per cent when using the net loss value instead of the total loss value. The net costs per hectare for the remaining three fires were only marginally less than the total costs due to the relatively higher area of forested areas burnt and the fact that there is very little compensation for ecosystem service losses (apart from such things as isolated rehabilitation works, etc.).

7. Discussion: How does the framework perform?

The SEIA-Model has shown that the impacts and costs related to wildfires are very broad and cover many areas across the economic, social and environmental landscapes. Its ability to provide meaningful data and results that allow comparability between multiple wildfires presents government agencies and other organizations with a powerful analytical tool. This section compares the results to similar studies, discusses high-priority impacts as identified using the SEIA-Model and the importance of selecting a meaningful boundary when conducting the assessment. It is worth noting that the degree to which the results can be analysed and conclusions drawn are limited by the data available during the assessment process. That is, not all impacts that can be valued have been valued for all five fires. Some impact data are no longer available (evident for the 1983 Ash Wednesday Fires). Other data may be available but were not located, or the information was not available at the time of conducting the analysis.

7.1. *Comparing these losses to other assessments: Are these values too high?*

The impacts assessed in this study are generally comparable when evaluated against other studies that measure wildfire impacts. Two examples are presented here. The first comes from the reports that have estimated the losses associated with the 1983 Ash Wednesday Fires. The BTE (2001) investigated these impacts, estimating that the total loss for both Victoria and South Australia was \$1.320 billion. The BTE (2001) assessment only accounted for economic and social losses (i.e. did not include environmental losses or the benefits). By only including these values from the current loss assessment (\$1.642 billion), it can be seen that the BTE (2001) figure is \$322 million below the value given in this current assessment. This can be attributed to the current assessment valuing more impact categories, such as timber losses and losses to national and state parks.

The second example comes from a 2003 southern California fire that burnt through 50,586 ha of upper catchment vegetation and houses scattered throughout the area (Dunn, Gonzalez-Caban, & Solari, 2005). While this fire was approximately one-third of the size of the 2005/06 Grampians Fires, Dunn et al. (2005) estimated the total loss as being $1.892 billion. This took into consideration the response and recovery expenditure of public agencies, private residents and businesses and non-profit organizations over a period of 2 years, but did not look at the benefits as defined in this article. Considering that the affected catchment was a major source of drinking water that now had to be treated and thousands of insurance claims were made (i.e. 787 total losses and 3860 partial losses were claimed by private citizens and businesses), the total loss seems reasonable.

7.2. *High-priority requirements when accounting for wildfires*

When accounting for wildfire losses, the results of this study indicate a number of impacts that lead to substantial losses and hence efforts should be made to manage these impacts to mitigate future costs.

7.2.1. *Human lives*

The highest priority when responding to natural disasters is always the preservation of life. The 2009 Black Saturday and 1983 Ash Wednesday Fires were the most devastating, resulting in losses of $714 and $375 million, respectively, using the value provided by the Australian Government Office of Best Practice Regulation. Some may think that it is inappropriate to place a dollar value on a life; however, the BTE (2001) asserts that estimating the costs of intangible impacts such as this generates opportunities for more informed decision making. It also creates a more accurate and holistic estimate of the total economic loss that is used by policy makers when making decisions about hazard prevention and mitigation strategies (BTE, 2001).

7.2.2. *Ecosystem services (that is, under 'Environment' in Table 4)*

The lack of ecosystem service values related to Australian natural environments was a significant limitation in analysing the impact on the environment, as the Costanza et al. (1997) framework developed global generic values instead of more location-specific values. Unfortunately, this study had neither the time nor the resources to complete this task. Even so, drawing on the values developed by Costanza et al. (1997) as applied in this article, highlights how important the environment is to human welfare, accounting for between 9 per cent (1983 Ash Wednesday Fires) and 71 per cent (2005/06 Grampians Fires) of the total losses.

It could be argued that the ecosystem service values given in this assessment are at the lower limits of what they could potentially be. Firstly, this assessment took a conservative estimate at the length ecosystem services would be affected, being 1 year after a fire burnt through the landscape; however, it is assumed that it would take a lot longer for some services to function at full capacity again. Secondly, the value placed on these ecosystem services may have become much greater since Costanza et al. (1997) first placed a dollar value on them (e.g. climate regulation, genetic resources), thereby increasing their dollar value per hectare beyond the annual increase in CPI value.

Even without knowledge of the study of 'ecosystem services', they have often been given a high priority by land managers. A prime example is the early recognition during the 2006/07 Great Divide Fires that the Thompson Dam catchment (the main source of Melbourne's drinking water) was under threat, which was saved by the construction of a 107 km control line

(Flinn, Wareing, & Wadsley, 2008). Translating the importance of the environment into a dollar value therefore justifies its place in an economic loss assessment.[1]

7.2.3. *Timber*

Timber losses were very high for the 2003 Alpine and Canberra ($1.494 billion) and the 2006/07 Great Divide ($705 million) Fires. These estimates were based on mill gate timber and pulp wood prices[2] for eucalypt ash species (Buchan, 2007), and for pine plantations in the case of Canberra. The values shown above have already discounted the value of the timber salvaged after the wildfires. Salvaging operations begin immediately after the fire and continue for one-and-a-half to 3 years, depending on the resources available and speed at which the timber degrades (DSE and Parks Victoria (PV), 2008). This study found that the area salvaged differed greatly between plantations and native timber in state forests. On average, 39 per cent of the plantation area burnt was salvaged across the 2003 Alpine and Canberra and the 2006/07 Great Divide Fires, while only 4 per cent of the native state forest available for harvest was salvaged within 2 years.

Different species of trees respond very differently to fire. Alpine and Mountain Ashes (eucalypts), which are valued highly for their uses in flooring and furniture making, are easily killed by fire and deteriorate rapidly in terms of their timber quality and value (VicForests, 2009), as does radiata pine. Other ‘mixed’ species of eucalypts, such as the Messmate Stringybark, Manna Gum and Mountain Grey Gum, possess dormant buds under the bark and on the roots that grow if the trees have been burnt by fire (Gill, 1981). Even though these trees will generally recover, the timber will likely possess some damage from the flames or heat, and will therefore have a reduced future harvestable value. Although not calculated in this assessment, the impacts on businesses that rely on the timber industry for their raw materials (e.g. builders, furniture makers) could also be significant.

7.2.4. *Agriculture*

Another primary industry that sustained heavy losses was the agricultural industry. Many assets were listed within the agriculture category; however, for the 2003 Alpine (Victoria only), 2006/07 Great Divide and 2009 Black Saturday Fires; losses to the viticulture industry were large. Direct contact with the flames and the spoiling of grapes through smoke taint resulted in losses of $23, $150 and $330 million, respectively. These values made up 37, 89 and 45 per cent of the total agricultural losses for these fires. Since smoke taint is such an expensive impact, government agencies, universities and the wine industry are working together to understand the impact of smoke on grape quality and find ways to combat it (Kennison, Wilkinson, Williams, Smith, & Gibberd, 2007; Whiting & Krstic, 2007).

7.3. *The benefits received*

The financial benefits received (from insurance, donations and government aid) as a proportion of the losses differed greatly between the fires, being 1983 Ash Wednesday Fires – 34 per cent, 2003 Alpine and Canberra Fires – 17 per cent, 2005/06 Grampians Fires – 9 per cent, 2006/07 Great Divide Fires – 8 per cent, 2009 Black Saturday Fires – 68 per cent. There was a general trend in that those fires resulting in higher economic and social losses received the greatest proportion of financial benefits and vice versa. For example, the 2005/06 Grampians and 2006/07 Great Divide Fires, which produced the highest environmental losses (as a proportion of total losses) (i.e. 71 and 50 per cent), also received the lowest proportion of benefits. This result is to be expected, as providing financial assistance in the form of government rehabilitation works, for example, will only go so far. Time is really the only way the natural environment and the ecosystem services it provides will be restored. This should not detract from the large ecosystem costs, however, as the consequences of removing large areas of forests will have implications for those who benefit directly from using it, such as the forestry and tourism industry, and for the services it provides to the community as a whole.

7.4. *The cost of a wildfire will change depending on the study's boundaries*

Because the study presented here was conducted in an economic loss assessment framework, the spatial and temporal boundaries were set before the data were collected. One advantage of the SEIA-Model is its flexibility, so if the boundaries were readjusted the framework would accommodate this. It is important to understand that by changing the boundaries, however, what is considered an economic loss and benefit would also change, therefore producing a new net cost. For example, if the Victorian Government wanted to look at the impact on the state's economy then they would reset the assessment boundary to the state's boundary. By doing this, many impacts that were considered losses and benefits to the LGA level would not be losses anymore, but transfers. For example, the destruction of businesses within the LGAs would force people to travel to other areas outside the LGA. While this would have been considered a loss in the original assessment, it is now considered a transfer effect occurring within the new boundary, with no losses (apart from any increased transaction costs) to the state of Victoria. In another example, the amount of donations included would be reduced, as the money raised from within Victoria would not be included.

Conversely, some significant impacts that were excluded from this study would now become economic losses if the boundary was increased to include the whole of Victoria. Notably, one major impact that affected an estimated 685,000 Victorian residential, commercial and industrial customers (mostly within the Melbourne metro area) was when the 2006/07 Great Divide Fires tripped the main power line connecting Victoria to New South Wales (The Nous Group, 2007). The estimated cost of this power outage was $531 million, with costs to customers directly affected being $250 million and flow-on impacts costing $281 million (The Nous Group, 2007). Furthermore, many indirect impacts arising from smoke would be included, such as smoke taint to the viticulture industry and other crops (e.g. apples) well outside the boundaries used in this study. Health problems arising from smoke drifting hundreds of kilometres from its source would also lead to substantial losses to the Victorian economy.

The boundaries placed on an economic loss assessment are crucial to what impacts are considered losses and benefits because they produce a completely different set of results on which important decisions are then made. While the purpose of the assessment will determine the geographic (and temporal) boundaries, the OESC (2008) maintains that conducting an economic loss assessment at the regional or local level provides data by which the efficacy of recovery arrangements and programmes can be measured. It also provides a greater understanding of how the community responds to the event and their level of resilience (OESC, 2008).

8. Future research needs and conclusion

While collecting and valuing the impacts, some important knowledge gaps became apparent. The most noticeable one was the lack of ecosystem service values relating to Australian natural environments. This is a contentious area, with the question not so much about whether ecosystem services should be valued, but how they should be valued. To ensure consistency and comparability, values are needed that are generic or averages that can be applied to different ecosystem types across Australia. Even though the present study used the framework developed by Costanza et al. (1997) because it enabled comparability, its limitations were well understood regarding its application in Australian conditions. The estimates in Costanza et al. (1997) were generated by extrapolating the results of several studies carried out in specific sites around the world. Pagiola et al. (2004) discuss the issue of benefits transfer and how the results gained from studies like Costanza et al. (1997) are often unreliable due to the wide differences in ecosystem service values from one location to the next.

Due to the difficulties in valuing indirect economic and social impacts long after the event has passed, some have not been valued. Collecting this information usually requires surveying affected people and businesses shortly after the fire and is therefore relatively labour intensive. They also require a very carefully planned and tested set of questions and post-survey analysis (Barkmann et al., 2008). In terms of this study, surveying those affected by the older fires was not a realistic option. The results of comprehensive household surveys have been published after a number of fires (Clayer, Bookless-Pratz, & McFarlane, 1985; Whittaker, Haynes, McLennan, Handmer, & Towers, 2010) focusing on people's psychological health, their movements before and during the fires, property impacts and community safety issues. A survey specifically designed to value indirect (namely household and business disruption) losses, social losses and benefits (e.g. community bonding), has been developed in the SEIA-Model and was used after the 2006/07 Great Divide Fires. To provide a more systematic way of accounting for these types of losses and benefits, this survey (or something like it) could be refined and standardized for distribution after severe wildfires, enabling comparability between different events over time.

While a large number of impacts have been valued, the list is by no means exhaustive, and could be viewed as only the beginning in which the number of impacts valued is built upon, leading to a better estimation of the cost of wildfires. This can only be achieved by using an economic loss assessment as the framework. By ensuring that the full range of economic, social and environmental losses and benefits are accounted for, a more complete and holistic picture of the loss to an economy will be known. This subsequently gives staff involved in creating policies and mitigation strategies, managers in the process of creating risk frameworks and treasury officials detailed and transparent information on which they can base their decisions. Until a large majority of the economic, social and environmental losses and benefits associated with wildfires are known, policies and strategies incorporating wildfire information will not be fully informed.

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Notes

1. Other reports by the same author (i.e. Stephenson) use 2008 Australian dollars.
2. Mill gate price is the price of a forest product delivered to the purchaser, such as a mill. This price includes the stumpage price paid to the owner of the standing timber before it is harvested, the cost of cutting the trees down, moving them to a loading area and transporting them to the purchaser (AgForests Queensland, 2006).

References

AgForests Queensland (2006). *Products and marketing guide for eucalypt (Hardwood) forests and woodlands*. Brisbane, Queensland: AgForests Queensland.

Barkmann, J., Glenk, K., Keil, A., Leemhuis, C., Dietrich, N., Gerold, G., & Marggraf, R. (2008). Confronting unfamiliarity with ecosystem functions: The case for an ecosystem service approach to environmental valuation with stated preference methods. *Ecological Economics*, *65,* 48–62.

BTE (2001). *Economic costs of natural disasters in Australia (Report No. 103)*. Canberra, Australian Capital Territory: Bureau of Transport Economics.

Buchan (2007). *Economic impact assessment great divide south and coopers creek bushfires*. Australia, in the Wellington Shire Council submission for the Inquiry into the Impact of Public Land Management Practices on Bushfires in Victoria, Final Report June 2008. Melbourne, Australia: Parliament of Victoria. Retrieved from http://www.parliament.vic.gov.au/images/stories/committees/enrc/079_Wellington_Shire_Council.pdf

Building Commission (2010). *A guild to building in Victoria after the bushfires.* Victoria: Building Commission. Retrieved from www.buildingcommission.com.au/resources/documents/guide_to_building_after_ bushfires_March10.pdf

Burrows, N. (2008). Linking fire ecology and fire management in South-West Australian forest landscapes. *Forest Ecology and Management*, *255,* 2394–2406.

Bushfire Recovery Taskforce (2003). *The report of the bushfire recovery taskforce – Australian capital territory*, *October 2003*. Canberra, Australian Capital Territory: Publishing Services for ACT.

Clayer, J., Bookless-Pratz, C., & McFarlane, A. (1985). *The health and social impact of the Ash Wednesday Fires*. South Australia: Mental Health Research and Evaluation Centre, South Australian Health Commission.

Commission on Geosciences, Environment, and Resources (1999). *The impacts of natural disasters: A framework for loss assessment*. Washington, DC: National Academy Press.

Costanza, R., d'Arge, R., de Groot, R., Farber, S., Grasso, M., Hannon, B., & van den Belt, M. (1997). The value of the world's ecosystem services and natural capital. *Nature*, *387,* 253–260.

Donovan, G., & Rideout, D. (2003). A reformulation of the cost plus net value change (C + NVC) model of wildfire economics. *Forest Science*, *49,* 318–323.

DSE (2010a). *Data collected and held by land and fire management division*. East Melbourne, Victoria: Department of Sustainability and Environment.

DSE (2010b). *Data collected for and stored on FireWeb (internal fire management system)*. East Melbourne, Victoria: Department of Sustainability and Environment.

DSE and PV (2008). *Great divide fire recovery plan*. Melbourne, Victoria: Department of Sustainability and Environment and Parks Victoria.

Dunn, A. E., Gonzalez-Caban, A., & Solari, K. (2005). *The old, grand prix, and Padua Wildfires: How much did these fires really cost?* A preliminary report on expenditures and discussion of economic costs resulting from the 2003 Old, Gran Prix and Padua wildfire complex. USDA Forest Service-Pacific Southwest Research Station, Riverside, USA, 18 pp.

ECLAC (2003). *Handbook for estimating the socio-economic and environmental effects of disasters*. Mexico: Economic Commission for Latin America and the Caribbean.

EMA (1998). *Manual 3: Australian emergency management glossary.* Australia: Emergency Management Australia. Retrieved from www.ema.gov.au/www/emaweb/rwpattach.nsf/VAP/%283273BD3F76A7A5DEDAE36942A54D7D 90% 29~Manual03-AEMGlossary.PDF/$file/Manual03-AEM Glossary.PDF.

European Commission (1999). *Guidelines for the assessment of indirect and cumulative impacts as well as impact interactions*. Luxembourg: Office for Official Publications of the European Communities.

Fleming, H., Fletcher, D., Sietsma, M., Tiddy, J., & van der Peet, S. (Eds.). (2007). *Beyond the smoke: Fires, destruction and images of hope – grampians region 2006*. Halls Gap, Victoria: Friends of Grampians – Gariwerd.

Flinn, D., Wareing, K., & Wadsley, D. (2008). *The victorian great divide fires: December 2006–February 2007*. East Melbourne, Victoria: Department of Sustainability and Environment.

Flint, A., & Fagg, P. (2007). *Mountain ash in victoria's state forests – silviculture reference manual no. 1*. East Melbourne, Victoria: Department of Sustainability and Environment.

Gill, M. (1981). Adaptive responses of Australian vascular plant species to fire. In M. Gill, R. Groves, & I. Noble (Eds.), *Fire and the Australian biota*. Canberra, Australian Capital Territory: The Australian Academy of Science.

Hammill, K., & Bradstock, R. (2009). Spatial patterns of fire behaviour in relation to weather, terrain and vegetation. *Proceedings of the Royal Society of Queensland*, *115,* 127–133.

Handmer, J. (2003). The chimera of precision: Inherent uncertainties in disaster loss assessment. *The Australian Journal of Emergency Management*, *18,* 88–97.
Handmer, J., Abrahams, J., Betts, R., & Dawson, M. (2005). Towards a consistent approach to disaster loss assessment across Australia. *The Australian Journal of Emergency Management*, *20,* 10–18.
Handmer, J., Read, C., & Percovich, O. (2002). *Disaster loss assessment guidelines*. Queensland: Department of Emergency Services, Queensland Government.
Karoly, D. (2009). The recent bushfires and extreme heat wave in southeast Australia. *Bulletin of the Australian Meteorological and Oceanographic Society*, *22,* 10–13.
Kennison, K., Wilkinson, K., Williams, H., Smith, J., & Gibberd, M. (2007). Smoke-derived Taint in wine: Effect of postharvest smoke exposure of grapes on the chemical composition and sensory characteristics of wine. *Journal of Agricultural and Food Chemistry*, *55,* 10897–10901.
Lindenmayer, D., & McCarthy, M. (2002). Congruence between natural and human forest disturbance: A case study from Australian montane ash forests. *Forest Ecology and Management*, *155,* 319–335.
Merz, B., Elmer, F., & Thieken, A. (2010). Reply to comment on significance of "high probability/low damage" versus "low probability/high damage" flood events' by C.M. Rheinberger (2009). *Natural Hazards and Earth Systems Sciences*, *10,* 3–5.
Middelmann, M. (Ed.). (2007). Impact of natural disasters. *Natural hazards in Australia: Identifying risk analysis requirements*. Geoscience Australia, Canberra, Australian Capital Territory, Australia, Chapter 2.
Ministerial Taskforce on Bushfire Recovery, 2007 (2007). *Report from the ministerial taskforce on bushfire recovery*. Melbourne, Victoria: Department of Innovation, Industry and Regional Development.
Mogas, J., Riera, P., & Bennett, J. (2006). A comparison of contingent valuation and choice modelling with second-order interactions. *Journal of Forest Economics*, *12,* 5–30.
Morrison, M. (2011). *A guide to estimating the non-market values associated with improved fire management*. East Melbourne, Victoria: Bush-fire Cooperative Research Centre. Retrieved from www.bushfirecrc.com/resources/research-report/guide-estimating-nonmarket-values-associated-improved-fire-management
New York City Partnership and Chamber of Commerce (2001). *Economic impact of the September 11th attack on New York City, New York*. New York.
OBPR (2009). *Best practice regulation guidance note: Decision rules in regulatory cost-benefit analysis*. Parkes, Australian Capital Territory: Office of Best Practice Regulation, Department of Finance and Deregulation.
OESC (2008). *The development of a socio-economic impact assessment model for emergencies*. Melbourne, Victoria: Office of the Emergency Services Commissioner.
Oliver, J., Britton, N., & James, M. (1984). *The Ash Wednesday Bushfires in Victoria 16 February 1983*. Townsville, Queensland: James Cook University of North Queensland.
Pagiola, S., von Ritter, K., & Bishop, J. (2004). *Assessing the economic value of ecosystem conservation* (Environment Department Paper No. 101). Washington, DC: The World Bank Environment Department.
Parker, D., Green, C., & Thompson, P. (1987). *Urban flood protection benefits: A project appraisal guide*. Aldershot, Hampshire: Gower Technical Press.
Rawson, R., Billing, P., & Duncan, S. (1983). The 1982–83 forest fires in Victoria. *Journal of Australian Forestry*, *46,* 163–172.
Read Sturgess and Associates (2000). *Rapid appraisal method (RAM) for floodplain management*. East Melbourne, Victoria: Department of Natural Resources and Environment.
Rose, A., & Lim, D. (2002). Business interruption losses from natural hazards: Conceptual and methodological issues in the case of the Northbridge earthquake. *Environmental Hazards*, *4,* 1–14.
Suggett, D., & Goodsir, B. (2002). *Triple bottom line measurement and reporting in Australia*. Melbourne, Victoria: The Allen Consulting Group.
Sullivan, A. (2004). *Nature of severe fire events*. Canberra, Australian Capital Territory: CSIRO Forestry and Forest Products Client Report No. 1470.
Teague, B., McLeod, R., & Pascoe, S. (2009). *2009 Victorian bushfires royal commission interim report*. Melbourne, Victoria: Parliament of Victoria.
TEEB (2009). *The economics of ecosystems and biodiversity for national and international policy makers*. Nairobi: United Nations Environment Programme.
The Nous Group (2007). *16 January 2007 Electricity supply interruptions in Victoria: What happened and why and opportunities and recommendations*. Melbourne, Victoria.
Theobald, M., & Lawlor, S. (2006). The Victorian alpine fires salvage program: Response, progress and lessons. *Australian Forestry*, *69,* 83–89.

van der Veen, A. (2004). Disasters and economic damage: Macro, meso and micro approaches. *Disaster Prevention and Management*, *13,* 274–279.

VicForests (2009). *After fire salvage harvesting and forest recovery.* Victoria: VicForests.

Wareing, K., & Flinn, D. (2003a). *The victorian alpine fires: January–March 2003*. East Melbourne, Victoria: Department of Sustainability and Environment.

Wareing, K., & Flinn, D. (2003b). Large fires in Australian alpine landscapes: Their part in the historical fire regime and their impacts on alpine diversity. *The Victorian Alpine Fires: January–March 2003*, *17,* 793–808.

Whiting, J., & Krstic, M. (2007). *Understanding the sensitivity to timing and management options to mitigate the negative impacts of bush fire smoke on grape and wine quality – scoping study.* Knoxfield, Victoria: Department of Primary Industries.

Whittaker, J., Haynes, K., McLennan, J., Handmer, J., & Towers, B. (2010). *Victorian 2009 bushfire research response household mail survey.* East Melbourne, Victoria: Bushfire Cooperative Research Centre.

Williams, R., Wahren, C., Tolsma, A., Sanecki, G., Papst, W., Myers, B., . . . Green, K. (2008). Large fires in Australian alpine landscapes: Their part in the historical fire regime and their impacts on alpine diversity. *International Journal of Wildland Fire*, *17,* 793–808.