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Welcome from Editors

It is our pleasure to bring to you the compiled papers from the Research Forum of the AFAC and Bushfire CRC Annual Conference, held in the Perth Exhibition and Convention Centre on the 28th of August 2012.

These papers were anonymously referred. We would like to express our gratitude to all the referees who agreed to take on this task diligently. We would also like to extend our gratitude to all those involved in the organising, and conducting of the Research Forum.

The range of papers spans many different disciplines, and really reflects the breadth of the work being undertaken, The Research Forum focuses on the delivery of research findings for emergency management personnel who need to use this knowledge for their daily work.

Not all papers presented are included in these proceedings as some authors opted to not supply full papers. However these proceedings cover the broad spectrum of work shared during this important event.

The full presentations from the Research Forum and the posters from the Bushfire CRC are available on the Bushfire CRC website www.bushfirecrc.com.

Richard Thornton and Lyndsey Wright

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Adapting to climate change: reflecting on our shared and uncommon knowledge

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Abstract

Across the country, fire management faces the common challenge of adapting to a changing climate. However, alongside social, environmental and economic changes, climate change will manifest differently across the country. If fire management is to support the capacity of our social-ecological systems to adapt to these interacting changes, the sector itself must be adaptive. Insights from literature across a range of disciplines highlight adoption of a ‘reflexive learning approach’ could enable such a capacity.

Reflexive learning in policy sectors involves exploring the frames and informal institutions that influence the shared (and assumed) knowledge underpinning current practices, policies and governance. It also involves exploring uncommon knowledge for additional ways of framing fire management and its issues. This paper presents research that used this theoretical position to explore the frames and informal institutions of Victoria’s fire management sector.

The analysis indicated a highly institutionalised emergency management frame that, without an explicit reflexive practice that taps into a diverse range of perspectives, fire management’s capacity for reflexive learning and thereby, adaptation may be constrained. Implications for disaster risk reduction (DRR) and adaptation (CCA) efforts within the sector, and for interchanges between DRR and CCA more broadly are discussed.

Introduction

Beyond biophysical projections for increasing likelihood of fire conducive weather, climate change has the potential to alter, if not increase, the complexities and challenges that infuse the sector's twin objectives of DRR and ecological management, and most certainly their interactions (Bosomworth and Handmer 2008). Because climate change will interact with our already dynamic socio-demographic, -economic and -ecological systems, lending it the capacity to exacerbate fire management's existing challenges, fire management requires considerable adaptive capacity across its policies, practices and governance. The challenge is that a sector's adaptive capacity relies on its ability to reflect on and possibly change the frames and informal institutions that influence the shared (and somewhat assumed) knowledge underpinning current practices, policies and governance. It also involves exploring uncommon knowledge for additional ways of framing fire management and its issues. This kind of 'reflexive learning' confers an adaptive capacity through an 'opening up' of a wider range of policies and practices upon which the sector can draw in response to change, uncertainties and novel events.

Reflexive learning enables adaptation in policy sectors

Reflexive learning is more than 'adaptive management'. It comprises three orders of learning. The first and second orders involve learning about and possibly changing existing policies or dominant policy instruments within the existing institutional landscape (Hall, 1993). This concept mirrors ideas of single and double-loop learning (Sabatier, 1999; Schön & Rein, 1994), and the intent of 'learning by doing' used in references to adaptive management. However, reflexive learning requires an additional, third order of learning that involves the potential for change to overall goals and shifts in the institutional landscape (Hall, 1993). This concept of learning is very different to that which sees learning as simply the acquisition of more information. "Gathering evidence is not always the same as learning" (Hudson, 2007:211), particularly when that evidence is gathered from the perspective of a particular and/or dominant frame. It requires influential actors to consider how they are conceiving of a policy sector's context and issues, how this directs preference for particular policies and programs, and how the sector's formal and informal institutions (cultural-cognitive practices) reinforce these ideas. Reflexive learning even asks that we reflect on how these frames, structures and patterns of action contribute to the persistence of policy 'problems' (Hendriks & Grin, 2007; Voss & Kemp, 2005). It demands that actors consider a broader range of different perspectives from which additional possible approaches might be illuminated.

The frame reflection component of reflexive learning is crucial for adaptation in a public policy sector. Every government department and agency has 'deep structures' of policy - the implicit collection of beliefs about aims and intentions of the department, agency and policies therein and about the relevant actors who influence or benefit from the policy (Parsons, 1995:146). These deep structures are based on a set of ideas about what constitute the main features and problems of the sector, and how these can be governed the best possible way (Boin & Hart, 2000). These ideas or frames, are a way of thinking about a problem or subject than an assemblage of facts (Fischer, 2003:103). While they vary in their internal coherence, their ability to provide cogent warrants for policy claims, and their congruence with empirical reality (Fischer & Forester, 1993), they influence how actors perceive the validity of policy options (Schön & Rein, 1994) including the information, research and perspectives that inform those options. Different frames direct attention to different aspects of a situation and tell a different story about what is going on, and what should be done (de Boer*, et al.*, 2010:464; Dewulf*, et al.*, 2004; Dewulf*, et al.*, 2007; Spence & Pidgeon, 2010). "Like a window, we see the world through frames that determine our perspective while limiting our view to only a part of a complex world around us" (Creed*, et al.*, 2002:36). It is often conflicts or differences between policy frames that are the source of 'policy controversies' (Schön and Rein 1994).

The strength of policy frames lies in their institutionalisation, the degree to which they inform a sector's 'informal rules in use'. These 'rules in use' might be understood as expressions of 'the way we (have to) do things around here'. Consequently, a sector's institutional landscape is as equally important as the construction of the ideas (frames) (Schmidt, 2009:197-8) that inform policies and practice. Over time, as frames are repeated in discussions, practice and research, they become unreflectively taken-for-granted, scarcely noted by the actors who employ them (Fischer, 2003:74). When institutionalised, frames define the terms of discourse within the bureaucracy of a policy sector, constraining and enabling the sphere of discussion regarding a sector's purpose, its policies and practices (Hall, 1993:292). By influencing these terms of discussion and practice, frames and institutions can constrain or enable reflexive learning, and certainly the introduction of new ideas that might shift, change or complement existing informal institutions, as well as their formal counterparts (policies and procedures).

Exploring policy frames and informal institutions

This paper discusses an exploration of policy frames and informal institutions within the public administration of Victoria's fire management sector, and the influence they have upon the sector's adaptive capacity. By taking its perspective from the sector's bureaucrats in state and local government, the study provided an insight into the public administration space in which the concept of adaptation will have to interact with the practical realities of policymaking in the complex sector of fire management. Through interviews and surveys, the study sought descriptions from a range of the sector's bureaucrats of the fundamental purpose of the sector, alongside barriers to attaining that purpose and actions to attain it or address those barriers.

The frame analysis identified two dominant master-frames: emergency management and sustainability. The majority of bureaucrats drew upon the sustainability frame. While recognising it as somewhat idealised, they described the sector's purpose in terms of trying to achieve a balance between safety and ecological conservation. This narrative reflects the globally popular storyline of humans living in harmony with nature. In this frame, a key barrier to attaining this 'balance' was described as a societal lack of environmental or landscape awareness. Consequently, a key action was to have community development aimed at a broader landscape-sensibility and thereby appreciation of fire risk and fire's role in landscape ecology. In contrast, the second identified master-frame was risk and emergency management. This narrative drew on another globally popular storyline, that of humans controlling nature. In this master-frame, a major barrier to attaining the risk management goal was described as a lack of community awareness of bushfire risk. Consequently, in this frame, the role of community development is raising bushfire risk awareness.

The presence of these two master-frames was unsurprising given the sector's two main objectives. In an interesting contrast, while most participating bureaucrats framed fire management as a sustainability challenge and climate change as exacerbating existing issues, risk management was framed as the approach for adapting to climate change. The question was, why is fire management a complex issue of sustainability, yet adapting to climate change is an issue of risk management? It was here that the institutional analysis provided much insight into the practical realities of policymaking in this sector.

As outlined earlier, informal institutions are 'the rules in use', the 'way things (have to) happen around here'. The institutional analysis of this study therefore sought to appreciate the prescriptions concerning what actions (or outcomes) are required, prohibited, or permitted, individuals perceive they have when making decisions. These 'rules-in-use' are those to which participants refer if asked to explain and justify their actions (Ostrom 2005:19). In this case, in relation to the conduct of policy administration generally, as well as more specifically to obtaining and sharing knowledge, and to questioning of the existing policy paradigm and its various components. The institutional analysis suggested that the participating bureaucrats share a sense that the fire management sector is obliged to be demonstrably reactive and to make infallible decisions. Reactive decision-making without underlying reflexive practice will rely on (and potentially entrench) existing frames and approaches. Perceived as constraints on decision-making, these institutions appeared drawn from a perception of a broader societal rationality of control and a rational model of public administration. They also appear to explain the presence of a number of other informal institutions.

These other institutions included a tendency toward 'scientism': that idea or argument that science, as the ultimate, neutral arbiter, can provide 'the solution'. The challenge to that institution is that a number of the issues facing fire management are value-based, and the issue of science or evidence-based policy, raises the obvious question of which and whose science? They are therefore political, not scientific questions. Viewed from the idea that science will provide the answer, it is apparent as to why fire-fighting and fuel management knowledge was perceived to have a greater level of legitimacy than other knowledge within the sector. Akin to the sector's 'conventional wisdom', these essential bodies of knowledge sit comfortably with a quantitative approach to science and risk management, where risk is assumed to be readily quantifiable and thereby, readily treatable. Such a focus however, is likely to ignore underlying drivers of vulnerabilities[1] to altered fire regimes and climate change impacts. That said, it is not the subject matter per se that has implications for reflexive learning, rather it is that tight demarcation of what is considered legitimate and common knowledge, irrespective of the matter, that can exclude other perspectives.

1 'Vulnerabilities' is used as a means of conveying the fact that we are all vulnerable to different hazards, at different times, for different reasons. As Barnett et. al (2008) argue, vulnerability is context specific, not a generic condition.

Maintaining such a limited frame is an anathema to the concept of reflexive learning and adaptation.

Finally, there was an institution surrounding competition for reputational capital. This institution draws on the same perception that there is ‘a’ solution to the fire management ‘problem’, and consequently, there is an implicit competition between the agencies to have ‘the solution’ – in this case study, either fuel reduction burning or community engagement. Again, this is more liable to entrench positions and arguments for a particular policy, than it is to expand the dialogue and openly question fundamental directions, purpose, and policy options.

When viewed collectively, the identified institutions (‘rules’) suggest a high degree of institutionalisation of the risk and emergency management frame, as an expression of the rational model of public administration and a societal rationality of control over nature. The institutionalisation of this frame emphasises physical, technical or engineered responses because they are visible and readily quantified, and has several implications for the sector’s adaptive capacity. Maintaining an institutionalised need for demonstrable reactivity will reinforce a ‘rationality of control’, even though participating bureaucrats identified it as constraining their ability to explore additional frames, policies and practices. In the face of projected increases in extreme weather events, quantifiable approaches will predominate and dictate the kinds of ‘science’ or evidence studied and used to inform policies.

The appeal of the institutionalised risk and emergency management frame likely lies in its implied depiction of hazards as amenable to conventional procedures of calculation, management and control within the capacities of established institutions (Pidgeon & Butler, 2009:679). It appears reliable in the face of a multitude of changes and degrees of uncertainty. Implications for the sector’s adaptive capacity lie in the inherent tendency of these sorts of institutionalised frameworks to neglect the systemic nature of contemporary hazards (*ibid*) that are embedded in dynamic, complex social-ecological-political systems. These kinds of institutions, which draw upon reductionist, positivist perspectives, often exclude many social, ecological and political considerations. This is often because these factors or consequences lie outside prevailing scientific risk-knowledge, and are therefore conceived as indescribable, unamenable to use of probability calculations or cost-benefit analyses so often used in risk management, and consequently are simply not given any standing (Cannon 2000; Wynne, 2002:469; Jasanoff, 1993).

Discussion

Overall, the findings suggested that it may be challenging to introduce frames or ideas that counter or do not ‘fit’ the sector’s current institutional landscape, which currently places emphasis on readily quantifiable and visible actions. Arguably, the institution of quantifiable reactivity is ubiquitous in public administration, and equally likely to constrain reflexive learning, particularly where knowledge from alternate but equally relevant, but less quantifiable perspectives are considered less legitimate. If these sorts of informal institutions shape the sector’s decision paths, ignoring the systemic nature of the issues faced, fire management’s capacity for reflexive learning may be limited. However, institutions are only path-shaping they are not path-determining, because institutions are created by people and people can de-construct and change them. There are at least two ways in which the participating bureaucrats framed fire management, which together present a basis for exploring shared and uncommon knowledge. Exploring uncommon knowledge and perspectives would reveal additional perspectives, including ideas for challenging and expanding the sector's current institutional landscape. By looking through different frames, the sector may find a broader range of policy options and build upon the somewhat implicit adaptive capacity that exists within the more uncommon knowledge of its practitioners, researchers, and communities.

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Visions of sharing responsibility for disaster resilience: sharing control

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Abstract

Strong normative statements have been made in key policy documents and public inquiries about the need to focus on a principle of 'Shared Responsibility' in Australian emergency management. However, these statements give very little guidance on what sharing responsibility might look like on the ground, leaving stakeholders wondering what this idea mean for the way they interact and what they are expected to achieve in this sector.

This paper analyses what the idea of 'sharing responsibility' means in the context of disaster resilience from the perspectives of stakeholders that participated in a workshop held in March 2012. The workshop brought together a wide range of stakeholders from across government, communities and NGOs, and research to discuss the idea and implications of 'sharing responsibility for disaster resilience'.

Of six facets of responsibility highlighted in the literature that theorises responsibility in the context of risk, one stood out clearly in the stakeholders presentations at the workshop: agency/control. In particular, the need for public sector agencies to share control as well as responsibility with communities was emphasised.

Introduction

A reinvigorated and reinterpreted principle of 'Shared Responsibility' is one of the many legacies that the Victorian 2009 Bushfires Royal Commission left to the field of emergency management (McLennan and Handmer 2012). Alongside the priority to protect human life, this principle underpinned the 67 recommendations the Royal Commission made for reducing the risks of a tragedy like the Black Saturday bushfires occurring again (Teague *et al.* 2010: preface, p. v).

According to the Royal Commission, this principle implies "increased responsibility for all concerned" (Teague et al. 2010: vol. 2, p. 352), with the focus of responsibility being on "community safety during bushfires", and the targeted parties being "the State, municipal councils, individuals, household members and the broader community" (p. 352). The Council of Australian Government's (COAG) National Strategy for Disaster Resilience gave the principle even greater policy traction by firmly placing it as a central pillar of a "whole-of-nation, resilience-based approach to disaster management" (COAG 2011: ii). It also expanded the scope of the principle to target the "whole of society" and to focus on responsibility for the broader area of "increasing disaster resilience" (p. 3).

While these documents make strong normative statements about the need for a renewed focus on Shared Responsibility in emergency management, they give very little guidance on what sharing responsibility might look like on the ground or about how stakeholders might do it in practice. This has left emergency management practitioners and other stakeholders wondering what this idea means for the way they interact with each other, and for what this interaction is expected to achieve.

It is in this context that the Centre for Risk and Community Safety at RMIT University held a one-day workshop in March 2012 that brought a wide range of emergency management stakeholders together to consider two central questions:

1. What does the idea of 'shared responsibility' mean, and what are its implications?
2. Is it a useful policy concept, and if yes what needs to be done to implement it, and what could undermine it?

The 'visions of sharing responsibility for disaster resilience' workshop (hereafter 'the workshop') was conducted on behalf of the Bushfire CRC and the Emergency Management network of the National Climate Change Adaptation Research Facility (NCCARF). It brought together over 80 stakeholders from across the public sector, research and civil society. Twenty-four people participated as speakers, responding in whatever way they chose to the above two questions. Importantly, the speakers represented a wide range of perspectives, cutting across public agencies, research and civil society, with the latter including community members and non-government organisations. A full schedule of speakers is available in the written account of the workshop, available for download via the Bushfire CRC website (McLennan *et al.* 2012).

This paper reports on an analysis of the meanings that speakers at the workshop associated with the idea of sharing responsibility. The written account of the workshop includes a lengthy summary of the content of presentations made by speakers and the key themes that emerged in discussions held during the day. This provides a valuable insight into the meanings given to the idea of shared responsibility in the context of Australian emergency management from a broad range of stakeholder perspectives. Despite the diversity of perspectives conveyed at the workshop, it was clear that for many of the speakers sharing responsibility, particularly between government and civil society (also agencies and communities), is also very much about agencies and communities developing closer relationships and sharing control of key aspects of the emergency management process.

Facets of responsibility

Our analysis was guided by a simple conceptual framework that encompasses six key facets of responsibility. Notably, no single understanding of the concept of responsibility has developed in social, political, economic or psychological theory. Indeed, a number of authors lament the lack of conceptual clarity that accompanies analyses of responsibility across fields that include social theory, philosophy and law (Auhagen and Bierhoff 2001; Cane 2002), governance (Pellizzoni 2004), and sociology (Strydom 1999). Rather, definitions of responsibility vary according to different philosophical approaches (Fleurbaey 1995), perspectives and goals (Auhagen and Bierhoff 2001). Because of this, responsibility has been described by theorists as “a difficult notion to grasp” (Fleurbaey 1995: 684) and “an interestingly ambiguous or multi-layered term” (Giddens 1999: 8). This ambiguity is evident both in academic debate as well as in everyday interaction (Auhagen and Bierhoff 2001: 180-181).

The concept of responsibility is therefore best thought of as a multi-faceted, catch-all term that refers to a collection of interrelated ideas and meanings. When the concept is applied in a particular context, one or more of these meanings may be emphasized above others. Further, different meanings may be emphasized by different stakeholders within the same context. This raises the question: what does sharing responsibility mean in the context of disaster resilience from the perspectives of stakeholders in the disaster management community?

Within the literature that theorises responsibility in the context of risk, six themes stand out as core facets of this complex concept (McLennan and Handmer 2011).They are; causality, obligation, accountability, trustworthiness, constraint and agency/control. Each of these facets is emphasized somewhere in the literature as being particularly important for understanding the way responsibility for risk management is conceived, allocated, shared or shirked.

The notion of responsibility is often associated with assumptions about causality (Giddens, 1999; Pellizzoni, 2004; Shaver, 1985; Weiner, 2006). This requires that the particular decision or action (or absence of decision or action, e.g. Arceneaux and Stein 2006) that caused a particular outcome is identifiable (Bickerstaff, et al., 2008). However, causal responsibility quickly becomes muddied when the outcome is attributable to multiple sources (Shaver & Schutte, 2001), as is generally the case in complex disaster situations.

Obligation refers to expectations and rules in society about the duties and roles of different parties with respect to particular activities, decisions or outcomes. Importantly, a single party may have different types of obligations that may or may not align. They include moral, legal, social and professional obligations (Bierhoff and Auhagen 2001; Shaver and Schutte 2001; Cane 2002; Bickerstaff *et al.* 2008; Pulcini 2010). These obligations may also be more or less formal in nature, varying from formal obligations codified in law to informal, unwritten but widely held social norms.

In a related sense, responsibility may also mean accountability. To be held ‘responsible’ for a particular outcome is to be held accountable, answerable, liable or to blame for undesired consequences. Importantly, accountabilities and obligations are interwoven. Parties are held accountable when they fail to fulfil the obligations that others perceive them to have – whether moral, legal, social or professional (Pellizzoni 2004). Accountability thus “emphasises the presence of moral or legal rules specifying rights and obligations” (Pellizzoni 2004, p. 547). As Witt (2001) points out: “Implying liability, accountability refers to individuals being subject to sanction when acting incongruently with formal guidelines, rules, or laws” (p. 139).

In a different sense, responsibility also refers to trustworthiness and the qualities of being reliable or dependable (Giddens 1999). In this sense, it is a positive quality of a person or organisation rather than a judgement about expectations or outcomes of an action (Bierhoff and Auhagen 2001). Relatedly, responsibility can also be associated with constraint in behaviour or action (Bierhoff and Auhagen 2001, p. 1). For example, we might describe a person as responsible (in the sense of trustworthy or reliable) when they refrain from doing something that, though it may benefit them personally, would disadvantage someone else. This aspect of responsibility highlights a tension between personal freedom and rights on one hand, and moral, legal and social obligations towards other members of society on the other. For this reason, responsibility is often described as a burden (Bierhoff and Auhagen 2001; Birnbacher 2001; Bickerstaff and Walker 2002, p. 2177).

Finally, the notion of responsibility is also associated with agency/control. Parties must usually be judged as having agency or freedom of choice in order to be held responsible (accountable) for the outcomes of their actions and decisions (Luhmann 1993, p. 101; Bierhoff and Auhagen 2001; Weiner 2006, p. 32). Without choice, parties cannot exercise control over outcomes and thus cannot be responsible for them. Yet even when a party has the freedom of choice to make a decision, they still may not have the capacity to put that decision into action. Hence, in addition to control over decision-making (freedom of choice), judgements of responsibility also commonly requires that a party has the capacity to carry out these decisions, also referred to as “control in acting” (Bickerstaff and Walker 2002, p. 2177) or being “response-able” (French 1992). This is highlighted by the fact that parties will argue against being held responsible for undesired outcomes on the grounds that they did not have sufficient resources, power, authority, knowledge and so forth to put an alternative decision into action (Montada, 2001).

Importantly, the agency/control facet of responsibility is particularly prevalent in theorising about risk. A number of risk theorists have shown that a close connection exists between responsibility and risk through the central importance of agency to both concepts. As social and political theorist Anthon Giddens (1999) points out, "risks only exist when there are decisions to be taken… The idea of responsibility also presumes decisions. What brings into play the notion of responsibility is that someone takes a decision having discernible consequences" (p. 8).

Sociologist Niklas Luhmann (1993: 101-102) also highlights this close connection by making a clear distinction between the ideas of risk and danger (for linguistic analyses of the difference in meaning of these terms, see Ingles 1991; Boholm 2011). Similarly to Gidden's statement above, the basis of Luhmann's distinction is whether or not consequences arise as the result of a decision. In the case of risk, negative consequences are attributed to decisions that parties have made, whereas dangers are attributed to external, uncontrollable factors. Consequently, risks are something that people have a choice about and therefore also a responsibility for. However, danger is imposed by outside forces and is uncontrollable. It therefore does not create the same responsibility as risks. In short, risks give rise to responsibilities.

Methodology

The written account of the 'visions of sharing responsibility' workshop provides a valuable insight into what 'sharing responsibility for disaster resilience' means from a wide range of stakeholder perspectives. Each of the 24 speakers who participated in the workshop was approached directly and invited to participate by the workshop organisers. They were selected because of their experience – professionally, voluntarily or personally – in aspects of disaster policy or disaster preparedness activities in which both government and community actors are widely held by law, policy or social norms to have (or potentially have) responsibilities. For example, speakers from public agencies included two people with senior roles in community safety in emergency service agencies, and two members of a Victorian Government taskforce that oversees the implementation of the National Strategy for Disaster Resilience in Victoria. Speakers from non-government organisations included people with recent experience in coordinating and supporting spontaneous volunteers during post-disaster recovery. Community speakers included residents of a small community in which ten lives and a majority of homes were lost in the 'Black Saturday' bushfires in Victoria in 2009 and a member of a bushfire-prone community with a background in community-based disaster preparedness activities.

The speakers' contributions to the workshop were captured by five note-takers and summarised in the written account that is now publicly available (McLennan *et al.* 2012). Importantly, a draft of this account was circulated to speakers to review and confirm. A small number of speakers requested minor changes to the summary to clarify key points or to better convey the meaning and emphasis they intended when they spoke at the workshop.

For the analysis reported here, this written account was thematically analysed to identify which of the six facets of responsibility outlined above – causality, obligation, accountability, trustworthiness, constraint, and agency/control—were most strongly conveyed by the speakers. These were identified using a simple method of manually coding the text of the written account through identification of these six key words and their synonyms.

Perspectives on sharing responsibility

Table 1 presents an overview of the results of this thematic coding according to three key stakeholder groups: government, community/NGO, and research. Facets/themes indicated as “weak” were referred to by a single speaker or had very few mentions overall amongst speakers in a particular stakeholder group. Those indicated as “medium” were referred to by a number of speakers but without a strong emphasis. The indication of “strong” was reserved for facets/themes that had a particularly high number of mentions by a majority of speakers in a given stakeholder group. As a full discussion of all the facets of responsibility included in Table 1 is beyond this scope of this paper, the remaining section focuses on the one facet of responsibility that was conveyed most strongly by speakers, particularly amongst the government and community/NGO stakeholder groups: agency/control.

Facets of Responsibility	Government (n=8)	Community & NGO (n=8)	Research (n=8)
Causality	Nil	Nil	Nil
Obligation/ expectation	Medium	Weak	Medium
Accountability	Weak	Weak	Medium
Agency/ control	Strong	Strong	Medium
Constraint	Nil	Weak	Weak
Trustworthiness	Nil	Medium	Weak

Table 1: Facets of responsibility conveyed most strongly by speakers according to key stakeholder groups

Table 2 (page 8) and Table 3 (page 9) outline some of the key points made by selected speakers who most directly engaged with the issue of control and responsibility. Table 2 summarises views on the need to share control between government and communities. Table 3 outlines some of the opportunities and challenges that speakers identified for sharing control in practice.

The speaker’s comments in Table 2 show that a theme of government allowing greater choice and control for emergency management to rest within communities underpinned the discussion about sharing responsibility. So, for example, Anne and Kate who spoke from the perspective of community/NGO stakeholders, talked about the need for government to let go of control in order to engage communities more actively in risk management. They claimed this would involve a greater degree of risk acceptance and trust in communities’ abilities to be responsible for managing risk.

From the perspectives of government stakeholders, the view was somewhat different, but nonetheless still indicated that if communities are to share greater responsibility for community bushfire safety, governments will need to relinquish a degree of control. As Chris pointed out, sharing responsibility with communities does not mean that government avoids responsibility but rather that it is honest about what it can and cannot do. In other words, government needs to communicate the limits to its capacity (e.g. its “control in acting”) to deliver risk management outcomes. He also asked how government can encourage shared responsibility without taking over, indicating that government should not control what communities do. Mark directly argued that sharing responsibility is not about government telling people what to do but supporting what people already do. Along a similar line, Terry indicated that the CFA is moving in the direction of supporting communities rather than doing things to them from the top down. Jeanette summed up the idea underlying these views by describing government’s role as an enabler as much as a provider.

The views given in Table 3 both highlight challenges associated with communities having control over risk management outcomes, as well as suggesting that some of the challenges are not as big as may be feared. A key challenge recognised by a number of government stakeholders was the tension between government making space for communities to have more control while also needing to be accountable for government decision-making and spending. As Steve pointed out, distributing responsibility can dilute responsibility. However, this tension was seen as one to be managed or confronted rather than one which would preclude sharing control with communities. For example, Vanessa allayed fears about liability associated with Council’s coordination of the involvement of spontaneous volunteers in emergency response, pointing out that in the case of the massive Brisbane Mud Army, liability costs to the Council were small. Limits in the risk management capacities of government and communities were also acknowledged by Kate and Terry respectively. In particular, Terry asked stakeholders to think about the limits to community members’ capacity to make decisions under stress and meet the responsibilities expected of them by government.

Conclusions

Of the six facets of responsibility highlighted in the literature that theorises responsibility in the context of risk, agency/control was clearly most prevalent in the workshop. In particular, the meaning most closely associated with the idea of sharing responsibility for disaster resilience in this workshop was *sharing control*. Collectively, government and community/NGO speakers at the workshop emphasised that in order for parties in these two stakeholder groups to share responsibility for disaster resilience, they must also share control over risk management decisions, actions and processes. This emphasis reflects, at a more practical level, the intricate conceptual relationship between risk, responsibility and agency that is elaborated by social and political theorists like Luhmann (1993) and Giddens (1999). In the contest of risk, taking responsibility is also about having control, both control in decision-making (freedom of choice) and ‘control in acting” (capacity) (Bickerstaff and Walker 2002, p. 2177).

The brief analysis presented here is based on a small number of stakeholder presentations at a single workshop and should therefore be taken as indicative only of stakeholder perspectives of the underlying meaning of sharing responsibility for disaster resilience in Australia. However, despite its limited scope, it draws attention to two potentially significant implications of putting a principle of Shared Responsibility into practice that may not be immediately evident to emergency management practitioners and other stakeholders.

Therese are: 1) that public sector agencies will need to allow a relatively greater degree of control of risk management processes and outcomes to rest with communities; and 2) that agencies need to clearly and directly communicate the limits of their capacities to control risk management processes and thus achieve risk management outcomes.

The active participation of community and NGO stakeholders in the workshop was important for drawing out the relationship between responsibility and agency/control more strongly than would have occurred in any of the more established stakeholder engagement forums in this sector that do not generally include community groups and NGOs. Thus an associated, broader issue highlighted by this paper is the need for a forum for emergency management stakeholders from across public sector agencies, private industry, research and civil society to exchange learning and perspectives on big questions collectively facing the sector as a whole.

Speaker	Description	Context
	Community & NGO perspectives	
Anne Leadbeater - Kinglake community, Murrindindi Shire Council	▪ Shared responsibility needs to be accompanied by a freeing up of control. ▪ It starts with risk acceptance. ▪ It is also about agencies and government trusting communities in order to give up control. Communities are engaged where they think they have influence and can affect change.	Bushfire preparedness and recovery
Kate Lawrence - Mount Macedon community, National Rural Women's Coalition	▪ Preparedness and shared responsibility is about shared power, mutual respect and partnership. ▪ Government has an overarching presence /control in our lives. Communities and citizens have become dependent and disconnected from own determinism/responsibility. Are overly regulated and so we expect that someone else is always in charge. ▪ When disaster hits "the baton of responsibility is suddenly thrust at us". We are told to be engaged, responsible, self-reliant. Then the baton cannot be handed back neatly – we want to keep holding it. ▪ Few communities are well-prepared for disaster. Government needs to let go and enable communities to think for themselves.	Disaster preparedness
	Government perspectives	
Chris Collett - Commonwealth Attorney-General's Department	▪ Shared responsibility is about increasing honesty about disasters and disaster risk reduction. It is not about governments avoiding responsibility. It is about governments being honest about what they can and cannot do. ▪ There is a tension in government about how to contribute to shared responsibility without taking over. How do we encourage shared responsibility from the position of big government?	Disaster resilience policy
Mark Duckworth - Victorian Department of Premier and Cabinet	▪ Shared responsibility is taking off as a central idea in government. It is not about government telling people what to do; it's about harnessing and supporting what's already happening, and people learning from each other.	Disaster resilience policy
Terry Hayes - CFA	▪ The CFA is completely changing the way it does things in order to support communities rather than to do things to them from the top down. It is difficult but we are committed to this change.	Community bushfire safety
Jeanette Pope - Victorian Department of Planning and Community Development	▪ Community resilience is related to networks within communities and networks that extend outside the community. Networks are built through participation. Government has a role in encouraging participation. ▪ The role of government is more as an enabler than as a provider.	Community development

Table 1: Selected views on sharing control between government and civil society

Speaker	Description	Context
	Community & NGO perspectives	
Vanessa Fabre - Brisbane City Council	▪ Dilemma - response and recovery geared around 'Command and Control' so when and how can community participate? ▪ People are often concerned about liability with managing volunteers. However, Brisbane City Council received only 10 insurance claims out of approximately 24,000 volunteers. The cost to Council was not high.	Spontaneous volunteers in flood recovery
Kate Lawrence - Mount Macedon community, National Rural Women's Coalition	▪ Communities are locked out of developing their own projects. There is no avenue for activism and agitation. ▪ Is a fear that communities will get it wrong: that misinformation will spread. But this is only worse when there is a gap between citizen and government. ▪ It needs to be said by Government "We don't know how to protect you all the time". Requires a leap of faith. It happens in other area, e.g. Landcare groups etc. but not in areas with a focus on disaster.	Disaster preparedness
	Government perspectives	
Mark Duckworth - Victorian Department of Premier and Cabinet	▪ Behavioural change is less about convincing communities and more about changing how governments engage with communities on these issues. ▪ Another big issue that governments need to face in doing this is accountability. How can governments be both enablers of what other groups do as well as being accountable for spending government funds? We don't have the answer to this, but it is an issue that is being talked about in government.	Disaster resilience policy
Terry Hayes - CFA	▪ There is no legislation that says people have to share responsibility. When did we agree with the community to share responsibility? When did we test their capacity to meet their responsibilities? Decision-making under stress is often poor: we are placing a lot on people in emergency situations.	Community bushfire safety
Jeanette Pope - Victorian Department of Planning and Community Development	▪ Community networks draw people back after a disaster, which helps with rebuilding. Government should reduce the red tape but the need for government accountability is a challenging issue.	Community development
Steve Opper - NSW SES	▪ Is it possible that the concept could be used to excuse government failure? Distributing responsibility can dilute accountability. ▪ Shift from a top-down to bottom-up (distributed funding) approach needs a leap of faith.	Flood preparedness and response

Table 2: Selected views on opportunities and challenges for sharing control

Acknowledgements

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Economic analysis of bushfire management programs: a Western Australian perspective

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Abstract

Bushfires can cause considerable damage to ecosystems, life and property. Protecting human and environmental assets is becoming more difficult as the wildland–urban interface expands in Australia. Fire managers can plan for and manage bushfire events to a greater extent than other large natural disturbances such as cyclones and earthquakes. However, fire strategies that have sought to respond to the increasing bushfire threat with greater suppression capacity do not appear to solve the problem of catastrophic bushfires. Although suppression capacity and the use of technology in bushfire management have greatly increased, the frequency of disastrous fires appears to follow an increasing trend.

Improved understanding and comprehensive appraisals of bushfire costs and benefits are needed in order to devise fire mitigation and management programs that optimally allocate resources and express informed, evidence-based judgements about trade-offs between available options. The aim of this project is to provide a comprehensive economic evaluation of alternative fire management programs in Western Australia in order to determine the optimal allocation of scarce resources for bushfire management.

In this paper we present our initial investigations into the application of the cost plus net value change (C+NVC) model to bushfire management programs in Western Australia.

Introduction

In Australia, bushfires are the deadliest natural disturbance. Although tropical cyclones, severe storms and floods have been the most costly natural disasters in economic terms (between 1967 and 1999), bushfires have been the most dangerous type of disaster in terms of risk to human life (Bureau of Transport Economics, 2001; Teague *et al.*, 2010). Between 1967 and 1999, bushfires accounted for 7 per cent of total economic losses due to natural disasters in Australia, which is a relatively small proportion of the total cost of disasters. However, during the same period bushfires were the cause of nearly 40 per cent of deaths and around 57 per cent of injuries (Bureau of Transport Economics, 2001). The difference between bushfires and disasters such as cyclones, floods and earthquakes, is that fire managers can plan for and manage bushfire events to a greater extent than other large natural disturbances (Venn and Calkin, 2011).

Despite greater suppression capacity, improved predictive systems, a remarkable increase in the use of technology in bushfire management and stronger cooperation between fire agencies, the frequency of large, disastrous fires appears to have increased in Australia and many other parts of the world in the last two decades (Calkin *et al.*, 2005; Morgan, 2009; Williams *et al.*, 2011). Catastrophic bushfires occurred in the summers of 2003, 2005, 2006-2007 in Australia, and in 2009 the bushfires of Black Saturday resulted in the highest loss of life and property from a bushfire in Australian history (Teague *et al.*, 2010). In the US, a similar pattern can be observed with several states suffering their worst bushfire in history in the past two decades (Williams *et al.*, 2011). In both locations annual suppression expenditures have increased remarkably over the past several years and the risk is that they might continue to increase without necessarily solving (or perhaps worsening) the problem of catastrophic wildfires (Morgan *et al.*, 2007). Fire protection managers and policy–makers have sometimes attempted to exclude fire from the landscape and avoid the disturbance in an effort to protect life and property. However, this often resulted in the accumulation of continuous, homogeneous fuel loads that increased the risk of high fire intensities (Williams *et al.*, 2011).

The main objective of fire management is to maximise social welfare by optimally allocating the resources used before, during and after fire events to achieve the most efficient outcome in terms of costs and damages avoided (Ganewatta and Handmer, 2006). The limited human and financial resources available may be utilized in a variety of ways in fire management activities and their alternative uses have different implications for economic, environmental and social assets. The consequences of different uses of fire resources may be profound, thus society needs comprehensive assessments of bushfire costs and benefits and sound analyses of trade-offs between available options. Economics can provide such analyses and help fire mangers and policy–makers devise fire mitigation programs that optimally allocate resources (Handmer and Proudley, 2008).

However, the use of economics in the bushfire literature is still relatively limited. Empirical economic analyses of bushfire management are scarce (Mercer *et al.*, 2007). There is limited understanding of bushfire impacts on human communities and ecosystems and little empirical evidence about the extent of total economic damages (or benefits) due to bushfires (Abt *et al.*, 2008). But concerns about the growing number of mega–fires and the increasing trend of suppression expenditures have prompted the bushfire economics field to expand. Economic analysis is now being applied to fire management in countries where none was previously applied (e.g. Pedernera *et al.*, 2008; Rodriguez y Silva and Gonzalez-Caban, 2010).

In this paper, we apply the cost plus net value change (C+NVC) model to a synthetic landscape, representative of the northern jarrah forest of the south west of Western Australia (WA). The purpose of the study is to determine the most economically efficient pre-suppression strategy for the synthetic landscape and evaluate which parameters significantly affect the results. We focus on prescribed burning as the main pre-suppression strategy. The primary objective of this model is to provide preliminary results which may inform the development of a more complete model based on actual areas of WA.

Methods

In economic terms, fire impacts and fire management activities may be encapsulated in a three–stages cycle: (i) the pre–fire or pre–suppression stage, which is defined as all expenditures associated with activities carried out before the fire event occurs (or before the start of the fire season) such as prevention, education, detection, fuels management (e.g., prescribed burning, mechanical fuels reduction) and pre–positioning of fire–fighting resources; (ii) the during–fire or suppression stage, which is defined as all expenditures associated with activities carried out during a fire event, i.e. after the fire–fighting resources have been deployed; and (iii) the post–fire stage, which encompasses the resulting net damages and expenditures for rehabilitation projects.[2] Although these stages are presented in a linear sequence, they should be envisaged as a circle, where the post–fire stage corresponds to the pre–fire stage of the next period, and so on (Gebert *et al.*, 2008).

To date, most fire economics applications have focused on a single aspect or stage of the fire problem (Gebert *et al.*, 2008). Economic analysis of trade–offs between pre–suppression activities, suppression efforts and bushfire impacts remain extremely rare, despite considerable work on the economic theory of bushfire management (examples of theoretical studies include, among others, Donovan and Rideout, 2003; Hesseln and Rideout, 1999; Rideout and Omi, 1990; Rideout *et al.*, 2008; Rideout and Ziesler, 2008). Among the few studies that have examined all stages of the fire problem, the majority have used the C+NVC model (or modified versions of it). The C+NVC provides the theoretical foundation for bushfire economics and has become the commonly accepted model for evaluating bushfire management programs (Ganewatta, 2008; Gebert *et al.*, 2008).

The C+NVC is a monetary–based framework that minimises the total sum of pre-suppression costs, suppression costs and net fire damages (Venn and Calkin, 2011), analogous to a benefit–cost analysis. In this model, pre-suppression is the independent variable that determines suppression costs and damages. The underlying assumption in this

[1] Initial attack, which corresponds to the action taken by the first fire–fighters that arrive at the fire incident, is sometimes considered to be part of the pre–suppression effort and in other cases considered to be part of suppression activities (direct fire–fighting expenditures).

formulation is that investment in pre–suppression results in gains in terms of reduced damage and suppression costs (Ganewatta, 2008). In theory, damages decrease with an increase in suppression expenditure, and suppression costs decrease as pre–suppression investment increases (Rodriguez y Silva and Gonzalez-Caban, 2010). The most efficient level of fire protection is the level at which the total cost of fire management plus damages is minimised (Gonzalez-Caban, 2007).

We used the following expression of the C+NVC, from Donovan and Rideout (2003):

$$\text{Min}\ C + NVC = W^P P + W^S S(P) + NVC\big(P, S(P)\big) \qquad \textbf{(1)}$$

with W^P the price of pre–suppression; P the pre–suppression effort; W^S the price of suppression; S the suppression effort, which is dependent on pre–suppression; and NVC the net fire damage (fire damage less fire benefit). Generally, the analysis yields a U-shaped function known as the C+NVC curve. The minimum point of the C+NVC curve corresponds to the most efficient level of pre-suppression investment (Gonzalez-Caban, 2007; Mills and Bratten, 1982; Rodriguez y Silva and Gonzalez-Caban, 2010). In Figure 1 this corresponds to the level of pre–suppression expenditure P^*.

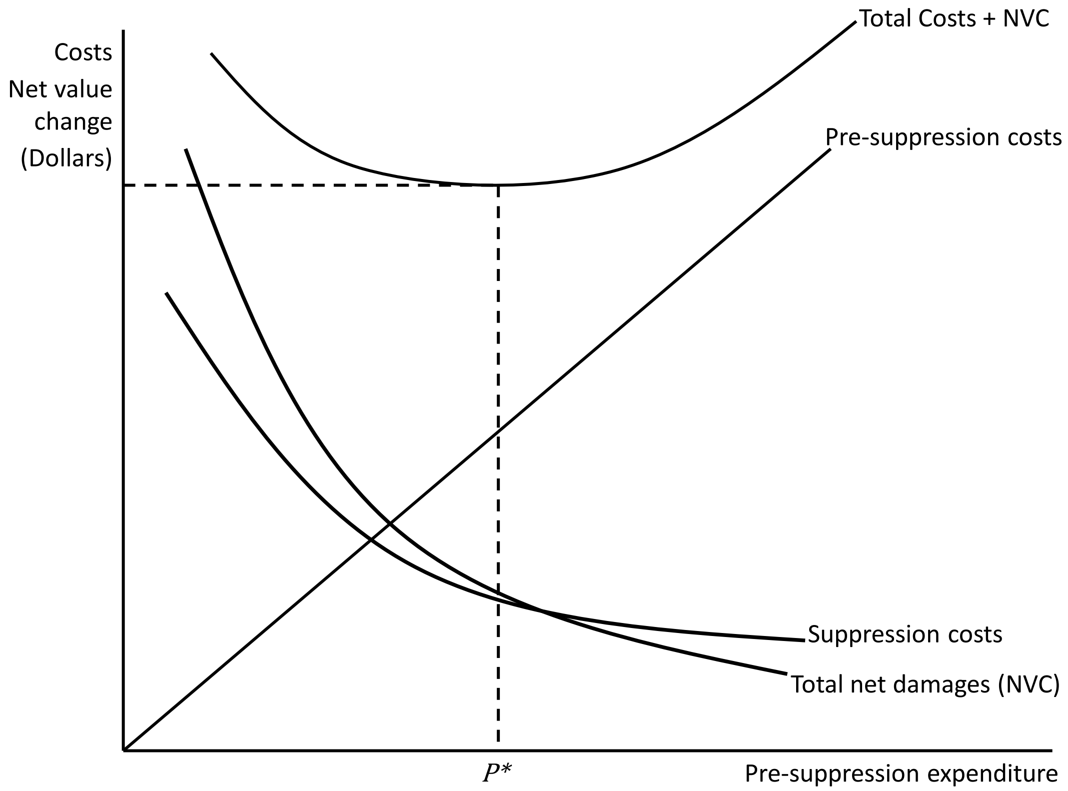

Figure 1.
The cost plus net value change (C+NVC) model

We applied the C+NVC to a square synthetic landscape of 100,000 ha with a flat, homogenous jarrah forest. This landscape is the type of landscape usually found in the northern jarrah forest of the south west of Western Australia (WA). Using the AUSTRALIS Wildfire Simulator[3], we simulated 1,200 bushfires under varying climatic conditions and different prescribed burning (pre-suppression) strategies. We tested three prescribed burning strategies with different patch sizes and a no-strategy case where the fuel age was uniformly set at 15 years across the entire synthetic landscape (see Florec *et al.*, 2012 for a detailed description of the construction of the scenarios tested and the simulator settings for prescribed burning experiments). Fire ignition points were generated across the entire landscape according to a random uniform distribution and each scenario was tested under 30 random ignitions. The outcomes of the simulated fires were multiplied by the probability of occurrence of the event under the specified weather conditions. Table 2 presents a summary of the scenarios tested.

Strategy **(% of total area burned)**	no-strategy, 5, 10, and 20
Patch size **(in ha)**	50, 500 and 4000
Forest Fire Danger Conditions **(FFDI)**	High, Very High, Extreme, and Catastrophic

Table 2. Summary of scenarios

Prescribed burning decreases the intensity with which bushfires burn, and hence it is generally expected to improve the probability of successful suppression (Fernandes and Botelho, 2003). Therefore, in our model we assumed a negative relationship between prescribed burning investment and suppression costs (see Florec *et al.*, 2012 for details on the functional relationships).

One of the major challenges that fire managers and policy–makers face is the growth of areas where highly flammable vegetation and human assets are intermingled in the landscape, i.e. the rapid development of the wildland-urban interface (WUI) (Marzano *et al.*, 2008). In order to incorporate this issue in our analysis, we assumed that a small town of 1,500 ha is located within the synthetic landscape and analysed bushfire impacts on urban structures and public infrastructure and smoke and fire-related (prescribed or bushfire) health costs.

[2] The AUSTRALIS Wildfire Simulator was developed at the School of Computer Science and Software Engineering, The University of Western Australia (see Johnston *et al.*, 2008 for a description of the fire simulator).

Results and Discussion

In our simulated landscape, the most efficient level of prescribed burning is the 5% strategy, where 5% of the area is prescribe-burned per year, corresponding to an annual investment of approximately AU$405,000 for the 100,000 ha (with our assumed costs of prescribed burning equalling AU$80/ha). The minimum of the C+NVC curve, i.e. the sum of prescribed burning costs, suppression costs and damages, amounts to about AU$785,000 (see Figure 2).

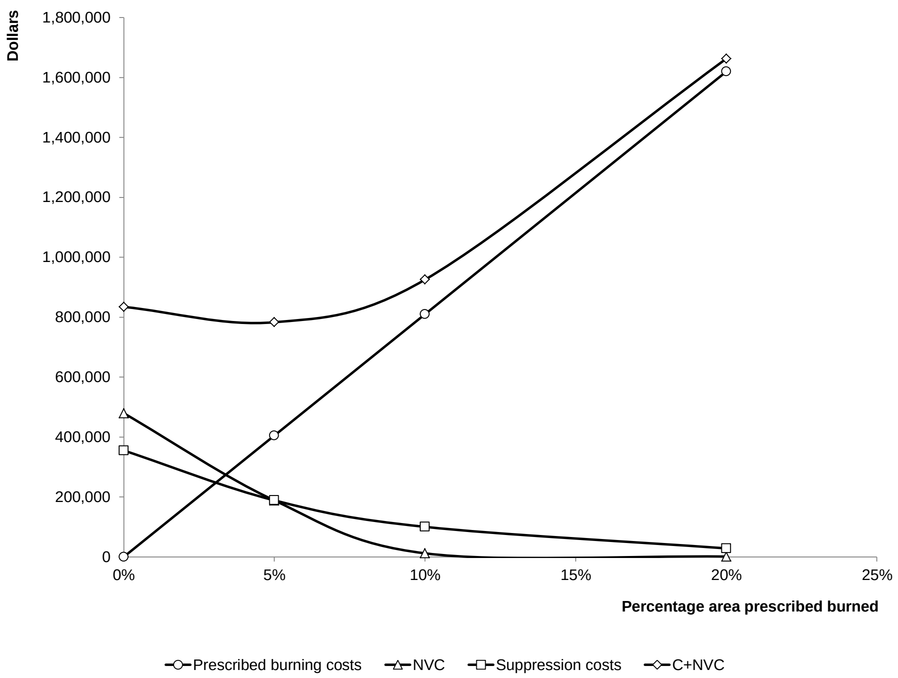

Figure 2.
Results for the cost plus net value change curve

To test the robustness of the results and identify the parameter values that most influence the results, we conducted a sensitivity analysis. We increased and reduced each parameter value by 50% and estimated the change in the minimum of the costs plus net value change curve. We found that prescribed burning costs (in average dollars per hectare), the probabilities of fire occurrence, urban area values (in average dollars per hectare) and suppression costs, are the parameters to which the results are most sensitive. Figure 3 shows the change in the minimum of the costs plus net value change curve in dollars when these parameter values are increased or reduced by 50%. The sensitivity of these parameters captures the key challenges faced by fire managers in developing sustainable fire mitigation programs: climate change, the wildland-urban interface and the effectiveness of suppression.

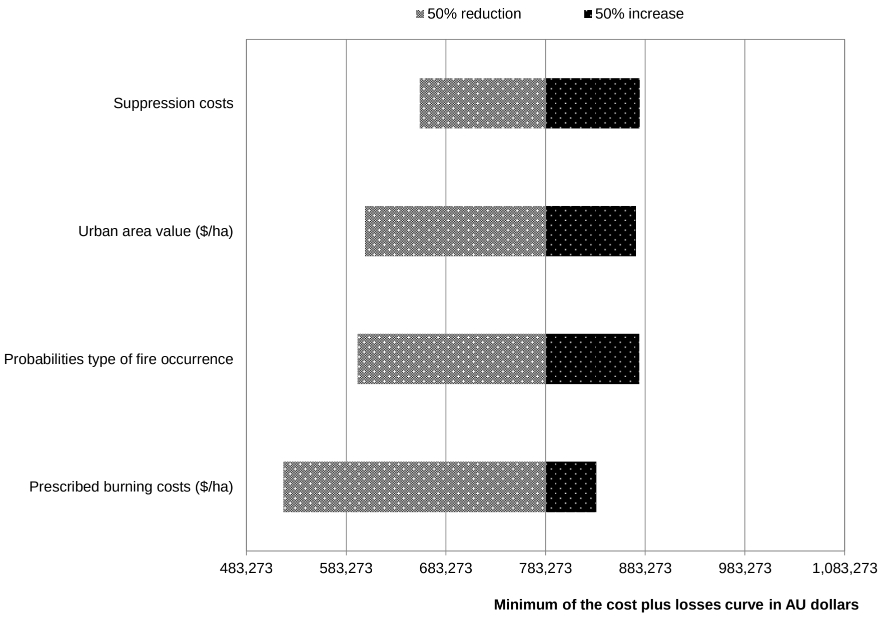

Figure 3.
Change in the minimum of the costs plus net value change curve with an increase and a decrease of 50% in selected parameter values

In our analysis, prescribed burning costs quickly become a large proportion of the C+NVC curve. The rate of change in prescribed burning costs (i.e. the slope of the line representing prescribed burning costs in Figure 2), the rate at which prescribed burning costs increase, is for the most part greater than the rate of change in suppression costs and damages, i.e. the rate at which these curves decline. Hence a change in average dollars per hectare for prescribed burning has generally a greater impact on the results than a change in the value of the other parameters.

The minimum of the C+NVC curve corresponds to a strategy of 0% of prescribe-burned area when the average cost per hectare for prescribed burning is very high. Conversely, the minimum value of the C+NVC curve corresponds to a strategy between 5 and 10% area prescribe-burned per year when the average prescribed burning cost per hectare is reduced by 50% (see Figure 4). In this case, the corresponding value in dollars of the minimum of the C+NVC curve decreases by 34% (see Figure 3). Comparing the three curves of the C+NVC curve in Figure 4, it can be seen that for the curve that represents our initial estimation, there is a wide range of prescribed burning levels near the optimal solution, but this is not the case when the cost of prescribed burning is increased or reduced by 50%.

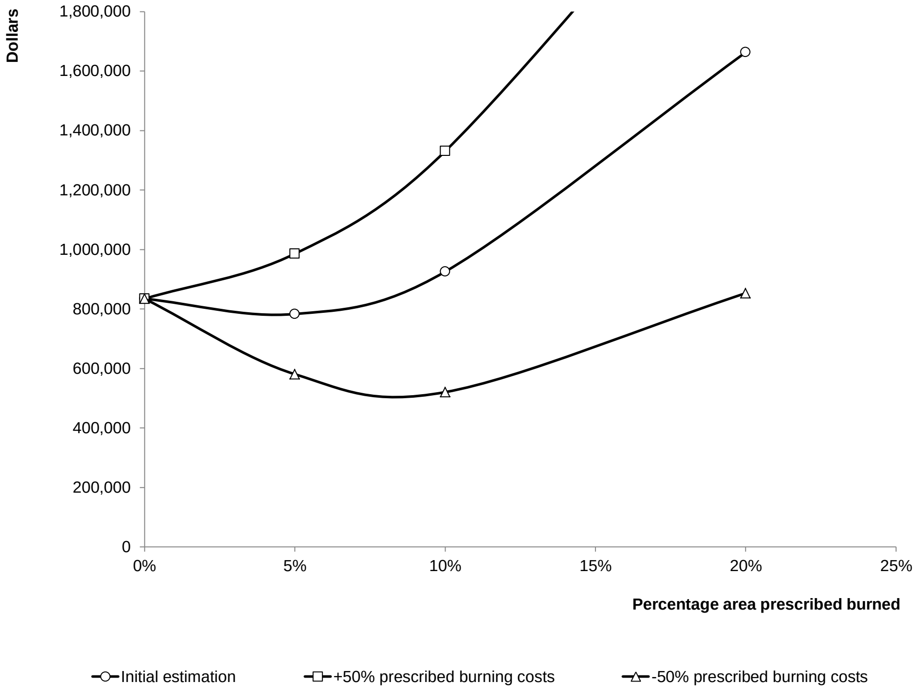

Figure 4.
Change in the cost plus net value change curve with different prescribed burning costs

Changes in the patch size of the prescribed burns had no significant effect on the results of the economic analysis. Other studies using simulation to examine the efficacy of prescribed burning have found similar results, e.g. Finney *et al.* (2007) and King *et al.* (2008).

Conclusion

We applied the C+NVC to a square synthetic landscape of 100,000 ha with a flat, homogenous jarrah forest, representative of the northern jarrah forest of WA's south west. Using the AUSTRALIS Wildfire Simulator we simulated 1,200 bushfires under varying climatic conditions to test three different prescribed burning strategies with different patch sizes and a no-strategy case.

Our results show that the most efficient level of prescribed burning is the 5% strategy, totalling an annual investment of AU$405,000 for the 100,000 ha. Our sensitivity analysis shows that prescribed burning costs, the probabilities of fire occurrence, urban area values and suppression costs, greatly affect the results. With prohibitive prescribed burning costs, the minimum of the C+NVC curve shifts to a strategy of 0% of prescribed burned area. Conversely, when the probabilities of fire occurrence, urban values or suppression costs are very low, the most efficient prescribed burning strategy is the no-strategy case.

The C+NVC model and, more generally, the bushfire economics literature mostly approach the bushfire management problem from an annual budgeting perspective. Fire agencies generally attempt to minimise the sum of fire management costs and damages for one single fire season, repeating the process every year for each fire season. Thus each fire season is treated as an independent problem, without necessarily being linked with previous or subsequent fire seasons. However, is it possible that because of the long term attributes of fuel accumulation processes and fire dynamics this paradigm of annual budgeting is not the most comprehensive approach to bushfire management issues? In addition to short term seasonal changes to bushfire risk, fuel management strategies together with land management practices and unplanned fire patterns may have long term effects on the ecology of a region and on incident probabilities (Hesseln and Rideout, 1999).

In the past two decades, the C+NVC model has been through some reformulation. But despite the limitations that have been identified in the model, the application of the C+NVC model in its current formulation can help fire managers recognise potential benefits and costs of different options for a given year, even if a global minimum is not obtained for the C+NVC curve (Rodriguez y Silva and Gonzalez-Caban 2010). We recognise the limitations of the model and their implications, and hope to address them in future work. Here we have used the C+NVC as a first step towards a more comprehensive analysis.

Acknowledgments

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Integrated economic assessment of management actions to reduce fire risk to Naseby, New Zealand

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Abstract

In the Otago region of New Zealand, Naseby is a small tourist town faced with an increasing risk of a severe fire event. Burning of tussock grasslands by pastoralists and recreational activity are just a few land management actions that pose significant risks to the town, surrounding communities, and biodiversity assets. We present a quantitative decision framework to provide an integrated assessment of the land management activities. The model was developed using existing literature and extensive consultation with stakeholders and fire researchers. We quantify trade-offs between economic, social and environmental outcomes from various fire risk mitigation strategies. We present results for a range of scenarios, exploring the tradeoffs between competing objectives for land management in Central Otago.

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Introduction

There are many strategies that can be implemented to reduce the risk of fire damage to infrastructure and life. Given that funds available for fire management are limited, knowing which fire risk mitigation strategies provide the best value for money is a key question for policy makers. In light of recent catastrophic fire events in various part of Australia (Teague et al. 2009), the potential fire risks faced by communities in New Zealand has become increasing apparent to authorities. In this study we undertake an integrated assessment of several strategies aimed at reducing the frequency of fire events in the town of Naseby, in Otago, New Zealand. We identify which management practices intended to reduce the frequency of serious fires provides the highest expected benefits per dollar of investment.

Background

Research approach

The approach to the research was highly participatory, requiring input from stakeholders at all stages. The research question was developed in consultation with the funding agency (Bushfire Cooperative Research Centre), industry partner (National Rural Fire Authority) and stakeholders. A series of workshops were held in the region to define the problem, collect data and foster ownership of the project and outcomes with the industry partner and stakeholders. A follow-up workshop was held to present the preliminary model, discuss results and refine the data. Subsequent discussions with key stakeholders and fire researchers assisted with the finalisation of the model and results.

Study area description

The study area chosen by the industry partner and stakeholders is Naseby, a small town within the Otago region of New Zealand (see Figure 1). It is situated at the base of the Mount Ida Range, on the edge of Naseby forest, surrounded by pastoral, tussock and rock lands. It has a permanent resident population of approximately 100 people. However the population swells to over 3000 during the summer months as tourists come to enjoy the range of heritage and recreational activities on offer. Pastoral farming and forestry are important industries within the surrounding landscape (Central Otago District Council 2010).

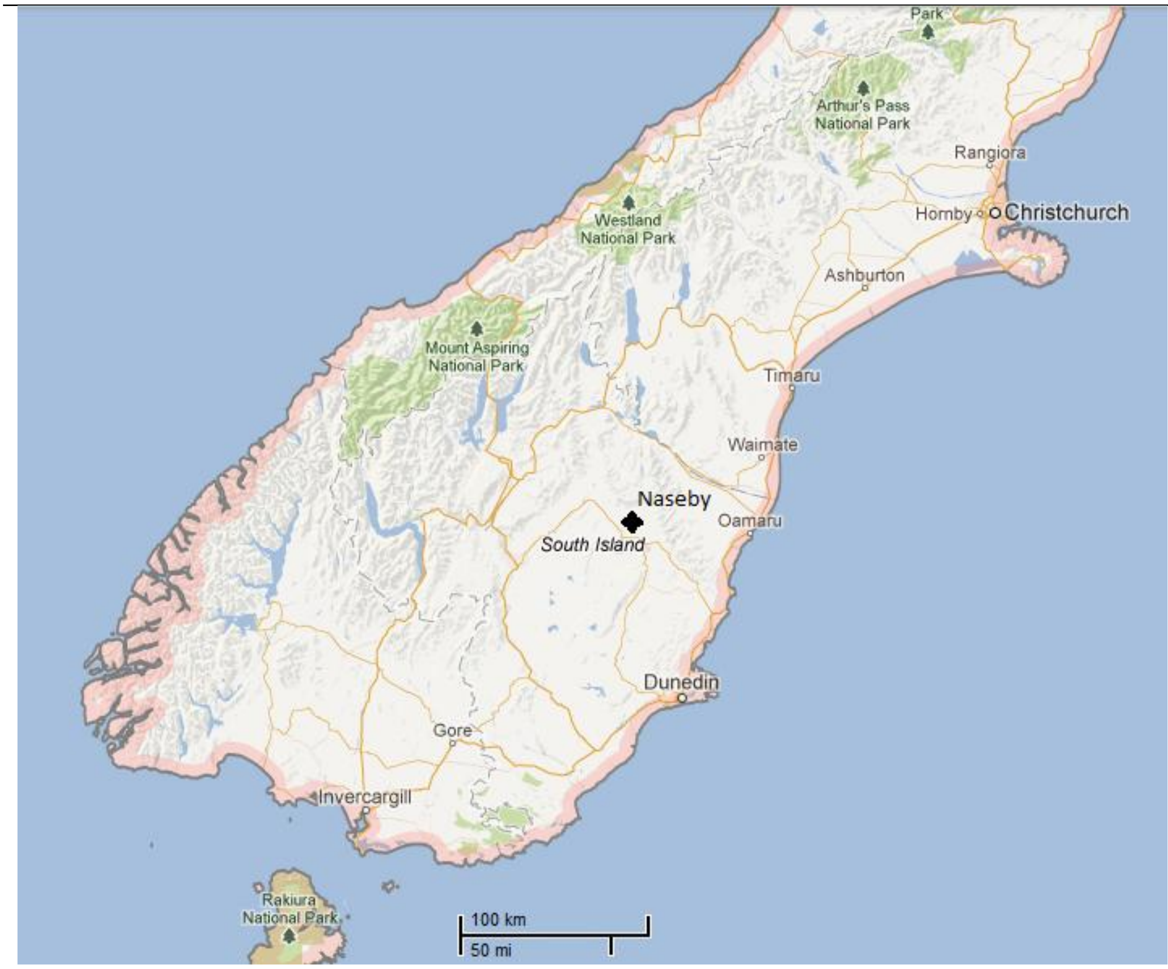

Figure 5 Study area location.

Fire risk and management surrounding Naseby

Fire risk varies considerably between different parts of New Zealand (Pearce and Clifford 2008). Climate change is predicted to increase fire danger in certain regions, including parts of Otago. This is primarily the result of predicted increases in temperature and decreases in rainfall, although higher wind speed and lower humidity is also predicted to contribute to higher future fire danger (Pearce et al. 2011).

Worsening fire conditions and limited capacity for fire suppression in some regions could result in more intense and damaging fires (Burrows 1999). Doherty et al. (2008) undertook an analysis of the reported fire incidents nationwide from the 1991/92 to 2006/07 and found that, within Otago, the number of wildfires has increased. The area of vegetation burnt in this region accounted for 41.5 percent of the total national area burnt.

Fire use by landholders within and surrounding Naseby is regulated through the fire authorities, which are set up to deliver on the objectives and requirements of the *Forest and Rural Fires Act 1977* and follow the policy direction of the National Rural Fire Authority (NRFA). Fire use on private and public land within and surrounding Naseby is controlled by fire seasons and permits. Fire use by recreationalists within the commercial forest is prohibited.

Model description

Overview

The model integrates fire risk, fire prevention options, costs of those management options and the damage caused by fires of different severities in order to estimate the benefits and costs of various fire risk management strategies for Naseby and the adjacent commercial forest. We have measured the benefits only as reduced damage to the assets, not reduced suppression costs. A base-line level of expected losses due to fire is estimated on the assumption that there is no additional management in place. The level of these losses is determined by the probabilities of different weather conditions, the probability of fire escapes in each of those weather conditions and probability of fire spread over different parts of the landscape. Then the calculation is repeated with a particular management regime in place. The difference between these two results (with and without management) provides an estimate of expected benefits, and this, together with the cost of the management regime, is used to calculate a benefit cost ratio (BCR). The model allows the user to simulate many different strategies for fire risk management and observe the estimated BCRs.

The nature of the management problem and the technical and economic relationships within the model were determined through extensive consultation with scientists, fire regulators, local experts and land managers. Parameter values for the model were determined through a literature review, existing databases and consultation with fire experts and land managers. We now describe key aspects of the model.

Asset description

The assets being protected is the town of Naseby, its residents and the adjacent commercial and recreational forest. The combined value of these assets is estimated to be $252 million. This includes the improvement value of 306 buildings, $42 million (obtained from Central Otago District Council), the threat to the lives of the town's permanent residents, $2 million per life (value of a statistical life obtained from New Zealand Fire Service Commission 2007), and the commercial value of the plantation forest, $10 million (obtained from Ernslaw One forest manager). Values were not assigned to the agricultural and conservation land in the other management zones in the model, as the focus of the analysis is on protection of the town and the forest.

Management zones

The town and surrounding area are categorised into ten zones. The zones are defined in Table 1, Appendix.

Different management actions and different risks of fire escapes and fire spread were specified for each of the zones, as outlined below. Zones of different distances from the assets were included to represent the fact that more distant fires are less likely to spread to the town or forest. We choose a 20 kilometre boundary around the asset in consultation with local experts, who advised that a fire that started more than 20 kilometres away from the asset was unlikely to reach it given suppression efforts and natural/man-made fire breaks. The five kilometre boundary was also decided on in consultation with local experts. The zones were split into north and south sub-zones to represent the higher fire risk from the north due to prevailing wind directions.

Fire risk

The model calculates the expected number of fires from each zone that reach the asset within a year. This is determined by the number of fire escapes occurring per year in each management zone, and the proportion of escaped fires that spread to the asset. Each of these aspects depends on the weather conditions. The fire weather conditions are categorised in the New Zealand fire danger rating system as low, medium, high, very high and extreme. A value for the Fire Danger Class (FDC) for each region is generated each day using the data recorded by the nearest weather station.

Fire escapes

Fire escapes are defined as a lit fire that requires a fire crew to extinguish. The frequency of fire escapes per year in each management zone in each weather category was estimated using data gathered by the NRFA within the study area from January 1 1998 to June 30 2012. The data consists of reported incidents where a fire crew was called to control an escaped fire. In total there were 223 reported fire escape incidents, distributed across zones as follows: 24 in Zone 1; three in Zone 2; two in Zone 3n and one in Zone 3s; 27 in Zone 4n and 45 in Zone 4s; four in Zone 5n and zero in Zone 5s; 54 in Zone 6n and 63 in Zone 6s.

Fire spread

Fire spread is defined as fire occurring in either zone 1 or 2 as a result of a fire escape in any of the zones. For example, a fire may spread from zone 3a to zone 1 (the town). The model includes probabilities of fire spread (conditional on a fire escape) for each zone in each weather category. For example, in extreme FDC weather, we assume that any fire that escapes in zone 3s has a 0.01 probability of spreading to zone 1. The probability of spread to zone 1 for an escaped fire in zone 1 is 1.0. These probabilities were set by calibrating the model to produce fires of different severities at pre-determined frequencies (see the next section).

Fire severity

Fire severity denotes the level of loss of infrastructure, life or plantation value due to fire. Fire severity classifications are not currently stipulated in government policy and so the damage defined within each category was developed with participants at the stakeholder workshops. Whilst there are no historical records showing fire severities greater than medium severity, the workshop participants agreed that fires greater than medium severity are possible. A description of each severity category, the estimated number of fires in each severity category per century, and percentage of damage done to each asset are provided in Table 2, Appendix. As the asset is a combination of two zones (the commercial forest and Naseby town) a percentage of damage must be determined for each.

The frequencies of fires of different severities depend on weather conditions (Table 3, Appendix). For example, we assume that, of the fires that reach zones 1 or 2 on a day of high FDC weather, 74 per cent will be of low severity, and 2 per cent will be of very high severity. Along with the probabilities of fire spread, these frequencies were determined by calibrating the model to produce the fire frequencies specified in Table 2, Appendix.

Fire management strategies

The strategies tested in the model were based on strategies identified in the stakeholder workshop and in further discussions with local experts. The parameter values used were derived from consultation with experts in fire and land management. The strategies are as follows:

- Payments to landowners to compensate or reward them for not using burning for land management in the agricultural zones.
- Regulation prohibiting burning for land management within the agricultural zones.
- On-ground support (i.e. provision of fire-fighting resources) to landowners undertaking burns.
- Training programs for landowners undertaking land clearing burns. The program is implemented across Zones 3 and 4. We assign half the costs to Zone 3 and half to Zone 4.
- Regulation prohibiting fire use within Naseby town.
- Implement the Queenstown Red Zone Plan (Queenstown Lakes District Council 2011). The program aims to change people's behaviour through awareness and knowledge of fire risk issues within Naseby and is targeted at permanent residents or those who own property within the town. There are 306 listed buildings.
- Fire breaks, of varying widths, around the northern edge of the commercial forest, or around conservation land in Zones 5 and 6. In Zone 2 the fire breaks would be located on private land. In Zone 5 and 6 the fire breaks would be on conservation land.
- Prescribed burning of conservation land to reduce the risk of fire spreading across them.

The management strategies address fire risk in different ways; they reduce escapes and/or reduce spread. The management strategies in the town (Zones 1) and agricultural region (Zone 3 and 4) are designed to reduce fire escapes. As each management strategy is designed to target a specific cause of escaped fires (i.e., land clearing burns), the strategy can only reduce the proportion of fire escapes attributable to that cause. It is estimated that 80 percent of escaped fires in Zone 1 originate from human activity. Therefore each policy option that reduces escapes in Zone 1 through targeting human behaviour can only affect 80 per cent of escaped fires. Similarly, within the agricultural regions 40 per cent of escaped fires originate from land clearing burns (Doherty et al. 2008; *per comm*. 2012), and strategies that reduce escapes can only affect that proportion of the full set of fires.

In evaluating the cost-effectiveness of each management strategy, an estimate of the reduction in fire escapes is required. These parameter values, along with the strategy costs, stakeholder behaviour and fire spread, are available from the authors.

Economics

The expected loss in asset value (*EL*) for a particular asset for a given scenario is calculated by:

$$EL = \alpha\beta V \quad (1)$$

where *V* is the value of the asset, α is the expected number of fires per year that reach the asset, and β is the proportion of asset value that is lost per fire. This is calculated for each asset (Zone 1 and Zone 2) and each fire severity level, and weighted by the frequency of each severity level (Table 4, Appendix).

Examining Tables 2 and 4, fires of low severity have by far the highest frequency, but they result in low loss per fire, so that the total expected loss per year from low-severity fires is relatively low: $39,000 in Zone 1 and $7,400 in Zone 2. At the other end of the spectrum, extreme-severity fires have extremely low frequency, but extremely high losses, so much so that for Zone 1, they provide the highest expected loss.

The benefit of a management practice is defined as the reduction in the expected loss in asset value per year as a result of the management practice. Expected loss is calculated with the management practice in place and subtracted from expected loss for the base-case management scenario, with no new management strategy. The decision metric evaluating the efficiency of each management strategy in reducing fire risk is a benefits cost ratio. The benefit-cost ratio (*BCR*) for strategy *X* is calculated as:

$$BCR_X = \frac{(EL_X - EL_0) \times P_X}{C_X} \quad (2)$$

where EL_0 is the expected loss under the base-case, P_X is the probability that strategy *X* will be successful, and C_X is the cost of strategy *X*. The decision rule when using a BCR is to accept a strategy only if its BCR is greater than 1, and in deciding between alternative policies, select the one with the highest BCR.

Dealing with uncertainty

Uncertainty about model parameters is addressed in a variety of ways. A subjective probability of failure for each strategy was estimated and included in calculation of expected benefits. Feedback on the model parameters and model results was elicited to stakeholders in documents and workshops. Break-even analysis is used to provide a guide to the robustness of the results. Break-even analysis is a form of sensitivity analysis that is useful to test whether a conclusion from the model is likely to change as a result of changes in parameter values within the range of uncertainty (Pannell, 1997).

Data collection

The parameter values were determined from the literature, from existing databases and thorough consultation with fire experts and land managers. The statistics on fire escape causes from the Otago region came from Doherty et al. (2008) and expert opinion. Data on fire escapes was provided by the NRFA. The data spanned from January 1 1998 to June 30 2012. Three stakeholder workshops were held in Alexandra, Otago, to assist in defining the decision problem, the management strategies and collecting information from local experts, including feedback on assumptions and preliminary results.

The effectiveness of each fire break strategy in reducing fire spread was estimated using the Australian grassland fire break breaching model (Wilson 1988) and expert judgement (Pearce pers comm. 2012). The effectiveness of a fire break in holding a fire is dependent on the width of the fire break, fire intensity and the presence of trees within 20 m of the upwind side of the break. Trees can provide a source of embers that can breach the break through spotting (Wilson 1988). The probability of a defined fire break width (6, 10 or 15 metres) holding a fire within Zone 2, 5 and 6 is given for each FDC under the following assumptions: the upper fire intensity value for each class and 10,000 kilowatts per metre for the extreme FDC (flame lengths of approximately 5.5 metres). As it was impossible to accurately determine whether trees were present or absent at each point along the zone boundaries, the probability of holding values were given as the midpoint between the tree absent and tree present estimate.

Results and discussion

The benefit, project risk, cost and BCR for each management strategy are provided in Table 5, Appendix, for standard parameter values. For agricultural and conservation management strategies each was initially tested jointly in both the within 5 kilometre and beyond 5 kilometre zones. If the strategy had a BCR greater than 1, the BCRs within each zone and each sub-zone were explored. Only eight of 22 strategies examined have BCRs greater than 1.

The highest BCR is for the community education program in Zone 1 (17.57). Regulating against fire ignitions within Zone 1 is moderately cost-effective (3.54); however implementing a council rubbish collection program is not (0.45). Within Zone 2, the 6, 10 and 15 metre fire breaks are all highly cost-effective (4.35, 6.17 and 7.58 respectively). Moderately high BCRs are also reported for landowner training within Zone 3 and 4 (2.33), and landowner training within zone 4 (2.92).

The remaining BCRs are less than 1, and range from .00 to .87. Payments, regulation and on-ground support strategies within Zone 3 and 4 are very poor value for money. Part of the reason for this is that, given the data and assumptions of the model, few fires would reach the assets from these zones. For example, 1 fire in 89 years would reach Zone 1 from Zone 4. Therefore, the benefits from reducing escapes within these zones is low, while the estimated costs of payments or regulatory compliance are high.

Fire break around conservation land (Zone 5 and Zone 6) result in benefits that are smaller than costs, except for the 15 metre break in Zone 5, for which benefits approximately equal costs.

The majority of the moderate to high BCRs are for management strategies within the asset zones, 1 and 2. Similarly, BCRs tend to be higher for management within the adjacent zones (3 and 5) rather than in the more distant zones (4 and 6), although not in every case.

Break-even analysis

Break-even analysis is applied here to the parameters judged to have the greatest uncertainty: management strategy effectiveness in reducing fire escapes and fire spread. The conclusion tested is whether each strategy has a BCR greater than 1. We report parameter values and percentage changes in parameter values that would result in BCRs of 1 (Table 6, Appendix).

Overall, the break-even analysis shows that the conclusion that minimising fire risk close to assets delivers the best value for money is a robust finding.

Conclusion

The model provides a number of insights into the relative cost-effectiveness of alternative strategies to reduce the fire risk for Naseby and the commercial forest. The most efficient policies to reduce fire risk are those that would be implemented within the asset zones, rather than on land some distance from the assets. The analysis suggests that the further away from an asset a fire risk reduction policy is implemented, the less efficient it will be in reducing fire risk. Particular strategies identified as offering high value for money include the community education program with Naseby residents and a fire break around the northern edge of the commercial forest. By contrast, strategies for which the expected benefits are greatly outweighed by the costs include payments or regulation to eliminate landowner burning practices, on-ground support to landowners and prescribed burning of public land. These findings are reasonably robust to uncertainty in key parameter values.

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Appendix

Zone	Definition	Current area (ha)
1	The town site of Naseby	62
2	The commercial forest adjoining Naseby	2100
3n	Agricultural land within 5 km to the north of Zone 1/ 2	2127
3s	Agricultural land within 5 km to the south of Zone 1/ 2	3184
4n	Agricultural land between 5 and 20km to the north of Zone 1/ 2	39074
4s	Agricultural land between 5 and 20 km to the south of Zone 1/ 2	55135
5n	Public land within 5 km to the north of Zone 1/ 2	114
5s	Public land within 5 km to the south of Zone 1/ 2	62
6n	Public land between 5 and 20 km to the north of Zone 1/ 2	33136
6s	Public land between 5 and 20 km to the south of Zone 1/ 2	1915

Table 3. Description of management zones and number of hectares (ha) within each zone.

Severity	Description	Estimated fires per century (per year) in Zone 1/ 2	Percentage of asset damaged	
			Zone 1	Zone 2
Low	20 percent of a single property or 10 ha forest	140 (1.4)	.0.01	.48
Medium	One property or 50 ha of forest	20 (0.2)	.06	2.38
High	Five properties or 350 ha forest	4 (0.04)	.28	16.67
Very high	30 properties and two lives or 1050 ha forest	2 (0.02)	3.00	50.00
Extreme	320 properties and 30 lives or 1800 ha forest	1 (0.01)	40.66	85.71

Table 4 Fire severity category, severity description, frequency of fires per century and per year and percentage of asset damaged.

	Fire Danger Class				
Fire severity level	Low	Medium	High	Very high	Extreme
Low	1	0.89	0.74	0.56	0.38
Medium	0	0.09	0.2	0.3	0.4
High	0	0.02	0.04	0.08	0.1
Very high	0	0	0.02	0.04	0.08
Extreme	0	0	0	0.02	0.04
Total	1	1	1	1	1

Table 5. Relative frequencies of fire severities in each Fire Danger Class rating.

	Expected loss ($/year)	
Fire severity	Zone 1	Zone 2
Low	$39,000	$7,400
Medium	$29,000	$18,000
High	$33,000	$30,000
Very high	$192,000	$61,000
Extreme	$948,000	$40,000
Total	$1,240,000	$156,000

Table 6. Expected loss in asset value per year given the probability of each fire severity occurrence.

Management strategies	Benefit	Probability of success	Cost	BCR
Zone 1				
Regulation	$791,000	0.90	$201,000	3.54
Community education	$439,000	0.80	$20,000	17.57
Rubbish removal	$95,000	0.95	$184,000	0.45
Zone 2				
6 metre fire break	$52,000	0.90	$11,000	4.10
10 metre fire break	$77,000	0.90	$12,000	5.61
15 metre fire break	$101,000	0.90	$14,000	6.66
Zone 3 and 4				
Payments	$17,000	0.81	$4,220,000	0.00
Regulation	$17,000	0.64	$4,580,000	0.00
On-ground support	$14,000	0.90	$398,000	0.03
Landowner training	$15,000	0.90	$6,000	2.33
- zone 3	$1,000	0.95	$1,300	0.80
- zone 4	$14,000	0.95	$4,550	2.92
Zone 5 and 6				
6 metre fire break	$58,000	0.36	$64,000	0.32
- zone 5	$19,000	0.6	$16,900	0.67
- zone 6	$40,000	0.6	$47,100	0.50
10 metre fire break	$84,000	0.36	$97,600	0.31
- zone 5	$28,000	0.6	$19,100	0.87
- zone 6	$59,000	0.6	$78,500	0.45
15 metre fire break	$109,000	0.36	$96,800	0.40

- zone 5	$36,000	0.6	$20,300	1.06
- zone 6	$76,000	0.6	$76,500	0.59
Prescribed burning	$2,000	0.25	$3,093,000	0.00

Table 7 Benefit cost ratios for each management strategy.

Management strategies	Original value(s)	Break-even value(s)	% change
Zone 1			
Regulation	.90	.26	-71
Community education	.50	.03	-94
Rubbish removal	.10	.22	+120
Zone 2			
6 metre fire break	.85,.83,.76,.76,.4	.21,.21,.2,.17,.1	-75
10 metre fire break	.96,.95,.92,.87,.62	.19,.19,.18,.17,.12	-80
15 metre fire break	.99,.99,.99,.97,.84	.15,.15,.15,.15,.13	-85
Zone 3 and 4			
Payments	.90	N[a]	N
Regulation	.90	N	N
On-ground support	.75	N	N
Landowner training	.75	N	N
- zone 3	.80	N	N
- zone 4	.80	.28	-65
Zone 5 and 6			
6 metre fire break			
- zone 5	.85,.83,.76,.76,.4	N	N
- zone 6	.85,.83,.76,.76,.4	N	N
10 metre fire break			
- zone 5	.96,.95,.92,.87,.62	N	N
- zone 6	.96,.95,.92,.87,.62	N	N
15 metre fire break			

- zone 5	.99,.99,.99,.97,.84	.89,.89,.89,.87,.76	-10
- zone 6	.99,.99,.99,.97,.84	N	N
Prescribed burning			
- zone 5	0.4,.2,.1,.1,.0	N	N
- zone 6	0.4,.2,.1,.1,.0	N	N

Table 8. Break-even values (and percentage changes) for uncertain parameters to generate BCRs of 1. For Zones 1, 3 and 4 the parameters tested are the proportional reductions in fire escapes due to the management scenario. For Zones 5 and 6 the parameters tested are the proportional reductions in fire spread to Zone 1.

[a] N means that there is no value within the range zero to 1.0 (the feasible range for these parameters) that results in a BCR of 1.0.

'Wait and See': The Elephant in the Community Bushfire Safety Room?

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Abstract

Australian community bushfire safety policy identifies two safe courses of action for householders under bushfire threat: leave well in advance of possible fire impact, or stay and defend a suitably-prepared property. Findings from a survey of residents of at-risk communities in south-eastern Australia were that under (hypothetical) bushfire threat on a day of Extreme Fire Danger 30% intended to wait and see how a fire developed before committing to a bushfire survival action. Reported reasons for waiting to see included: perceptions that the risk associated with waiting is low; expectations that others will warn or protect in case of serious threat developing; efficacy beliefs about successfully defending against smaller fires; and reluctance to leave because of potential costs and dangers associated with leaving unnecessarily, and with driving during a bushfire. We conclude that householders who intend to wait and see: (a) understand that bushfires are dangerous; (b) believe that waiting and seeing what develops does not involve significant risk; and (c) view waiting and seeing as an appropriate response to an initial bushfire warning. We suggest some ways fire agencies could better address this reality--'wait and see' may not be considered a safe course of action by community safety policy makers and practitioners, but it is what many householders at risk of bushfire intend to do at present.

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Introduction

Background, outline and aim

Investigations following multi-fatality bushfire disasters in 1967 and 1983 lead Australian fire authorities to conclude that householders (a) were most likely to be killed by radiant heat or vehicle accident while attempting to flee at the last moment; and (b) could successfully defend suitably-prepared houses against bushfires (Handmer and Tibbits 2005). These conclusions contributed to a general fire agency bushfire safety position that: "By extinguishing small initial ignitions, people of adequate mental, emotional, and physical fitness, equipped with appropriate skills, and basic resources, can save a building that would otherwise be lost in a fire...People should decide well in advance whether they will stay to defend or leave if a bushfire threatens" (Australasian Fire Authorities Council 2005, p. 6). This position came to be summarized as the 'prepare, stay and defend, or leave early' policy (Tibbits *et al.* 2008). Such a policy differs from that adopted in most North American fire jurisdictions, where evacuation of residents from threatened communities is generally the preferred strategy[1] (Paveglio *et al.* 2010).

Following disastrous bushfires in Victoria on 7 February 2009 (often described as the Black Saturday bushfires) the 'prepare, stay and defend or leave early' policy came under intense critical scrutiny (e. g., 2009 Victorian Bushfires Royal Commission, 2010). When the Australasian Fire and Emergency Services Authorities Council (AFAC) reviewed their community bushfire safety position following the 2009 bushfires, three issues identified in the aftermath of the fires appear to have been given considerable weight: (a) the generally low levels of householders' preparations for a bushfire; (b) the risks associated with failure to act decisively in the face of a bushfire threat warning; and (c) the dangers involved in defending a property under extreme fire danger weather conditions (Handmer *et al*. 2010; Whittaker *et al*. 2009; Whittaker *et al.* 2010). The revised AFAC (2010a) community bushfire safety position encapsulated these issues in a new safety summary statement *PREPARE. ACT. SURVIVE:*

> *PREPARE: ...If you are going to leave...what will you do, where will you shelter, and how will you get there?...Prepare your house and property to survive the fire front...*
>
> *ACT: ...Act decisively the moment you know there is a danger. Do not wait for an official warning. Do not just "wait and see".*
>
> *SURVIVE: The safest place to be is away from the fire...* (AFAC, 2010b)

In this paper we focus on what seems to have emerged as a core component of "*ACT"*: 'do not wait and see' in the face of a bushfire threat warning. We note that the phrase 'wait and see' does not appear in the AFAC (2010a) position paper *"Bushfires and community safety*". However, all fire services in the south eastern States and the Australian Capital Territory incorporate an injunction to 'do not wait and see' in their community bushfire information material. We review past evidence that many residents plan to, and do, 'wait and see' what develops following a bushfire threat warning, in Australia and in the United States. We then describe findings from a 2012 survey of householders in south-eastern Australian communities deemed by authorities to be at-risk of bushfire attack. We focus on the 30% of respondents who reported that they intended to wait and see what developed if they received warning of a bushfire threat. We describe the reasons they gave for adopting this approach, and discuss possible implications of an apparent rejection of fire agencies' urgings to 'do not wait and see' by many householders. Our aim is to encourage discussion of the 'wait and see' issue among community bushfire safety policy makers and practitioners. We note the measured tone of discussion in the AFAC (2010a) position paper:

> Fire agencies need to take into account that relatively few people in bushfire-prone areas make decisions or effective plans before bushfires threaten. When bushfires do threaten, many people don't make timely decisions about what they will do. Rather, they wait until the fire is close before making decisions. Safe options available to people who linger when fires are burning under 'severe', 'extreme' or 'catastrophic' fire danger ratings are often severely limited. Being away from the fire under these conditions is often the only safe option, yet travel over even very short distances is likely to be hazardous if the decision is made late. (p. 13)

We suggest that translating this nuanced summary of complex issues into a brusque "do not wait and see" directive might be simplistic and ineffective.

'Wait and see' in the community bushfire safety research literature

The earliest research-based reference to 'wait and see' we located was a paper by Rhodes (2007) which reported findings from five surveys of householders affected by fires in NSW, South Australia and Victoria over the period 2002-2007: "A significant minority in all studies (11-23%) intended to wait until told what to do, and 17-32% intended to wait but leave if they felt threatened" (p. 71). Tibbits and Whittaker (2007) described findings from focus groups of residents who had been threatened by a bushfire which burned an extensive area in north-eastern Victoria in 2003. While only 3% reported that they planned to 'wait and see' Tibbits and Whittaker concluded that "Many of those who decide to stay and defend are consciously or unconsciously retaining late evacuation as a last minute option...People who decide to leave early but wait for a trigger and those who decide to stay and defend unless they feel threatened are essentially planning a late evacuation, the most dangerous strategy" (p. 289).

Following the 2009 Victorian bushfires (Black Saturday) a Bushfire CRC Task Force conducted interviews with a cross-section of those affected. McLennan *et al.* (2011b) analysed transcripts of those interviewed and concluded that 6% had planned to wait and see what developed following a bushfire threat warning, and their data (pp. 15 & 27) suggested that approximately one-third waited to see how events unfolded following indications of a bushfire threat before committing to a final course of action to leave or to stay and defend. A subsequent postal survey of residents in locations affected by the Black Saturday bushfires found that 9% of respondents had intended to wait and see what a bushfire was like before deciding to stay and defend or leave, and a further 2% had intended to wait for police, fire and emergency services to tell them what to do (Whittaker *et al.* 2010).

Handmer *et al.* (2010) examined the circumstances associated with each of the 172 civilian fatalities resulting from the Black Saturday bushfires and concluded "… that many of the fatalities were 'waiting and seeing' before deciding what to do. From the evidence, it appears at least 26% of fatalities fall into this category, waiting for a trigger -- although it is rarely clear what this trigger might be -- before making a decision and taking action" (p. 23).

Whittaker and Handmer (2010) summarised findings from research conducted by CFA and the (Victorian) Office of the Emergency Services Commissioner following the 2009 Black Saturday bushfires and "...found that around one quarter of those who intend to leave would wait for advice from emergency services before leaving" (p. 10). McCaffrey and Winter (2011) reported that in a survey of residents of three United States communities threatened by a wildfire 16% had planned to evacuate but waited until they were told by authorities to leave; 30% waited to see what happened and stayed because the risk was not great; and 17% waited to see what happened but left when the danger felt too great (p. 92).

In 2011 two significant fire events occurred which destroyed homes in communities in the south-west of Western Australia: the Lake Clifton Fire (10 January 2011) and the Perth Hills fires (5 & 6 February 2011). Following each, field research teams interviewed members of affected households. McLennan *et al.* (2011a) reported findings from interviews with 40 Lake Clifton residents. While 5% said that their plan was to wait and see what developed, 58% left under imminent threat after waiting for some time to see if their homes were actually threatened. Heath *et al.* (2011) reported findings from interviews with residents of 372 households affected by the Kelmscott-Roleystone Fire and the Red Hill-Brigadoon Fire. Approximately 30% described their fire plan as "wait and see how bad it is, then decide" (p. 61) and approximately 25% reported that on learning of a possible bushfire threat they went back inside their house and waited to see what happened.

Taken together, these nine reports make clear that a significant percentage of residents of at-risk communities (a) plan to wait and see what happens on receipt of a bushfire threat warning, and (b) will wait and see what develops when such a threat warning is received (or perceived[2]). What remains unclear is why these residents plan and act in such a manner. The study described below was an attempt to address this question.

Method

As part of a Bushfire CRC project[3] fire agency staff in the ACT, NSW, Tasmania and Victoria identified locations which they considered to be notably at-risk of bushfire in the immediate future. The locations identified included rural communities, communities around country towns, and bushland-urban interface suburbs[4]. A survey instrument was developed which could be completed either online (using the *Survey Manager* software tool) or as a paper questionnaire for return by reply-paid mail. Residents in the selected communities were invited to participate by news items in local newspapers and interviews on local radio, advertising posters in settings where residents congregated, and bulk mailouts of advertising leaflets to residential mail boxes. Householders were invited to complete the survey online using a link, or to contact the researchers by phone or email to request a paper questionnaire and a replied-paid envelope.

A feature of the survey (in both formats) was presentation of the following bushfire threat scenario:

> Now imagine that during the fire season you and all those who normally reside with you are at home. It has been declared a day of "Extreme Fire Danger", and there is a Total Fire Ban for your Region of the State/Territory. At about 3pm you become aware of a warning (on the radio, or a web site, or by email, or text, or telephone) that there is a large bushfire burning out of control and that it will probably hit your location in 1-2 hours. You look outside and see a large plume of smoke being blown toward your property.
> What do you think you would most likely decide to do?
>
> a. Leave as soon as you can
>
> b. Stay to defend the home
>
> c. Wait and see what develops, before finally deciding whether or not to leave, or to stay and defend.

Responses of those who selected option c: "Wait and see what develops" were then analysed and the findings follow. (Responses of those who chose the other two options are not discussed here, but are described in McLennan and Elliott 2012, which also contains a copy of the survey questionnaire).

Results

Of 554 respondents, 164 (30%) indicated that they would 'wait and see'. These householders comprised 84 (51%) men and 80 (49%) women. Their mean age was 57.4 years (SD = 13.2 years). Respondents were invited to describe in their own words why they had chosen the 'wait and see' option rather than to either leave as soon as possible or to stay and defend. Ninety-one householders provided a total of 99 reasons for choosing 'wait and see what develops'.

Category		Statement and # statement number
Perceived low level of risk: **52%**	Probability of fire impact low or uncertain	*Our home is in a relatively low-risk location surrounded by farmland and open country (#2)*
	Threat level low if fire impacted	*Although the bush is fairly close I think our house is unlikely to be affected (#3)*

	Safe last minute escape route	*Easy escape route to protected beach (#20)*
	Ample time for final decision	*The fire can only approach from the south and I have a clear view of this (#60a)*
'Others' responsible – will warn or protect: **19%**	Agencies	*Because I hope that the fire brigade is in my street and would keep me safe (#9)*
	Family/neighbours	*The neighbours will help fight the fire (#9)*
Self-reliant confidence of survival: **16%**	Self-efficacy	*I have had extensive experience in fighting bushfires (#33)*
	Preparation	*Feel prepared with generator, water tank and 10 years CFA experience (#22)*
Reluctance to leave because of potential costs and dangers: **13%**	Unnecessary house loss	*Most homes are destroyed because people departed (#57)*
	Danger in leaving	*There could be panic by others on roads (#81)*
	Concern about being unable to return	*Would need to attend livestock (#83)*

Table 1: Reasons (n = 99) given by householders for choosing the 'wait and see' option in response to the bushfire warning threat scenario: categories and examples

The 99 reasons were analysed and sorted into categories on the basis of content. Four categories were evident (Table 1): (a) Perception of low-risk involved in waiting (52%); (b) Belief that others would warn or protect them if danger threatened (19%); (c) Self-reliant confidence of ability to survive (16%); and (d) Reluctance to leave because of associated potential costs and risks (9%). Overall, the main driver of choosing to wait and see thus appeared to be belief that this is a safe choice in response to the initial warning information.

Respondents were invited to state in their own words why they had not chosen the 'stay and defend' option. Ninety-five householders provided a reason for not intending to stay and defend their home. The reasons were analysed for content and were found to fall into one of five categories (Table 2): (a) Potential danger to self or others associated with staying and defending (58%); (b) Successful defence would depend on the actual severity of the fire threat (21%); (c) Age, infirmity, or disability of the respondent or other household members (12%); (d) Reliance on agencies for information about the danger posed by the fire (7%); (e) The house was rented (2%). The reasons indicate that most respondents understood bushfires to be very dangerous hazards, suggesting that choosing the 'wait and see' option was not due simply to lack of awareness of the potential threat posed by a bushfire.

Categories	Examples (# statement number)
Danger to self and others: **58%**	*A property can be rebuilt, a human life can't (#2)* *Children are my priority (#17)*
Staying and defending depends on the severity of the bushfire threat: **21%**	*If it was a really big fast fire I would not be confident that I could defend against it (#58)*
Age, Infirmity, or disability: **12%**	*Physically not up to it (#76)*
Reliance on agencies for advice about the threat posed by the fire: **7%**	*I would not stay if authorities told me I should leave (#49)*
The house is rented: **2%**	*It's a rental property and it is not worth me risking harm to myself for someone else's property, and my possessions are not worth much (#63)*

Table 2: Reasons (n = 95) given for not committing to stay and defend: categories and examples

Respondents were invited to describe their reasons for not intending to leave as soon as possible; and 136 respondents provided 150 reasons. These were analysed for content and categorised (Table 3). The content categories which emerged from the analysis process were almost the same as those resulting from the earlier analysis of reasons given for choosing the 'wait and see' option in response to the hypothetical bushfire threat scenario (Table 1). However, compared with Table 1, a higher percentage of householders reported reluctance to leave because of potential costs and dangers associated with leaving (34%) as the reason they did not choose the 'leave as soon as possible' option. There were no indications of concerns about being unable to return as a reason for not leaving. There were, however, several references to the inconveniences involved in packing and leaving unnecessarily. (Several respondents commented that they had experienced this in the past).

Category		Examples (# statement number
Perceived low level of risk: **45%**	Probability of fire impact low or uncertain	*Because I do not feel our home will ever be under threat (#16)*
	Threat level low if fire impacted	*Feel our property if defendable (#35)*
	Safe last-minute escape route	*There are numerous safe routes available (86b)*
	Ample time for a final decision	*Unless it is windy the fire will be far enough away to see (#123)*
Reluctance to leave because of potential costs and dangers: **34%**	Unnecessary house loss	*I would hate my house to be destroyed by a small fire I could have put out easily (#54)*
	Danger in leaving	*Potential for roads to be cut or involved with fire (#93)*
	Inconvenience	*Because packing and unpacking is time consuming and potentially damaging to my goods(#20)*
Self-reliant confidence of survival: **12%**	Self-efficacy	*As a trained firefighter I believe I have the skills and ability to defend my property (#8)*
	Preparation	*The property is well-equipped for firefighting (#107)*
'Others" responsible – will warn or protect: **7%**	Agencies	*Instructed to stay until given the order to evacuate by authorities (#63)*

	Family/neighbours	*Street is well trained and equipped through the (Community fireguard Unit) system (#98)*
Depend on others for transport: **2%**		*No transport, too much stuff to carry on my own (#82)*

Table 3: Reasons (n = 150) given by householders for not choosing the 'leave as soon as possible' option in response to the bushfire warning threat scenario: categories and examples

Discussion

Before discussing possible implications of the findings it is important to note that the sample is unlikely to be truly representative of residents in the communities. Overall, the respondents are almost certainly more engaged with issues of bushfire threat and safety than many of their neighbours. This is because of the methodology employed in which, unlike a telephone or individually-addressed postal questionnaire survey, participating required motivation to actively 'opt-in' to the study by typing or pasting a link into an internet search engine, or telephoning or emailing the researchers to request a questionnaire.

Our reliance on householders' stated intentions may be criticised. We have no impregnable defence against an assertion that there is no reason to believe that householders will, in fact, do as they said they intended under actual bushfire threat. Whittaker and Handmer (2010), for example, argued that the gap between what residents say they will do on a day of extreme fire danger in relation to leaving early, and what they actually do represents a serious challenge to agencies. However, in our study we did not simply ask residents if they intended to leave early on a day of extreme fire danger. We presented a hypothetical bushfire threat scenario and asked which of three options (leave, stay and defend, or wait and see) the householder believed he or she would most likely choose to do under such circumstances. It is interesting that 30% chose the 'Wait and see' option given that community bushfire safety information provided to households by fire agencies tells residents bluntly **not** to wait and see. If these householders were merely reporting intentions that they believed were socially acceptable it seems unlikely that so many would confess such a roundly-condemned intention. There is evidence from the social psychology research literature that stated intentions are good predictors of behaviour provided that there are no situational incentives or social pressures to endorse a particular intention (e.g., Sheeran, 2003). In short, we suggest that while there will always be some uncertainty about the strength of the link between a given stated intention and a specific future action there is no reason to assume that there will be no link. Interviews with householders impacted by the 2009 Victorian bushfires indicated that the most important determinant of what a householder did under threat was his or her prior intentions or plans in the event of a bushfire (McLennan et al. 2011b).

Bearing in mind the above considerations, in summary, the present findings are consistent with those of previous studies which showed that significant percentages of residents of communities at-risk of bushfires plan to wait and see how events unfold in the event of a bushfire warning, and will wait and see what develops following an actual bushfire threat warning. While the factors determining what a given individual plans and does following a bushfire warning are likely to be complex, our findings suggest that in broad terms most householders who plan to wait and see what develops following a bushfire warning:

(a) understand bushfires to be dangerous hazards which can pose a threat to life (although most probably under estimate the danger, *cf* Handmer *et al.* 2010) and do not intend to stay and defend their home if they think a fire will pose a serious threat;

(b) believe that waiting and seeing what happens does not involve a significant level of risk to their life; and,

(c) thus view their intention to wait and see what develops following a potential bushfire threat warning as appropriate for their circumstances.

If (a) – (c) above is an accurate summary of a general situation in at-risk communities, then a fire agency injunction simply to 'do not wait and see' is unlikely to be very effective[5].

We suggest looking afresh at 'wait and see' in relation to bushfire warnings from the vantage point of three years after the 2009 Victorian Black Saturday bushfires disaster. It is now known, with some confidence, that following a bushfire threat warning on all but a day of Code Red, or Catastrophic, fire danger: (i) a small percentage of residents in the threatened location will leave as soon as they can, because they perceive their personal risk from the fire to be high; (ii) a (probably) somewhat larger percentage will initiate final preparations to defend their property because this is what they have planned and prepared to do; while (iii) the majority will 'wait and see' what new information becomes available before committing to either leaving, or to staying and possibly defending their home--each option having its own perceived potential costs and risks. The question can surely be asked: is 'waiting and seeing' a poor choice? We suggest in answer: "not necessarily". To expect people to commit to an action involving potential life or death outcomes without knowing as much as they can about the situation is surely a 'big ask'![6] From a common-sense perspective, waiting and seeing under many bushfire warning situations is probably prudent—the relevant issues are *what* is the householder waiting to 'see' and what does he or she intend to *do* once 'it' is 'seen'? To think in this way would allow 'wait and see' to be moved from its current status of being condemned by authorities but widely practiced by the public into the mainstream of bushfire household survival *planning*.

- **We propose that agency bushfire safety injunctions to 'do not wait and see' be replaced by 'do not wait and just hope for the best'**.

The available research shows that most householders who leave do so in response to a specific trigger event such as credible information that their property is very likely to come under attack, or the sight of smoke, embers or flames. This suggests that householders could be encouraged and assisted to identify trigger events appropriate to their bushfire risk circumstances and incorporate these explicitly into their household bushfire survival plans[7].

Our findings suggest some additional approaches which fire agencies might consider as ways to address what we propose as the 'real' problem: householders delaying leaving until such time as they feel forced to either (a) flee at the last minute into a hazardous bushfire environment, or (b) shelter (passively or actively) in house which is ill-prepared to survive bushfire attack. There is nothing new in what we suggest, we simply revisit ideas in the context of the preceding discussion of 'wait and see':

1. Continue to improve the accuracy, comprehensiveness, timeliness, and *location-specificity* of bushfire warnings to residents in threatened locations so as to (i) reduce householder uncertainty about their threat situation and (ii) encourage early survival decisions and actions. Future developments in communications technology can obviously contribute[8].
2. Increase householders' knowledge and understanding of the risks involved in last-minute flight or last-ditch defence of an unprepared property. Instead of a cryptic 'do not wait and see' message, elaborate: "a plan to wait until you see how bad things are is a plan to either flee at the last moment and maybe die on the road, or to die in an unprepared house".
3. Reduce householders' reluctance to leave (a): assist them with advice about preparation to leave which is minimally inconvenient but sufficient to survive. Perhaps encourage planning for staged moves to successively safer locations during the course of a bushfire warning event as their known threat level increases.
4. Reduce householders' reluctance to leave (b): de-couple preparing their house to survive bushfire attack from necessarily having to be present to actively defend it: "The safest place to be during a bushfire is somewhere else, and here are things to do so that your house is more likely be standing when you return".
5. Reduce householders' reluctance to leave (c): following on from 4(b) above, concentrate on advising householders about low-cost, low-effort actions they can take to reduce house vulnerability to bushfire rather than high-end, costly measures.
6. Continue working to convince more householders that while they should be alert for bushfire warnings from authorities, they should not expect personalised advice that they are in danger and now is the time leave but instead decide on their own triggers to leave safely.

There is a tried and true human factors principle which practitioners in that field ignore at their peril: *It is better to put in place systems which match what people actually do, rather than put in place systems which rely on them doing as we <u>wish</u> they would* (Vicente 2003). This is no doubt true in relation to community bushfire safety.

Notes

[1] While 'sheltering place' (SIP) is discussed as an option in some North American literature (e.g., Cova *et al.* 2009; Paveglio *et al.* 2010) it is not endorsed currently by Australasian fire agencies.

[2] Householders may become aware of bushfire threat in one or more of several ways: official agency warnings; news broadcasts; unofficial warnings or information from friends, family neighbours; or cues from the environment—smoke, embers, sounds, flames.

[3] Communicating Risk: Decision Making Under Stress (2). School of Psychological Science, La Trobe University. Research Leader: Jim McLennan. End-User Leader: Damien Killalea.

http://www.bushfirecrc.com/sites/default/files/1009_researchlist_lowres.pdf

[4] The selected locations were:

> ACT: Bonython, Duffy, Fisher, Hackett, Holder, Tharwa, Weston.
>
> NSW: Captains Flat, Diggers Camp, Hornsby Heights, Kandos, Leura, Nelson Bay, Walla Walla.
>
> Tasmania: Bothwell, Deloraine, Dover, Mount Nelson, New Norfolk, Ouse, Port Sorell/Shearwater.
>
> Victoria: Beechworth, Delatite, Warrandyte, West Wodonga, Wonga Park, Yackandandah.
>
> (Responses also came from other, adjacent, locations).

[5] However, we do not know if the directive has influenced householders to commit to a plan to leave early or stay and defend a suitably prepared property, rather than waiting and seeing.

[6] Recently, a best-selling author has argued persuasively, and on the basis of impressive science, that under many different real-life circumstances the wisest course of action is to 'wait and see', rather than act precipitately! See Partnoy F (2012) *Wait: the useful art of procrastination* (Profile Books: London).

[7] This in no way implies that agencies should retreat from their fundamental position that leaving early, before there is any possibility of danger from a bushfire, is always the safest option.

[8] Despite optimistic predictions (e.g., Palen, 2008) social media like *Twitter* and *Facebook* remain largely untested as crisis communications tools in the Australian bushfire context.

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Couples' bushfire survival planning: a case study The 2011 Lake Clifton (WA) Fire

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Abstract

Evidence from several sources indicates that during the 2009 Victorian bushfires (Black Saturday), many couples did not have a bushfire plan, others failed to execute their plans and some members of couples perished. Whilst there were many cases of successful couple decision-making, there were also apparent failures of survival-related couple decision-making. In this study, transcripts of 29 interviews with members of different households conducted following the Lake Clifton bushfire (WA, 10 January 2011) were analysed to examine couples' long term bushfire planning and preparation. Findings indicate mostly moderate levels of concern by couples about bushfire risk. Long-term preparation was mostly focused narrowly on protection of the house, with less attention given to the likely needs of children, pets, important records, and other valuables. Husbands mainly managed home protection bushfire preparation. The majority of those interviewed said that if they were threatened by a bushfire in the future, they would act in the same way as they had on the day of the fire.

Introduction and Overview

In potentially hazardous threat situations such as bushfires, threatened householders undertake one of three survival actions: (a) evacuate the area before the fire threat is obvious; (b) stay and defend a suitably prepared property; or (c) flee once the threat is imminent. Historically, this last alternative has been found to be the most hazardous (Haynes, Tibbits, Coates, Ganewatta, Handmer, & McAneney, 2008). A plan, either to stay and defend the property or to leave early, requires careful thought and preparation having regard for a household' particular circumstances. However, a common feature of those affected by the Victorian fires of 7 February 2009 was a lack of planning and preparation to either to stay and defend or to leave safely (Handmer, O'Neil, & Killalea, 2010). It seems clear that in order to minimize loss of life in future catastrophic bushfires, there is an urgent need to examine and address the apparent general lack of bushfire survival planning by households in bushfire-prone locations.

The present study reports findings from interviews conducted by a Bushfire Cooperative Research Centre team with householders who were impacted by the bushfire which destroyed 10 homes in the rural community of Lake Clifton (WA) on 10 January 2011. The original field-research investigation is described in McLennan, Dunlop, Kelly and Elliott (2011). Transcripts of the interviews with 40 residents were examined, 29 transcripts were selected for analysis because the households comprised couples. These transcripts were analysed so as to identify couple-related issues concerning planning for bushfire threats.

Background

Systematic research contributing to a better understanding of the psychological processes involved in householder decision making related to bushfires is scarce (McLennan, Elliott, & Omodei, 2012), particularly research focused on marital or couple dynamics related to bushfire survival. The literature concerning bushfire survival-related decision making has largely focussed on individuals (e.g., Martin, Bender, & Raish, 2007). A notable exception was the research conducted by Proudley (2008) where the influence of family dynamics on family bushfire-safety related decisions was identified. Proudley concluded that the roles adopted within family units strongly influenced householders behaviours during a bushfire threat; and that women and men differed in their intentions and actions, with women taking children to safety, and men more likely to engage in fire fighting activities.

Improved community bushfire safety will only be achieved through better understanding of how members of households in at-risk communities understand their situation in relation to bushfire (Collins, 2008). The present study extended previous (limited) research on how householders think about bushfire risk by focussing on how a sample of couples responded to a bushfire which destroyed homes and threatened lives in their community. Here, the term 'couples' refers to two persons who are unified by marriage or in a de facto relationship and who are usually resident in the same household (Australian Institute of Family Studies, 2011).

Aim

The study was exploratory. The aim was to identify issues and processes involved in couples bushfire planning and preparation which emerged in the course of interviews with householders affected by the bushfire which impacted the small community (about 60 households) of Lake Clifton (100 kilometres south of Perth) on Monday 10 January 2011. The purpose was to inform development of a larger and more comprehensive future research program which will investigate important factors involved in how couples plan for bushfire survival.

Method

Participants and data sources

As indicated previously, the study involved analyses of transcripts of interviews conducted by Bushfire Research CRC research teams following the Lake Clifton (WA) bushfire of 10 January 2011. In total, 40 interviews had been conducted. Eleven interviews were excluded from the present study because these interviews did not include any reference to a couple. Thus the total number of transcripts considered in the present study was 29. While the unit of analysis was the resident couple, in seven interviews the informant was the husband, in fourteen it was the wife, and in eight both members of the couple participated.

Procedure

A content analysis, which relates to "…a research method for the subjective interpretation of the content of text data through the systematic classification process of coding and identifying themes or patterns" (Hsieh & Shannon, 2005, p.1278), was used to identify categories and themes relating to the issues listed below.

Each interview transcript was examined in relation to six variables:

Couples' bushfire risk perception and risk awareness.

Couples' long term bushfire planning and preparation.

Couples' relationship.

Gender differences in approach to bushfires.

What couples did on the day of the fire.

Couples' future bushfire plans.

Data analysis

In order to facilitate the analysis, statements in the transcripts were categorized. A Coding Form for the interviews transcripts was developed. The coding form enabled information to be extracted from the interview transcripts about factors such as couples' awareness of the bushfire risk for the area; gender differences in bushfire risk perception; knowledge of fire (what to do before and when a bushfire threatens), previous experience with fires, and implementation of the household bushfire plan—if any. Additionally, Rating Scales were developed to facilitate the estimation of the comprehensiveness of a plan, the degree of detail, and the amount of couple consensus regarding the household bushfire plan. A copy of the Coding Form and the Rating Scales is in the Appendix.

Results

The findings from content analysis are presented below in relation to each six major couple-related bushfire issues.

Couples' bushfire risk perception and risk awareness

Findings showed a generally high level of awareness about the possibility of a bushfire. However, 33% of the couples described a level of concern only ranging from very low to moderate: "*You don't sort of really worry about it";* and *"You never think it's going to happen to you".*

This suggests that some couples find it difficult to envisage that a specific risky event represents a serious potential threat due to an under-estimation of their level of the risk (Caponecchia, 2012; Weinstein, 1987). Previous research suggests that such underestimations may result in reduced motivation and willingness to adopt effective natural hazard threat mitigation behaviours (Farace, Kenneth, & Rogers, 1972; Jan, George, & Linda, 2011). In this way, couples' effective long-term bushfire planning and preparation may be compromised.

Couples' long-term bushfire planning and preparation

The present study found a general lack of couples' long-term bushfire planning: 21 couples did not have a formal bushfire plan; and for those who had a plan (n = 8), it usually consisted of *"a fair bit of talking"* (without plans for action), mainly discussion about the most important things to do and what to take on leaving. The most frequently reported intention was not to stay at home if a bushfire threatened (*"we always said we'd just leave anyway"*).

The findings also highlight some specific characteristics of the long-term planning and preparation made by those couples who prepared for a bushfire threat. Long-term preparation was mostly focused narrowly on the protection of the house. This included: sprinkler systems; petrol pump and water tank systems; keeping the area clear of native vegetation; fire hoses; and in some cases generators. Little or no attention was given to the likely needs of children and pets, or the safety of important records and other valuables. As a result, most couples evidenced a generally low level of comprehensiveness in their long term planning and preparation. That is, their intended actions focused on one aspect rather than on a broad range of aspects. As a couple stated, *"Never mind the rest of - never mind the insurance and the passports and all the photographs, the dog is the main ".* Attention to detail, that is who does what before, during, and after a bushfire, was mostly not specified.

There was only one case of very detailed long-term planning and preparation for an active defense of the house. This couple was very aware of their vulnerability and remained convinced that without their detailed planning and preparation the house would have been lost. Their primary plan was active defence, but they had a backup plan to leave if defence was impractical. Thus, they had two simultaneous preparation activities: (1) packing for them to go, in the worst case scenario; and (2) getting blankets, towels, water containers, and hoses ready for defending. The long-term plan had been carefully thought through, and the couple went through it again after the event to identify flaws: *"Two things in our plan that we'd overlooked, that was having batteries in the radio [...] and a recharging plug in the car for the mobiles".* On the day of the fire, their defence plan was fully implemented and the house was saved.

Couples' relationship

'Couples relationship' refers here to: their level of engagement, initiatives, power and consensus in planning for bushfire threats. Practical actions and initiatives related to the preparation of the property (yard and house) were mostly managed by the husband. This was especially so in the case of the couple described above. Both in regard to planning and actions on the actions on the day, the husband was in charge of the preparation and his style appeared to be very directive. He took all the initiatives; organized task divisions; and gave orders: *"The only time I* [the husband] *panicked was I told S____ to not go down into the smoke and she disappeared down there and I didn't see her come back into the house so I went mad at her for a while about that because you know you've got to obey the chief".* Nonetheless, the couple presented a high level of agreement and solidarity to the interviewers (J. Mclennan, personal communication).

Among most other couples interviewed, there appeared to have been a generally tacit process of no formal planning, but a shared intention to simply leave the property if a fire threatened: *"I don't think we ever dreamed for a moment that we would stay here when the fire was coming right over the top of us".* It may be that when the level of risk is perceived as minimal, decisions are less likely to be the result of joint decision-making processes (Sheth, 2011).

Gender differences in household bushfire

Differences in preferred actions along gender lines have been found previously in couples' actions under bushfire threat, with men preferring to stay and women wanting to leave and take the children to safety (Handmer et al., 2010; Proudley, 2008). This suggests the operation of unwritten household rules (Sholevar, 2003) about bushfire-safety based on gender expectations, which are likely to influence couples decisions about bushfire plans and safety. The analyses of the interviews following the Lake Clifton bushfire found that household bushfire house and yard preparation was mainly managed by husbands. Wives generally focused on taking paperwork and other relevant important documents such as insurance papers, birth certificates, passports, and photos.

On the day actions: from "WAIT AND SEE" to "*WENT TO SEE*"

In their review of fatalities prepared for the Victorian Bushfires Royal Commission by Handmer, O'Neil, and Killalea (2010) described evidence of procrastination by many of those who perished. Almost 30% of fatalities were 'waiting and seeing' before making a final decision to stay and defend their property or leave. Some couples affected by the Lake Clifton fire exhibited a very different pattern of behavior in which one member of the couple drove toward the fire to see where the fire was and what was happening, with the partner remaining at home waiting for his or her return. As a result, many became couples separated when the fire front arrived. Due to a lack of prior discussion among family members about the possibility of having to face the disaster separated from one another some were, in hindsight, critical of their action, as they regretted leaving their partner alone. As a wife commented: *"that was an okay decision. But as far as splitting the family, that didn't always sit well. But it was like, stay as long as it's safe but we're not going to -- I will keep the kids safe".*

Couples' bushfire plans for the future

One of the questions asked during the interviews was about thinking of possible actions in case of a future bushfire threat. The majority of those interviewed said that if they were threatened by a bushfire in the future, they would act in the same way as they had on the day of the fire. A frequent comment was that there would not be anything they could really do as they already had firebreaks and sprinklers. What seemed to emerge was a general lack of knowledge about specific actions to undertake under bushfire threat. However, some of the couples interviewed said they would "*probably*" do some things different. Below are some examples:

Switching the electricity off and packing more valuables.

"... basically start the pumps and got the sprinklers going around the property".

"… probably would have collected up the chooks and birds, as [...] discussed".

Would have liked to remove more trees that it was allowed to, to feel safer. Also, have had their neighbours' phone numbers.

Would have waited much further from the place affected by the flames. An interviewee said to her husband: *"You should never have sent us there. Because that was worse for her* [the daughter], *the one who'd just left, to sit there and watch; knowing".*

"*I'm going to get a box up, and I'm going to put the box there and I'm going to put all these relevant papers in, they're really material things that*…"

"Probably clothing".

The wife would want to stay, with the kids as well. "[...] *So the kids will be older so they'll be able to help out a bit". [...] But if it's a howling wind and it's moving, you'd probably just say, no. Got to go".*

Would probably be more organized in terms of having things ready to go, such as a permanent ready-to-go kit packed.

Would like to take the phone charger, the wedding album and would think about their pets (a fish and chooks).

Would have grabbed more papers.

Comments such as these suggest that community bushfire safety educational material provided by the fire agency had not been studied carefully by residents prior to the fire of 10 January 2011.

Limitations

Due to the nature of the data gathering, there have to be acknowledged inherent limitations of the study. The interviews were not specifically designed to investigate couples' joint planning and preparation for bushfires. Consequently, much specific information on the about the couples was missing or be incomplete, including length of the relationship, gender stereotypes, family decision making styles, and styles of relating. A more focused and comprehensive study involving couples residing in at-bushfire risk locations will be designed and will take into consideration couples' relationship dynamics and other processes which may determine how couples approach household bushfire safety.

Conclusions

The study explored six major areas concerning couple-related bushfire matters. Consistent with what Proudley (2008) noted, family dynamics and particularly the roles exercised within the family unit affected couples' behaviours during the bushfire. Household bushfire preparation of those couples affected by the Lake Clifton fire (2011) was mainly managed by husbands, while wives generally focused on taking relevant important documents. Gender expectations had established unwritten household rules which influenced bushfire-safety planning decisions and behaviours. Couples often focused narrowly on the protection of the house, and gave less attention to the likely needs of children, pets, and valuables. Above all, couples tended to under-estimate the level of their risk. Remarkably, while the majority of those interviewed said that if they were threatened by a bushfire in the future they would act in the same way as they had on the day of the fire, they also identified numerous specific actions they wished they had taken. This implies a lack of knowledge about the specific actions likely to enhance survival if threatened by a bushfire threat. Notwithstanding the considerable effort spent every year by Australian fire agencies in making available information to residents in fire-prone areas about bushfire safety plans and preparation, the study found that levels of household planning and preparation were generally low. It is thus more important than ever to better understand couple (or family) relational processes in relation to bushfire threat. Further research planned will involve surveys of, and interviews with, couples residing in at-bushfire risk locations about their perceptions of bushfire risk and plans and preparations to survive bushfires so as to improve our understanding of how to promote community bushfire safety at the couple level.

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Appendix- Coding Form and Rating Scale

CODING FORM – Couple decision making				
Interview n. ___________________				
Fire event	*Lake Clifton*	*Black Saturday*	*Perth Hills*	
Family structure	*Unknown*	*Only the spousal dyad*	*The spousal dyad with children*	*The spousal dyad with other family members*
Children age (if any)	*Unknown*	*Under 16*	*Adult children*	*No children living with the couple*

COUPLE AWARENESS OF FIRE PRONE AREA				
Unknown	1. Nil	2. Minimal	3. Some	4. High
GENDERED DIFFERENCES IN RISK PERCEPTION				
Unknown	1. Nil	2. Minimal	3. Some	4. High
KNOWLEDGE OF FIRE (what to do before and when the fire approaches)				
Unknown	1. Nil	2. Minimal	3. Some	4. High
PREVIOUS EXPERIENCE WITH FIRES				
Unknown	1. Nil	2. Minimal	3. Some	4. Several
LONG TERM BUSHFIRE PLAN				
Nil	1. Minimal	3. Discussed in general terms	4. Very detailed	
JOINT PLANNING				
Unknown	1. Nil	2. Minimal	3. Some	4. High
MAIN INTENDED ACTION				
Stay and defend	1. Leave early	2. Wait and see	3. Other	
DEGREE OF COUPLE CONSENSUS				
0. Unknown	1. Nil	2. Minimal	3. Some	4. High
TASKS DIVISION BY GENDER				
Unknown	1. Nil	2. Minimal	3. Some	4. High
BEHAVIORS/INTENDED ACTIONS THAT SOUGHT TO BENEFIT THE COUPLE AS A WHOLE				

Unknown	1. Nil	2. Minimal	3. Some	4. High

IMPLEMENTATION OF THE PLAN					
Unknown	1. Not implemented	2. Minimal	3. Some implementation	4. Fully implemented	5. Done something else

Long term planning Scale

SCALE LEVEL	COMPREHENSIVENESS	DEGREE OF DETAILS	AMOUNT OF COUPLE CONSENSUS
Level 4 High	Very comprehensive plan either about leaving or staying and defend well – prepared properties. Intended actions are focused on a broad range of aspects, such as the property, people, vehicles, pets, valuables, etc. The personal ability to mentally and emotionally cope with the event, as well as the physical preparedness, is taken into consideration.	Highly detailed and written plan either about to leave or to stay and defend the property. Who does what before, during, and after a bushfire is meticulously thought. This may include: Home preparation Arrangement of transports Consideration of a number of travel routes to avoid risky areas All persons with special needs are considered and accommodated Important items (such as insurance policies, family photos and valuables) Emergency kit Development of a list of items couple/family will need, and prepare a relocation kit. OR: Clearness of defendable spaces and undergrowth	Partners agree with the all intended actions, tasks distribution and timing, either about leaving or staying and defend.

		Checking of resources and equipment to effectively fight a fire (sprinkles, pumps, hoses, strong buckets, water supply, etc.) Arrangement of safe refuge locations Basic equipment and clothing.	
Level 3 Some	Some approximate arrangement on different aspects.	Intended actions are discussed at some level and a broad list of general 'things to do' may be included. There may be present a quite detailed arrangement consistent with usual roles.	The couple appears in agreement with several aspects of the plan/intended actions. Nonetheless, some divergences characterize couple consensus at this level.
Level 2 Minimal	The level of comprehensiveness is minimal. The plan (or intended action) is mainly focused on one aspect, with all the rest barely mentioned.	Abstract ideas in broad terms. These may be hypotheses about potential actions of leaving or stay and defend or wait and see, discussed at a minimal level. A potential tasks distribution is outlined.	The amount of consensus is low. Partners may agree of general aspects such as safety issues. However, they may intend safety is different way: for instance, sheltering or fleeing. Conflicts may arise.
Level 1 Nil	Focus on one aspect or the other. The plan appears vague and unclear.	No details are present. Who does what before, during, and after a bushfire is unmentioned.	Strong disagreement between partners. Actions are individually thought and undisclosed.
Level 0 Unsure or N/A	No plan	No plan	No plan

A comprehensive, nationally consistent climatology of fire weather parameters

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Abstract

The weather, at various time scales, is a major factor influencing the risk from bushfires and grassfires. As our scientific understanding develops, a growing number of meteorological parameters have been recognised as contributing to this influence. This paper reports on progress to date in a project to develop a comprehensive and nationally consistent climatology of these parameters, as part of the Fire Danger Rating Project.

National consistency is achieved by the use of high-quality reanalysis data from the European Centre for Medium-Range Weather Forecasting (ECMWF) Interim Reanalysis Project ERA-I, which avoids the problem of gaps, both spatial and temporal, in the observation coverage. These data, available 3-hourly on a 75 km grid worldwide, also avoid the problem of site-based observations that may be representative only of a geographically small area.

The set of parameters to be analysed is wide, and ranges from traditional fire weather indices, the ingredients that go into them, through to indications of vertical stability, wind-change strength, and the outcomes of recent research such as the importance of "dry slots". Only a small sample is shown here.

As well as providing a useful dataset in its own right, the climatology will underpin future work within the Fire Danger Rating Project by providing both a baseline for that research, and a computational infrastructure to calculate the weather component of proposed experimental indices.

This conference paper is a report on progress to date. A full report will be prepared as part of the completion of the project.

Data

The fire weather indices were calculated from a subset of the ECMWF Interim Reanalysis (ERA-I) held at the Bureau of Meteorology, which covers the period 1979 – 2011. Full details of the indices to be analysed are given in Section 3. The initial plan was to restrict attention to 6-hourly data from the period 20-year period 1989 – 2008, but a significant effort was made to obtain the additional 13 years of data, and at 3-hourly frequency for the entire period, for completeness and also to include the significant Ash Wednesday and Black Saturday events. Fuel moisture indices were calculated from the Bureau's operational rainfall and temperature analyses. These datasets were chosen since:

- Reanalysis data are as close to homogeneous in space and time as is possible. Observations, in contrast, do not provide complete spatial coverage, and may have gaps of varying lengths in the record.
- The ERA-I is widely recognised as the highest-quality reanalysis available over Australia at present. The high quality is partly due to the use of an extremely sophisticated four-dimensional variational assimilation (4D-Var) system to prepare the reanalysis, partly to the high degree of refinement of the ECMWF atmospheric modelling system, and partly to the very extensive diagnostics and verification used during the preparation of the reanalysis (Dee et al., 2011). The reanalysis uses a version of the operational ECMWF Integrated Forecasting System, generally regarded as being the best in the world. Importantly, the same system is used for the whole of the analysis period, ensuring that the entire analysis benefits from the near-current state-of-the-science in computer power and numerical weather prediction technology. The data will contain some unavoidable variation in quality through the period, due to steady improvements in weather observing technology and other changes in the observing network. However, post-1979 is generally regarded by meteorologists as being the "satellite era", during which satellite technology had attained a sufficiently high standard that the artificial trends due to improvements in observational technology are acceptably small.
- A limitation of all reanalysis products is that the rainfall may be inaccurately estimated, due to a number of factors including insufficient resolution to fully resolve the fine-scale processes that determine rainfall. Thus the historical gridded soil-moisture index data described by Finkele et al. (2006a, b) and held by the Bureau of Meteorology was used to calculate the various moisture quantities used in the fire indices, rather than the ERA-I precipitation field.

Parameters to be analysed

The list of parameters was chosen after extensive consultation with project stakeholders, including during a meeting of the Project Advisory Group at Mt Macedon on July 20-21, 2011, and through the distribution of a document detailing the proposed parameters (Kepert and Tory, 2011). The following list is extracted and updated[4] from that document.

Existing fire indices

- Forest Fire Danger Index Mark V (FFDI)
- Grass Fire Danger Index Mark IV (GFDI)
- Canadian Fire Weather Index (FWI)

Atmospheric parameters

- Atmospheric stability (continuous Haines, vertical velocity at 850 hPa).
- Boundary-layer depth.
- Air temperature at screen level.
- Humidity at screen level.
- Wind speed and direction at 10 m. Experience shows that this parameter often has a negative bias against observations. Hence the mixed-layer mean wind will be calculated also.
- Mixed-layer mean wind, calculated over the depth of either the boundary layer (if available) or the mixed layer.
- Wind-change strength, time permitting. The Huang-Mills wind change index (Huang and Mills, 2006, 2007; Huang et al., 2008) is designed for use with time-series data, and the 3-hourly ERA-I data may be too infrequent to use this approach directly. If time permits, a modification of the index to gridded synoptic data will be investigated. Alternatively, vorticity may be used as a proxy.
- 1000-500 hPa thickness gradient vector.
- An index of dry lightning favourability, for example following Dowdy and Mills (2009).
- An index of dry slots, to be devised.
- An index of plume behaviour, if a suitable measure exists.

Data processing

The above parameters will be extracted or calculated from the ERA-I dataset and 3-hourly values stored in a suitable format such as NetCDF.

Statistics to calculate

The raw data for the whole of Australia over the full period will be available. Various summary statistics will be calculated, including

- Mean

[4] Updates include the improvement from 6- to 3-hourly sampling, and some editorial corrections.

- Standard deviation
- Histograms
- Percentiles, especially of extreme fire-favourable thresholds (e.g. 95th and 99th percentile temperature, 1st and 5th percentile humidity).

Comparison to Observations

The ERA-I dataset represents the state of the science as far as reanalysis products go, but is nevertheless of relatively coarse spatial and temporal resolution (75 km and 3-hourly). Many users of fire-weather indices are more familiar with their calculation from point data from weather stations. More recently, the Bureau of Meteorology has moved to define the district fire-weather index as being the 90th percentile of the index calculated within that district from hourly data in the Bureau's national forecast database. This database represents meteorological parameters at hourly intervals on a 3-km or 6-km grid, depending on the state, and forms part of the Bureau's NexGen forecasting system, which is currently becoming operational.

To set the scene, we present an initial illustration using data from the Bureau's Yarrawonga automatic weather station (AWS), chosen because it has a relatively long record of high-frequency (1 minute) data, and is located in a quite flat area in the fire-danger prone southeast of Australia. We calculate the frequency distribution of the FFDI using the raw 1-minute mean data, and the same data averaged to 10 minute, 30 minute and 3 hour blocks. The more frequent data lead to a slightly higher estimate of the FFDI climatology, but the differences are not large (Figure 1 left). In contrast, if we choose to characterise the FFDI climate by its daily maximum value, the sampling frequency has a significant effect. Higher-frequency sampling leads to significantly higher daily maxima (Figure 1 right), with a range of about 20 FFDI points between 1-minute and 3-hour samples in this case. The frequency distribution of the 3 pm local standard time (LST) FFDI is also shown, and in this case (but not others) is quite similar to that of the 3-hourly sampled data. The impact of sampling frequency on daily maximum FFDIs here is similar to that found for three Tasmanian stations by Fox-Hughes (2011).

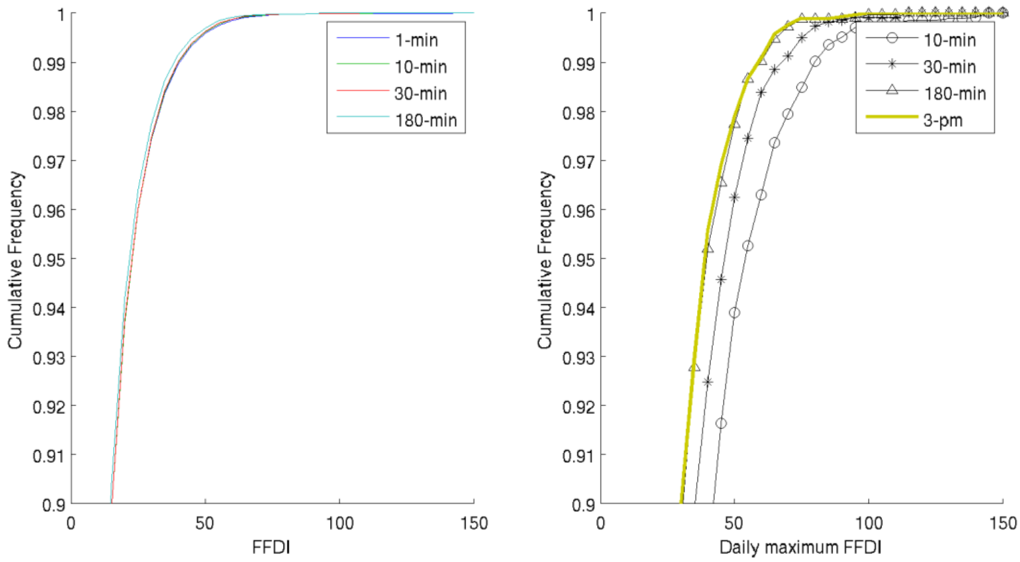

Figure 1: Left: Cumulative frequency distribution of FFDI at Yarrawonga AWS, calculated using 1-minute mean meteorological data (blue), 10-minute mean (green), 30-minute mean (red) or 3-hour mean (cyan). Right: Cumulative frequency distribution of daily maximum FFDI at Yarrawonga AWS, calculated from 1-minute data subsampled to 10-minute intervals (black curve with circles), 30-minute intervals (asterisks), or 3-hour intervals (triangles), together with the 3 pm local standard time values (thick tan line).

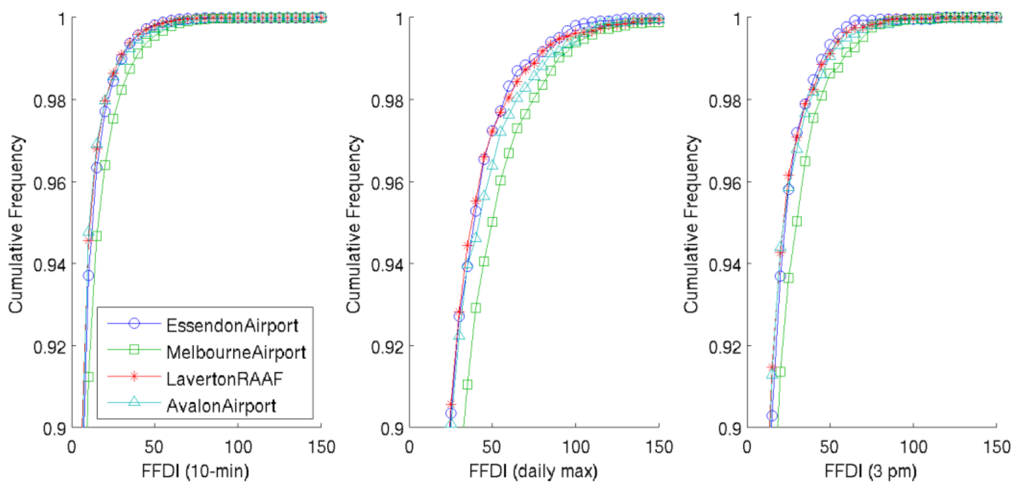

Figure 2: Cumulative frequency distribution of FFDI calculated from 10-min mean data at several AWSs in the vicinity of Melbourne. The individual panels show (left) the distribution of 10-minute FFDI, (centre) the distribution of daily maximum FFDI and (right) the distribution of 3-pm local standard time FFDI.

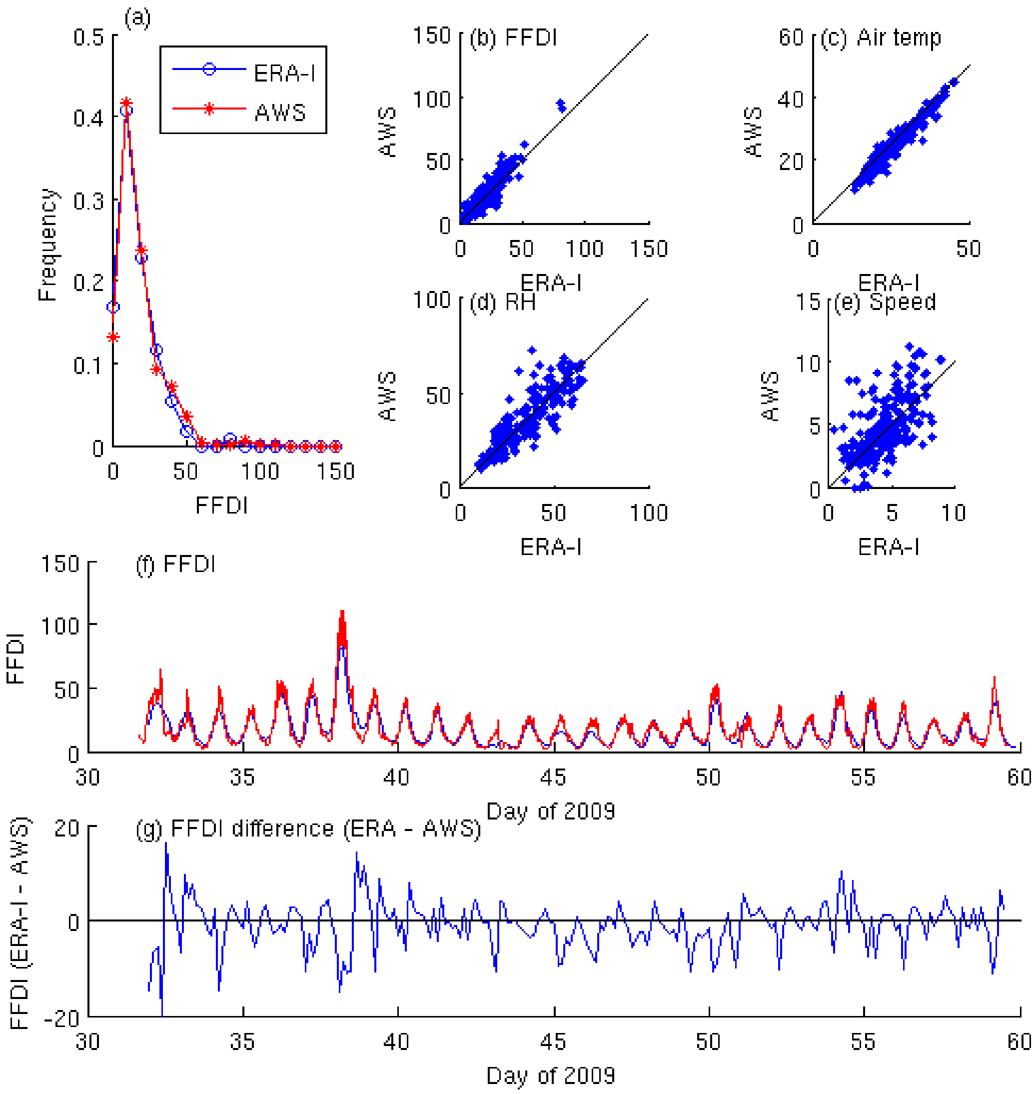

Figure 3: Comparison of ERA-I to station data at Yarrawonga for February 2009. (a) Frequency distributions of FFDI from ERA-I (blue) and AWS (red). (b – e) Scatter-plots of FFDI and its meteorological components. (f) Time-series of FFDI from ERA (blue) and AWS (red) for the month of February 2009. (g) Time-series of the difference in FFDI for the month of February 2009.

Significant spatial variations in FFDI climatology can exist over small distances. Figure 2 shows three depictions of the cumulative frequency distribution of FFDI from four stations in the vicinity of Melbourne. These stations are located within about 50 km of each other, less than the grid spacing of the ERA-I data, so would potentially be represented in that data by a single cell. The percentile values of FFDI vary by 5 to 10 FFDI units between stations, with Melbourne Airport generally having the highest values, presumably because it is furthest inland and less subject to sea breezes.

We therefore recommend that the following elements be considered in interpreting the ERA-I FFDI data, relative to station data:

- Daily maximum FFDI will be underestimated relative to AWS data due to the 3-hourly sampling, by up to the order of 20 units.
- The distribution of instantaneous FFDI is much less affected by the sampling frequency.
- Grid cells in the ERA-I data may cover a range of distinct climatologies, due (for example) to strong near-coastal gradients in temperature and humidity. Similar heterogeneity effects are likely in regions of significant topography. The smoothed topography in ERA-I is an additional factor to consider here.

Figure 3 presents a direct comparison of the ERA-I data with station data, in this case for Yarrawonga (in northern Victoria). The shape of the density functions is similar for observations and reanalysis, and there are only slight systematic biases, either in the FFDI ingredients, or in the index itself. The diurnal cycle in FFDI is well reproduced. The temperature and humidity data have small scatter, while the wind speed is more variable. A time series of the station and reanalysis data provide a consistent view of the extreme fire weather on Black Saturday (7 February, 2009). Similar comparisons to data from other AWSs are in preparation.

ERA-I's view of Ash Wednesday

As a further illustration of the verity of the ERA-I dataset, Figure 4 shows the sequence of the fire weather on Ash Wednesday (16 February, 1983), as depicted by the FFDI. Similar plots have and will be examined for other notable events; so far the dataset appears to depict their development very well.

A Preliminary Climatological Analysis

As an initial look at fire climatology, the FFDI was calculated for the entire data set. The necessary drought factor data were obtained from the gridded data described by Finkele et al. (2006a,b)[5]. We note that FFDI is strictly only meaningful in forested regions; the reader should take this into account when interpreting the remainder of this section.

Maps of the maximum, 95th percentile and mean of the FFDI over the summer months (December, January and February) for the eight analysis hours are shown in Figures 5 to 7 respectively. Note that the colour bars are different on each figure. The three irregular regions of zero values in each map represent data voids in the drought factor data, due to there being insufficient rainfall data to calculate the Keetch-Byram Drought Index (KBDI) there (see Jones et al. 2009 for more detail on the underlying daily rainfall analyses).

[5] The computation of these data has continued, and they are available up to the present.

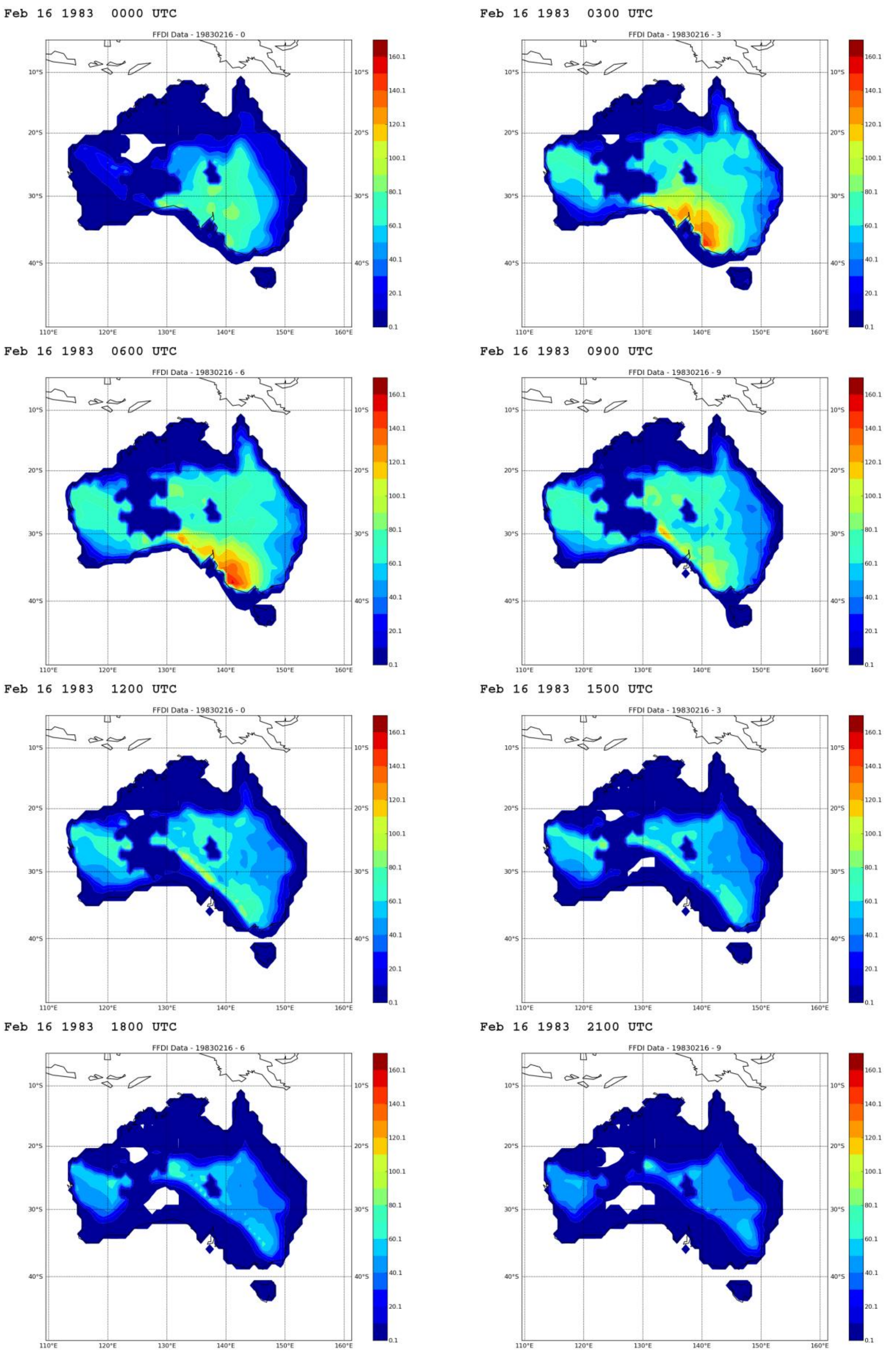

Figure 4: 3-hourly fields of FFDI on Ash Wednesday 1983, beginning from 00 UTC (1100 EDT) on 16 February 1983. Note the high values in and around western Victoria in the afternoon, and the subsequent progression of the wind change across the continent. The irregular dark blue or white regions in the sparsely populated interior are due to data voids in the daily rain gauge network, making the drought factor data unavailable.

On average (Figure 7), the highest values are found in the interior of the continent, extending to the west coast between about 20 and 30°S and to the region around the head of the Bight. Mean summertime values in the southwest, southeast, eastern and northern coasts are quite low. In contrast, the all-time (i.e. 1979 to 2011) maxima (Figure 5) show values in excess of 50 along much of the coast during the afternoon. However, these extreme values are quite rare, and are not apparent in these regions in the 95th percentile maps (Figure 6). It is interesting to note that Tasmania is barely visible at these colour scales in these figures, supporting the current practice of using different thresholds of FFDI for some fire danger rating categories in Tasmania, from those on the mainland.

The seasonality is illustrated in Figures 8, 9 and 10, which show the all-time maximum of FFDI at 0300, 0600 and 0900 UTC for each of the four seasons. Here, seasons are defined in the conventional way as blocks of three whole months. Australian local standard time is 8 hours ahead of UTC for WA and 10 hours for the eastern states, so 0300 UTC corresponds to 11 am (1 pm) local standard time in the west (east), 0600 UTC to 2 pm (4 pm), and 0900 UTC to 5 pm (7 pm). A number of interesting features are apparent, including that extreme events tend to persist later into the day in summer than in spring, and that spring generally has higher peak FFDI values than autumn. It is clear that further analysis will reveal many more interesting features.

Summary

The complete ERA-I dataset has been obtained at full horizontal resolution for the Australian region, allowing a detailed, nationwide analysis of climatological parameters pertaining to fire activity.

The preliminary analysis herein shows that the data have little bias, but that estimation of parameters such as daily maxima may be biased low compared to more frequently sampled data, due to sampling frequency effects. Interpretation of the data should also take account of possible spatial gradients, for example near the coast or mountains.

Maps of FFDI for the country as a whole reveal a range of intriguing regional differences in climatology. We expect that further analysis of this dataset will continue to reveal much about the fire weather climatology of Australia, and be of significant value to the Fire Danger Rating project. It will also serve as a valuable resource in the effort to develop new, and improve current, fire danger rating methods.

A more complete report on this work is nearing completion, and will be published as a CAWCR Technical Report in due course (Wain et al. 2013).

Acknowledgments

The research described here is partially supported by the Attorney-General's Department under the National Emergency Management Committee. We also gratefully acknowledge the European Centre for Medium-Range Weather Forecasting for their generous provision of the ERA-I dataset.

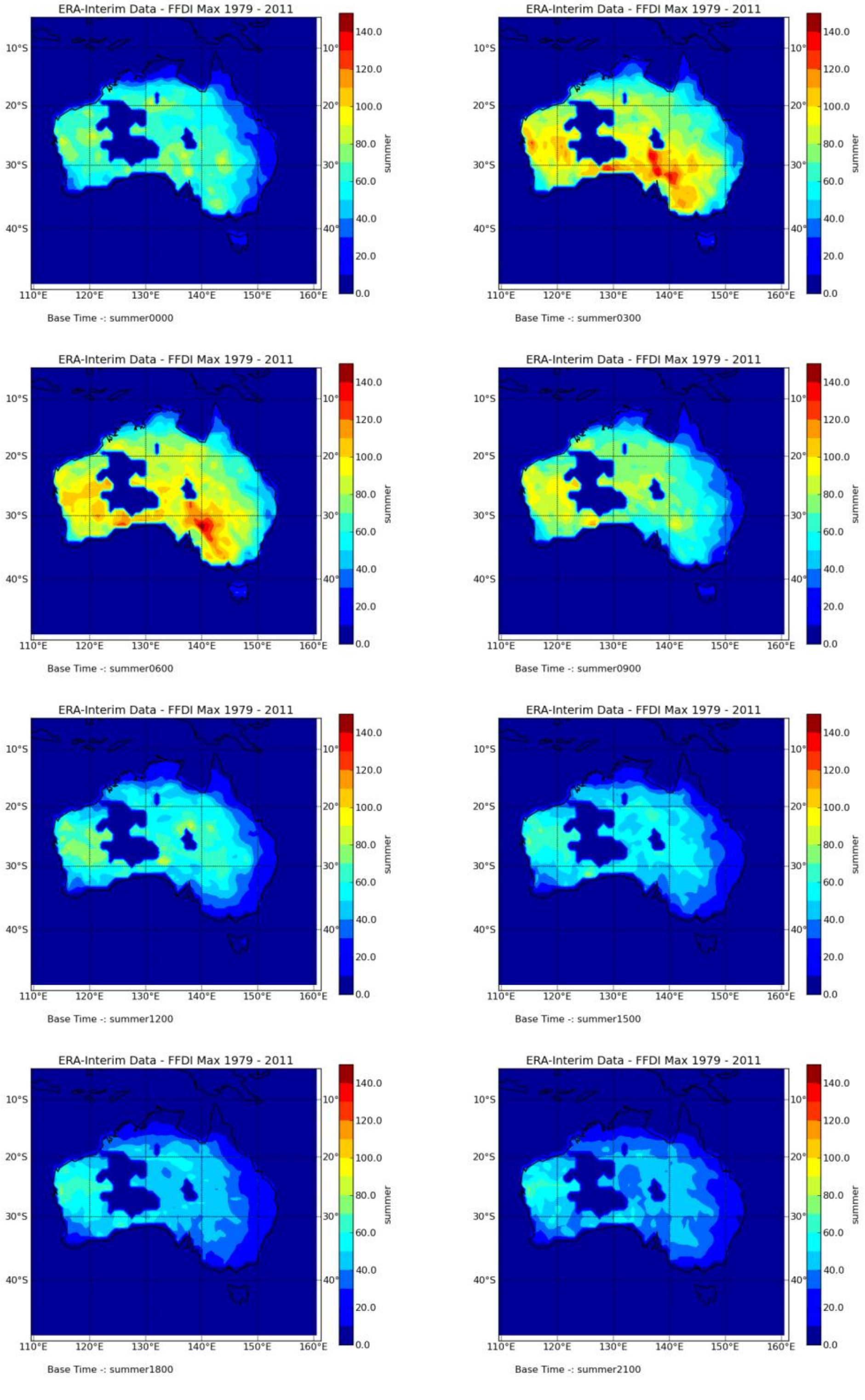

Figure 5: Maximum summertime FFDI during the period 1979 – 2011 from the ERA-I dataset as described in the text. The individual panels correspond to 3-hour periods, starting with 0000 UTC in the upper left and finishing with 2100 UTC at the lower centre. The irregular dark blue regions in the sparsely populated interior are due to data voids in the daily rain gauge network, making the drought factor data unavailable.

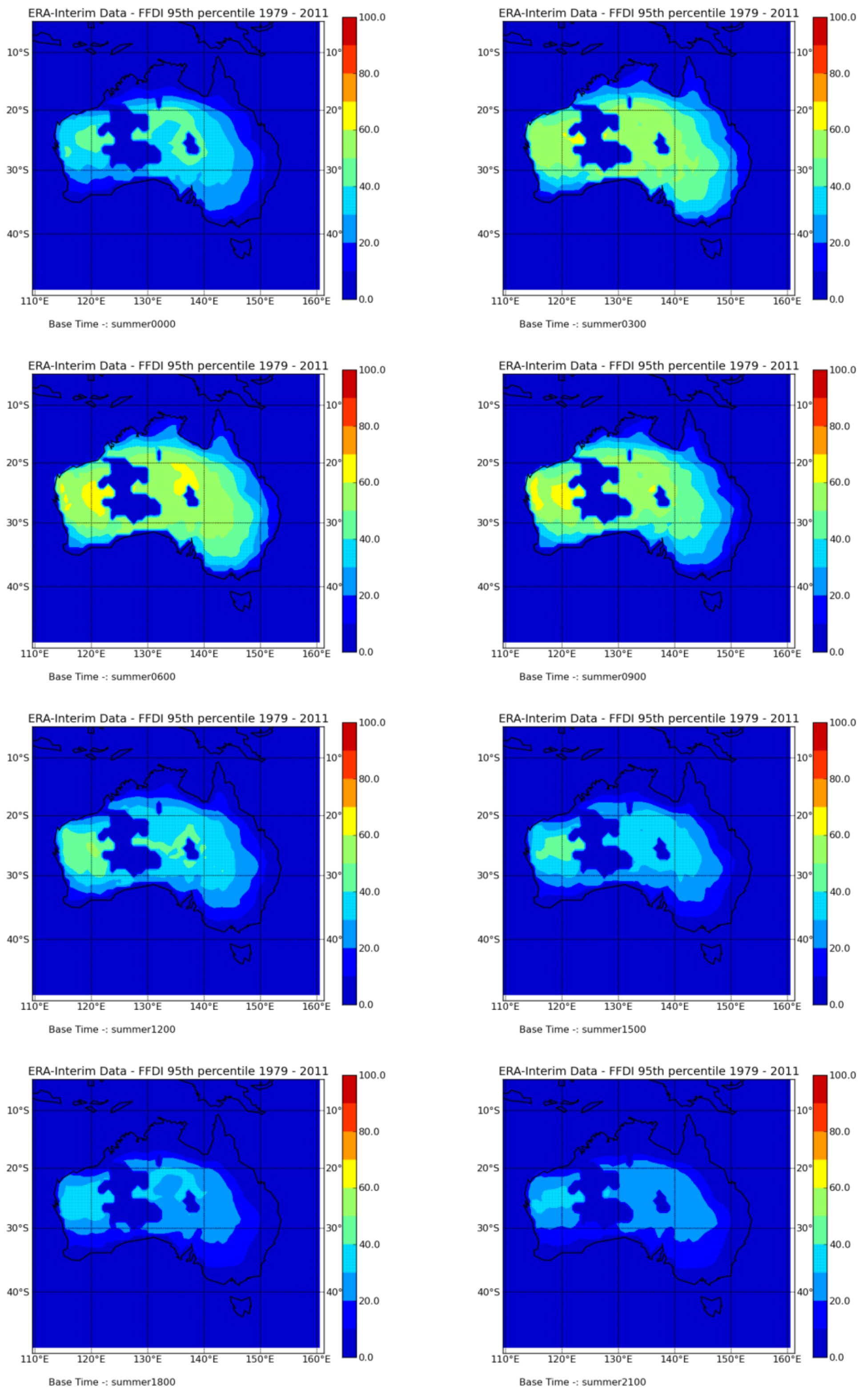

Figure 6: As for Figure 5, except for the 95th percentile summertime FFDI. Note that the colour scale has changed.

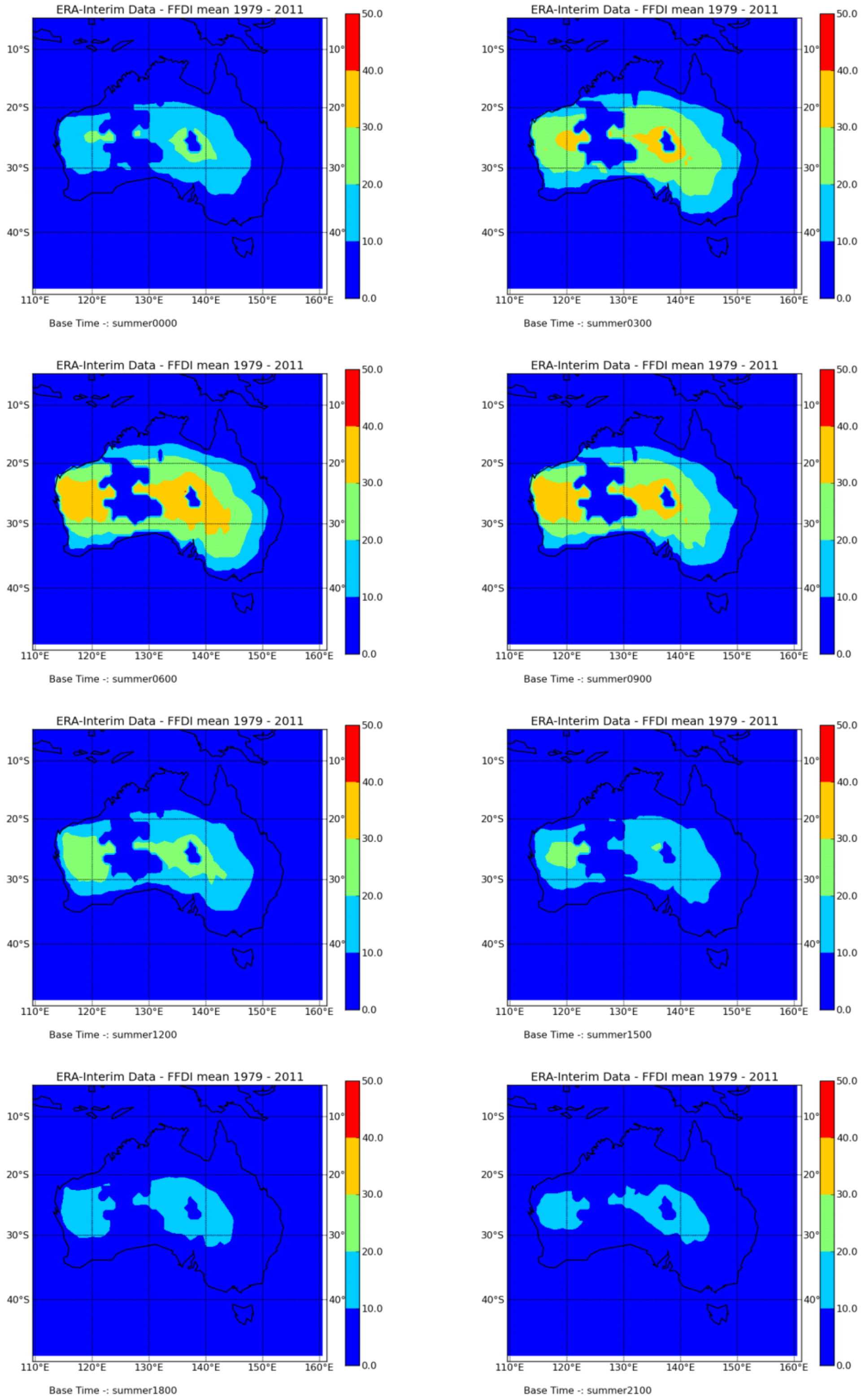

Figure 7: As for Figure 5, except for the mean summertime FFDI. Note that the colour scale has changed.

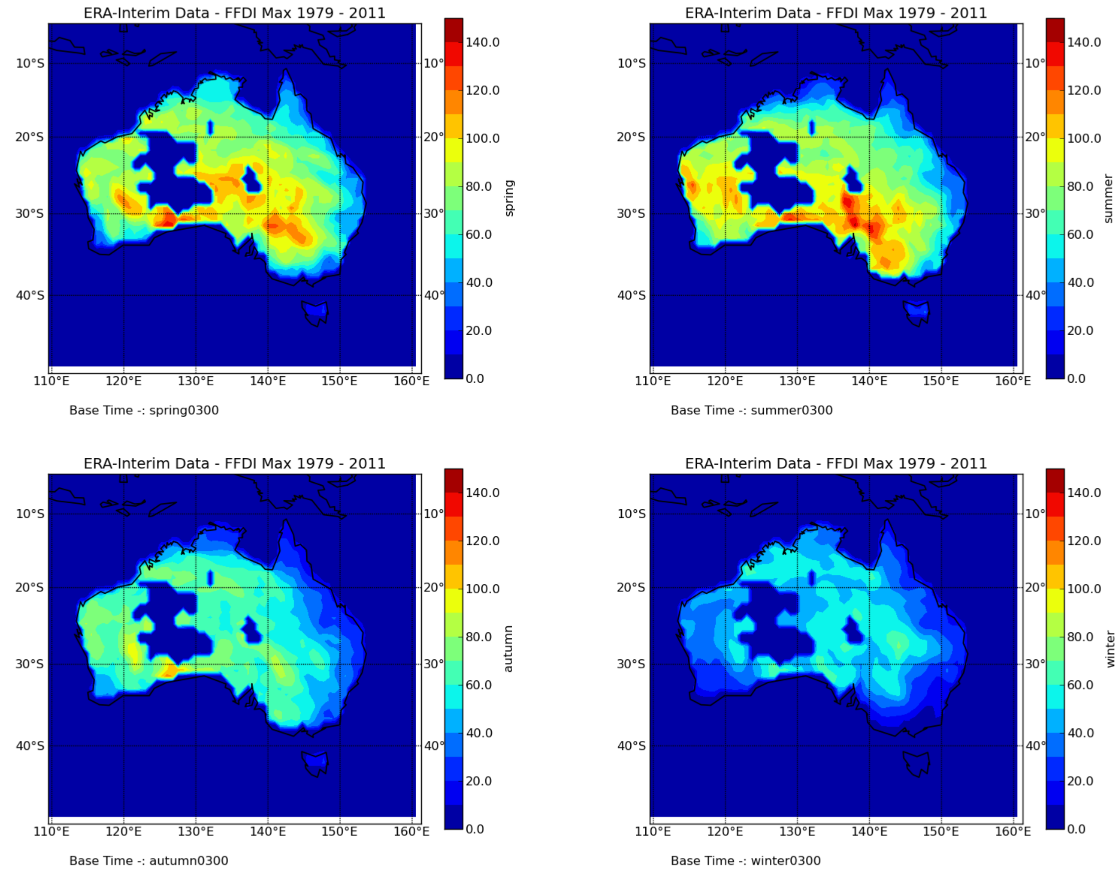

Figure 8: Maximum summertime FFDI at 0300 UTC over the period 1979 – 2011 from the ERA-I dataset as described in the text. The individual panels correspond to seasons: spring (top left), summer (top right), autumn (lower left) and winter (lower right). The irregular blue regions in the sparsely populated interior are due to data voids in the rainfall network making the drought factor data unavailable. Note that 0300 UTC corresponds to 11 am local standard time in the west and 1 pm in the east.

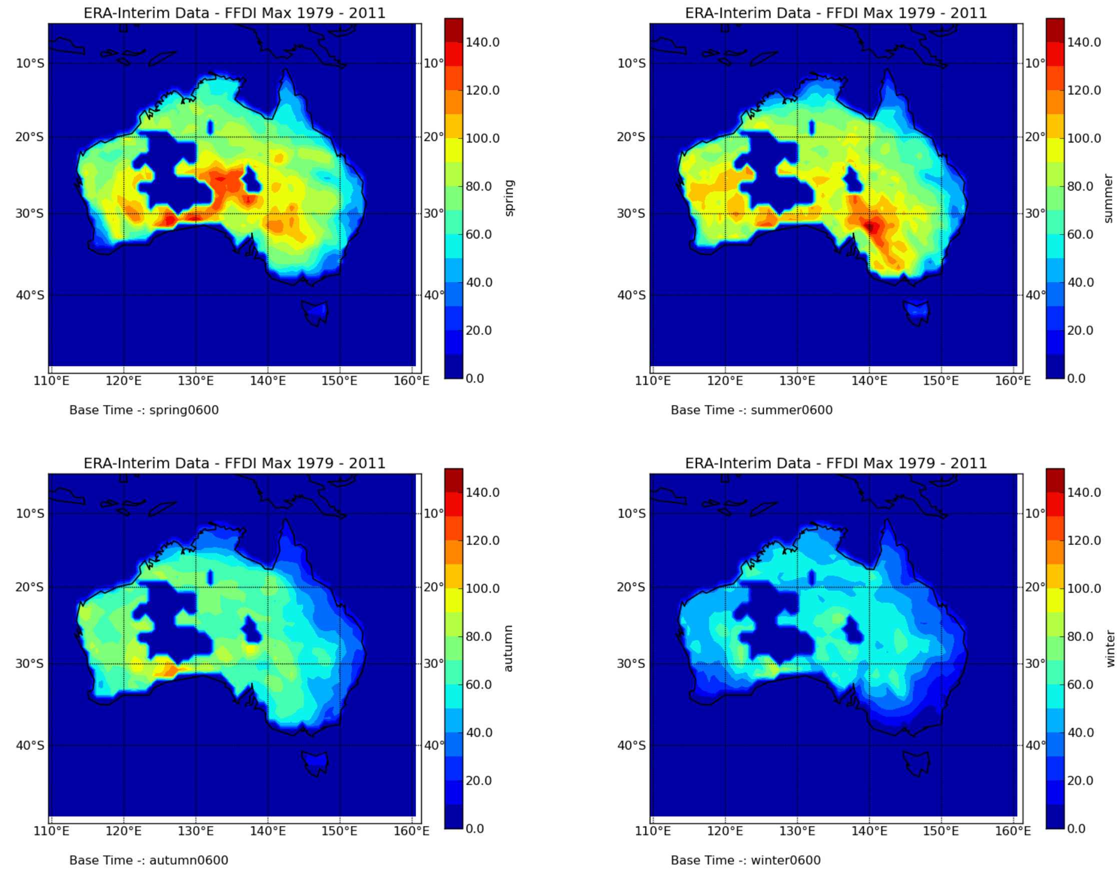

Figure 9: As for Figure 8, except at 0600 UTC. Note that 0600 UTC corresponds to 2 pm local standard time in the west and 4 pm in the east.

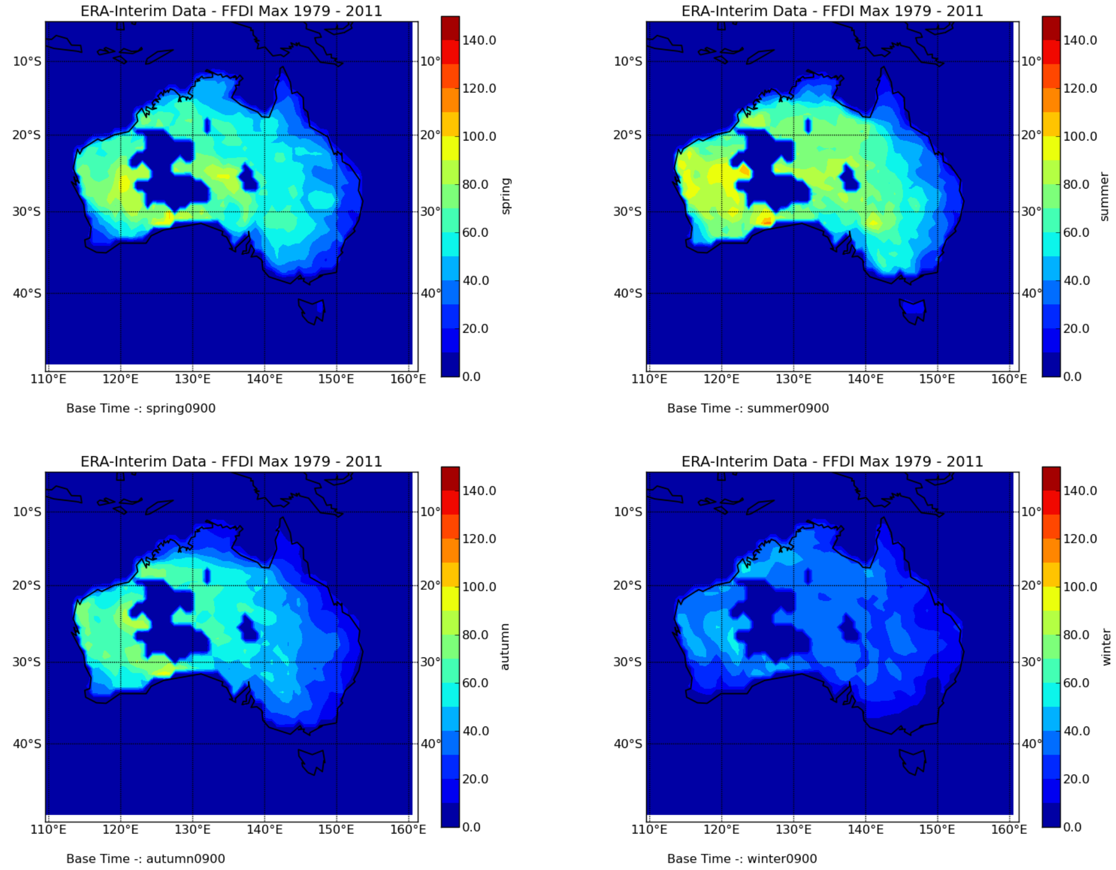

Figure 10: As for Figure 8, except at 0900 UTC. Note that 0900 UTC corresponds to 5 pm local standard time in the west and 7 pm in the east.

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The effects wildfire on water yield and its relationship with vegetation response

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Abstract

The response of vegetation regrowth and water yield after a wildfire is dependent on factors such as fire intensity, climate and vegetation type. Australian woody vegetation species have evolved two mechanisms for surviving fire disturbance; i) seed germination (obligate seeders) and ii) resprouting from dormant vegetative buds and/or lignotubers (obligate resprouters). The majority of post wildfire vegetation response studies have been conducted in Victoria, Australia and have been in obligate seeder dominant communities. These studies have found that there is a significant delay in vegetation regrowth as they rely on the seed bank, whilst also finding there is a significant change in water yield post-wildfire. Those studies are not representative of the vegetation in the Sydney Basin, which is dominated by obligate resprouter species. This study examines vegetation recovery and its potential effects on water yield in a burnt subcatchment of the Nattai River, which was affected by wildfire in 2001/02. The study used was designed to detect i) changes in vegetation growth during recovery and ii) establish if these changes corresponded with changes in water yield. The first approach used an 18 year time series of Landsat data to assess annual vegetation 10 years pre-wildfire and 8 years post-wildfire. Several vegetation indices were compared to assess the health and integrity of eucalypt forests and woodlands (NDVI, NDVIc and NBR). The second approach used weekly rainfall, water yield and temperature data over an 18 year time series. A generalised additive model (GAM) was used to create a water yield model and change in water yield was detected through the use of prediction intervals and error plots. Results show that there was no significant impact on vegetation or water yield following wildfire as both recovered within 8 years.

Introduction

Wildfire plays an important role in modifying vegetation communities. Vegetation communities regenerate by the production of seedlings from seeds (obligate seeders) or by vegetative buds that resprout from the stem and branches and/or lignotubers of plants (obligate resprouter). The response of vegetation communities to wildfire is dependent on many factors such as the fire intensity, burn severity, climate, light and nutrient availability, and species type (Williams, 1995; Wright and Clarke, 2007).

Many recent studies have attempted to quantify the impact of wildfire on vegetation regrowth (Diaz-Delgado et al., 2002; Hernandez-Clemente, 2009; Jacobson, 2010; Lhermitte et al., 2011). This has been achieved through the use of remote sensing data, in particularly Landsat TM imagery. Remote sensing is used to analyse vegetation recovery by implementing various vegetation indices into the analysis, including: Normalized Difference Vegetation Index (NDVI); Normalized Burn Ratio (NBR); Enhanced Vegetation index; and Leaf Area Index (LAI).

Previously, NBR has been used to determine post-wildfire burn severity (Tanaka et al., 1993) and has now been incorporated into many studies to generally determine the annual vegetation regrowth (van Leeuwen, 2008). More recent studies have also incorporated the use of NDVI which has been demonstrated to display similar spatial patterns to NBR (Epting et al, 2005; Lhermitte, 2011). Diaz-Delgado et al. (2010) studied the 1994 wildfire which occurred in the province of Barcelona, Spain using Landsat TM and MSS images. By using the NDVI it was found that there was an immediate response by shrubland and oak tree woodland due to their reprouting capabilities. Aleppo pine forests, in comparison, were found to have a slow recovery due to the limited availability of a seedbank.

In this study Landsat imagery has been used to assess the recovery of vegetation regrowth post-wildfire. The results from the analysis of vegetation recovery were then used in the interpretation of wildfire-effects on water yield. Previous studies in Australia have examined water yield response post-wildfire and have found that a decline in water yield occurs in the first 3-5 years followed by slow recovery (Langford 1976; Kuczera, 1987). However, these studies have been located in communities influenced by obligate seeders. This study, in comparison, is located in the outer Sydney Basin which is influenced by obligate resprouter species. The aim of this study is to determine the relationship between water yield and vegetation recovery following wildfire (in a resprouter dominated forest), and establish if water yield and vegetation recover within eight years post-wildfire.

Study area and methods

Study area

This study focuses on the Nattai River subcatchment which was burnt during the 2001/2002 summer wildfire event in the outer Sydney Basin, Australia (Fig. 1). A total of 57% (47740 ha) of the subcatchment was burnt.   Nattai River subcatchment delivers water to Sydney's main water reservoir, Lake Burragorang, which supplies 80% of the drinking water to the Sydney region.

The underlying geology of the region consists of Triassic sandstone plateau with Narrabeen mudstone embedded throughout. Tenosols, Kandosols and Kurosols are the dominant soils throughout the Nattai River subcatchment (Isbell, 2002). Dry sclerophyll forests and shrubby woodlands are dominant with moist sclerophyll forest and rainforest communities present within the valleys (Keith, 2006).

The study area has a warm temperate climate with an overall average minimum summer temperature of approximately 15°C and average maximum temperature of 28°C. Summer is generally more moist than winter. Mean annual rainfall across the study area ranges from 700 - 1400 mm per annum (BOM, 2010). Twelve months before the 2001/02 wildfire the study region experienced drought conditions, associated with El Niño- Southern Oscillation (ENSO).

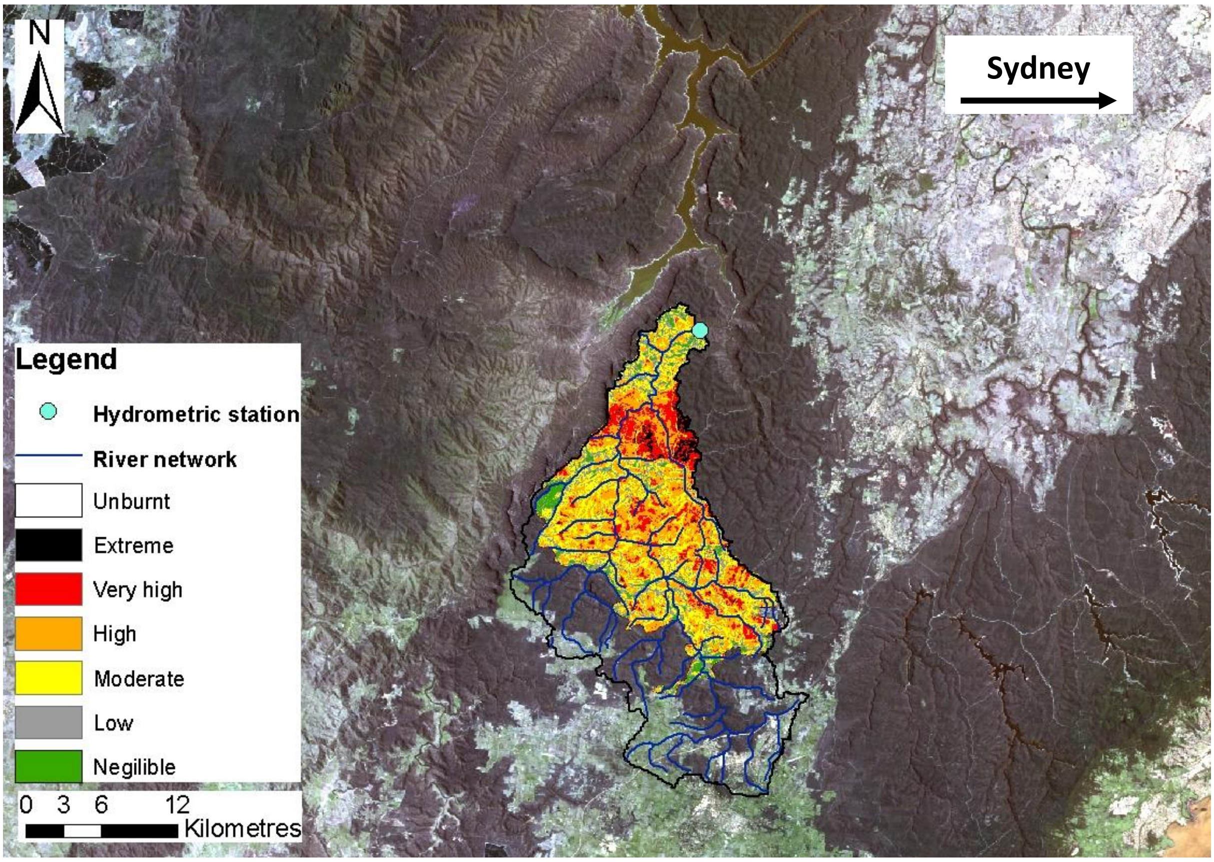

Figure 1. Nattai River subcatchment; This map also provides details on the location of the hydrometric station, river network and the different burn severity classes.

Vegetation analysis

Image processing

A wildfire severity map derived from differenced Normalised Difference Vegetation Index (dNDVI) was extracted from the work of Chafer et al (2004) (Figure 1). In order to assess the regrowth of vegetation following the summer 2001/2002 wildfire, one Landsat image for each summer between 1990/1991- 2009/2010 was obtained from either SCA or downloaded from Glovis (USGS, 2012). Spectral bands 1-5 and 7 were then stacked to form one composite image. Top of atmosphere (TOA) correction was used to create a spectral radiance. This involved a two step process.

The first step converted the digital Number (DNs) values to spectral radiance values through the use of bias and gain values for each of the Landsat scenes (equation 4):

$$L = \alpha D_n + \beta, \qquad (4)$$

where L = spectral radiance values, α is the gain and β is the recalled bias.

The second step converts the radiance to ToA reflectance (equation 5).

$$\rho_0 = \pi * L_0 * d^2 / E_0 * \cos \vartheta_z, \qquad (5)$$

where ρ_0 = Unitless plantary reflectance, L_0= spectral radiance, d = Earth-Sun distance in astronmoical units, E_0 = mean solar exoatmospheric irradiances and θ_z = solar zenith angle.

Each Landsat image was then reprojected to the correct spatial reference (GDA_1994 Mga zone 56) and clipped to a smaller area around the catchment to allow for faster processing.

Spectral indices

The Normalized Difference Vegetation Index (NDVI), the corrected Normalized Difference Vegetation Index (NDVIc) and the Normalized Burn Ratio (NBR) was calculated for each scene, as we believe these are more precises than other metrics for studying vegetation recovery.

The NDVI is the most common vegetation index used when assessing vegetation recovery post-wildfire as it is sensitive to fractional changes in vegetation cover. The NDVI is calculated by the reflectance of the red and near-infrared (IR) portions of the spectrum, which are characteristic of many common surfaces (Chen, 2011; equation 6).

$$NDVI = \frac{near\ IR - red}{near\ IR + red} \tag{6}$$

The NDVI values range from -1 to 1, with areas occupied with large vegetation canopies having higher positive values i.e. 0.75. The pixel values may be affected by the atmosphere causing a decrease in the NDVI values (Tachiiri, 2005). Therefore, NDVI can be estimated after the appropriate atmospheric correction takes place, causing the replacement of the NDVI values with NDVIc values (equation 7).

$$\mathrm{NDVI_c} = \frac{\mathrm{near\ IR - red}}{\mathrm{near\ IR + red}} * (1 - \frac{\mathrm{mIR - mIR_{min}}}{\mathrm{mIR_{max} - mIR_{min}}}) \tag{7}$$

where mIR refers to one of the middle-infrared bands (bands 5 or 7).

The NBR integrates the use of both near infrared (NIR) and mid-infrared (SWIR) (equation 8).

$$NBR = \frac{(NIR - SWIR)}{((NIR + SWIR))} \tag{8}$$

Similar to the NDVI/ NDVIc, NBR also has values ranging from -1 to 1.

Water yield

Data processing

In this study we used weekly discharge, rainfall and temperature data for the period January 1, 1991 to January 31, 2010. Data was excluded for the first year post-wildfire due to malfunctioning of the hydrometric station. The study therefore focused on the medium term impacts, using 10 years of pre-wildfire (1991-2001) and 7 years of post-wildfire data (2003-2010).

Hourly discharge data and rainfall data was acquired from Sydney Catchment Authority (SCA). Discharge was measured using a flow meter installed at the outlet of the subcatchment, whilst rainfall data was obtained from two rainfall gauges which were used to create a spatially weighted average of rainfall (Yoo et al., 2007). The maximum daily temperature was obtained from the Bureau of Meteorology (BOM, 2010). All data collected was aggregated into weekly total rainfall and water yield, and weekly average maximum temperature.

Modelling approach

In this section we are concerned with detecting a change in water yield. The modelling approach first involved calibrating a statistical model for the pre-wildfire period (January 31, 1991-December 16, 2001). A generalized additive model (GAM) was used in the Mixed GAM Computation Vehicle (mgcv) package in R (Wood, 2011). The model consists of four predictor variables including rainfall, maximum temperature, lagged water yield and lagged rainfall. The pre-wildfire water yield model was used to predict the post-wildfire water yield. Systematic differences in the residuals of the predicted and observed post-wildfire water yield could then be attributed to wildfire effects.

GAMs were preferred over other models due there greater flexibility when compared to standard parametric models such as the generalized linear model (GLM) (Hastie and Tibshirani, 1990) as GAM can model the non-linear relationships between rainfall and runoff. The most general form of the GAM is:

$$E(Y) = f(X_1,...,X_p) = s_0 + s_1(X_1) + ... + s_p(X_p)\,, \qquad (1)$$

where Y is a random response variable; X_1, ... , X_p is a set of predictor variables;and $s_i(X)$, i=1, ..., s_p are smooth functions.

A log normal model (Equation 2) using thin plate splines was used (Wood, 2003). The smoothing parameters were selected using restricted maximum likelihood (REML).

$$\log(y) = \beta_0 + \sum_{i=1}^{n} s_i(X_i) \qquad (2)$$

where s_i is the i^{th} thin plate smoothing spline, X_i is the i^{th} covariate.

Goodness-of- fit

The goodness-of-fit (GoF) of the pre- and post-wildfire model was tested by using the Nash-Sutcliffe coefficient (NSE) (Legates and McCabe Jr., 1999; Nash and Sutcliffe, 1970). The NSE is a normalized statistic which determines the relative magnitude of the residual variance compared to the measured data variance (Nash and Sutcliffe, 1970). Due to the sensitivity of NSE to outliers and the difficulty of modelling large flow events, the modified NSE (mNSE) was also used (Legates and McCabe Jr., 1999). The efficiency test values for both the NSE and mNSE range from $-\infty$ to 1. Efficiency test values of 1 (E=1) correspond to a perfect model, while an efficiency value of less than zero (E < 0) indicates the observed mean is a better predictor than the model (Krause et al., 2005).

Change detection

A number of indicators of change due to wildfire were considered. One method of detecting change used between pre- and post-wildfire periods was to plot the modelled predictions and observations for the post-wildfire period and look for deviations. The advantage of a statistical model is that the standard error of prediction can be used to create the 95% prediction interval (PI). If many of the observed data fall outside the PI range it would indicate there is a large difference between the observed and predicted water yield.

An alternative method is to plot a residual error model through time. A systematic pattern in the error plots would suggest a systematic change in water yield. Based on previous Victorian studies, it would be expected that a pattern may form to resemble that of the Kuczera curve, where by a sudden decline in water yield occurs post-wildfire and then begins to recover from about 25 years post-wildfire to pre-wildfire conditions (Kuczera, 1987). Modelled error showing a random scatter would indicate that wildfire had no impact on the post-wildfire water yield. A smooth spline was fitted to the error in order to aid in identifying whether there was a trend in the model error.

Results

Vegetation recovery

The reason for analysing vegetation response post-wildfire is to establish if the vegetation has recovered according to the regrowth of the vegetation canopy. Pre-wildfire data was required to determine the time frame it took for burnt vegetation to return near its pre-wildfire conditions. This study used Landsat imagery from the summer of 1990/1991 to the summer of 2009/2010. Three vegetation indices were implemented to assess the regrowth of vegetation in this period (NDVI, NDVIc, and NBR; Figure 2). The NDVI graph shows values in the pre-wildfire period ranging from 0.77 to 0.85% (Figure 2a). Once the 2001/2002 wildfire event took place, the NDVI declined to 0.64%. Within 6-12 months post-wildfire the NDVI graph suggests vegetation recovered rapidly with a NDVI of 0.71 %. After two years post-wildfire the vegetation had returned to pre-wildfire conditions with a NDVI of 0.81%.

The NDVIc and NBR have lower vegetation indices values during this period when compared to the NDVI values, and display a slightly different trend in the post-wildfire period (Figures 4b and 4c). Both NDVIc and NBR displayed vegetation indices above 0.4 % in the pre-wildfire period and increased to 0.49 % and 0.74 for NDVIc and NBR, respectively. Both indices show an obvious decline in vegetation for the 2001/2002 summer (with a value of 0.35% for NDVIc and 0.32% for NBR). Both indices indicate that it takes up to five years for vegetation to reach pre-wildfire levels.

Water yield

The key point of the water yield test was to determine if there was a change in subcatchment hydrology post-wildfire. The goodness of fit between the models was produced and observed values were investigated. In the case of Nattai River, the model was the better predictor over the mean of the observed data as the NSE value is > 0. Within the pre-wildfire period, Nattai River had a NSE value of 0.16 and a mNSE value of 0.41, whilst in the post-wildfire period there was less variation (NSE value of 0.40 and mNSE value of 0.35). Since the NSE and mNSE remained high in the post-wildfire period, there was no substantial change in the quality of the model predictions.

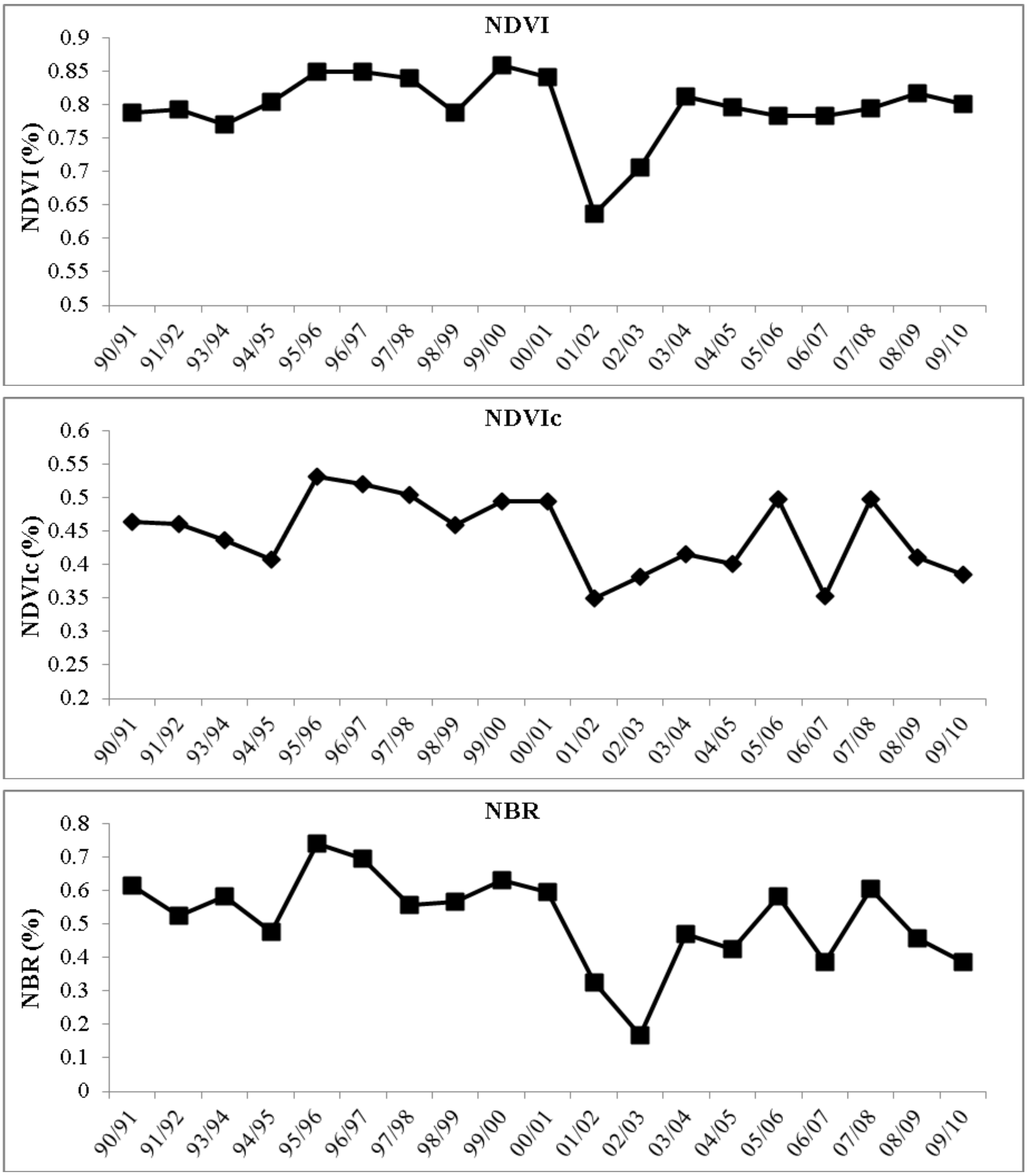

Figure 2. Vegetation growth from summer 1990/1991-2009/2010 using four different vegetation indices including a) NDVI; b) NDVIcand c) NBR.

The 95% prediction interval graphs were used to detect change in hydrology in the post-wildfire period (Fig. 3). In this case, the Nattai River showed some variation between the observed and predicted water yield in the 95% PI graphs. The median error value on the log scale for the Nattai River was -0.87, whilst the exponent of this was 0.42 meaning observed data matches predicted data was within 42% on average predictions, indicating water yield was generally over predicted. Variations between the two occurred primarily in dry years when flow flows occurred or the model predicted flow when the observed water yield was zero. For instance, in 2006, 21.6% of the data fell outside the lower 95% PI range. This is mainly due to zero flow being recorded as indicated by the flat observed line being situated below the lower 95% line.

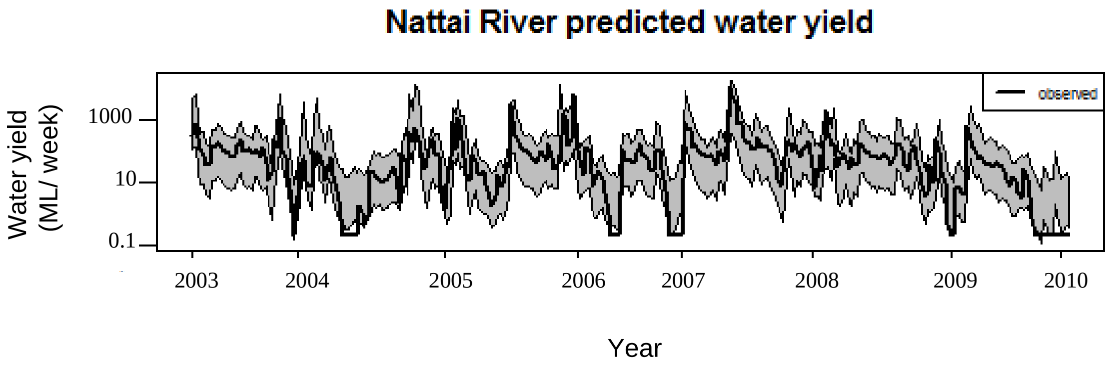

Figure 3. Nattai River 95% prediction interval for water yield post-wildfire

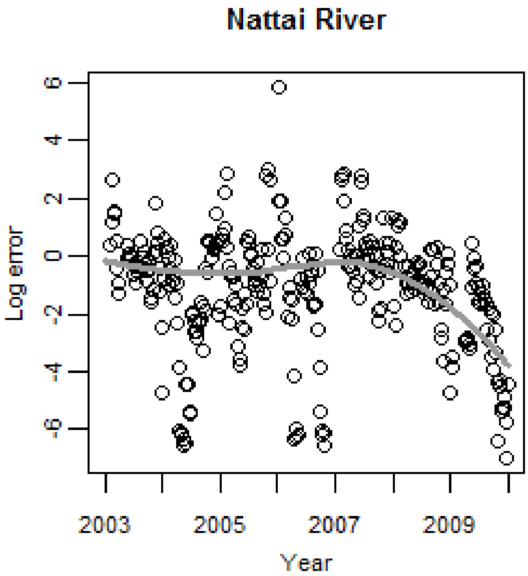

Figure 4. Nattai River error plot, displaying the overall trend in error post-wildfire.

In this instance, a small systematic shift in water yield data is seen to occur post-wildfire as the smooth line curve is less than zero on the log error axis (Fig.4). Such a shift could be a result of the model being parameterised for non-drought years, whilst the post-wildfire period underwent drought conditions due to the presence of El Nino. This would have caused a change in water yield and therefore a change in the smooth line. The smooth line is flat until the end of 2007, where it then begins to steeply decline. This decline suggests that the model is over predicting water yield and becomes higher the closer to 2010.

Discussion

Wildfire is evident throughout previous worldwide studies to have a detrimental effect on the different environmental values within a catchment (Certini, 2005; Wilkinson et al, 2006), through changes in soil chemical, physical and biological properties, change in water yield and destruction of vegetation. However, each of these values has only generally been studied individually, and the impact of wildfire on each value has only been investigated immediately post-wildfire (Doerr et al., 2004). In comparison, this study measured change vegetation regrowth post-wildfire through remotely sensed data and examined change in water yield post-wildfire, over an 18-year period to determine if both have a similar response to wildfire, hence have some form of a relationship.

The study developed a Generalized Additive Model (GAM) of water yield to predict the expected water yield of the burnt catchment during the post-wildfire period. The use of the GAM to examine the response of the Nattai River subcatchment has proven to be a practical method to use when forecasting a catchments normal water yield regime within eastern Australian. As water yield is constantly being influenced by external factors, limitations occurred when establishing a model. Villarini et al. (2009) found similar limitations in their GAM based model when attempting to predict high flow events in the Little Sugar Creek watershed located in North Carolina. In Nattai River, the water yield was could have been influenced by El Niño conditions in the post-wildfire period. This process would have continued until 2007 when El Nino conditions weakened, slowly being replaced by a La Nina event. Most of the error which occurred in model was due to extreme water yield values being predicted in response to high rainfall events. Therefore, as we are interested in the medium term changes in water yield, a NSE and mNSE value greater than 0.35 in the post-wildfire period displays a good fitted model.

The removal of vegetation within a catchment can have adverse impacts on water yield (Brown, 1972; Langford, 1976; Cornish and Vertessy, 2001). Bailey and Copeland (1961) show that with ground coverage of about 37%, 14% of rainfall contributes to runoff. With only 10% ground cover, 73% of rainfall contributes to runoff, suggesting that less ground cover causes an increase in water yield levels. According to the Kuczera curve (Kuczera, 1987), once vegetation re-growth begins, a decline in water yield should occur as immature vegetation requires a higher water intake. However, within the Nattai River there was no evidence of changes in water yield due to wildfire.

The changes in water yield which occurred post-wildfire could be strongly influenced by the quick recovery of the vegetation communities within the Nattai River subcatchment.

According to Chafter et al. (2004) and Chafer (2008) the initial shrub understory which contributes to ~80% of fuel within a eucalypt community (Chafer et al 2004, Chafer, 2008) would have rapidly regrown within months post-wildfire allowing for a short recovery period. This is evident in Figure 4a-c, as vegetation recovers to pre-wildfire levels within 2-5 years post-wildfire. The minimized impact on water yield is a result of the vegetation recovery method. The dominant species in this catchment are classed as obligate resprouters. These species rely on the growth of their vegetative buds, which resprout on the stem and branches of the plants within weeks to months post-wildfire, to recover. Such immediate regrowth means water is consumed by vegetation immediately post-wildfire, but not in significant amounts as mature vegetation only requires water for new leaf development. This is different to the studies conducted within the Melbourne water catchments as they are classed as obligate seeders and rely on the seedbank to produce new seedlings (Langford, 1976). This can take months to years for seedlings to occur as they rely on the right climatic conditions. Furthermore, as the seedlings grow they require more water than mature plants resulting in more water being taken out of the catchment for vegetation growth. This would cause a larger change in water yield to occur within the Melbourne catchments in comparison to the Sydney Basin water supply catchments.

A change in both water yield and vegetation took place by the 2007/2008 summer which is influenced by the change in climatic conditions as the transition from El Nino to La Nina conditions took 10 months arriving in early-mid spring 2007 (Hope and Watkins, 2007). By November, eastern Australia received above average total rainfall. La Nina event dominated summer 2007-2008, peaking in February 2008 (Wheeler, 2008). However, El Niño followed in winter 2009 but was only present until August 2009, leaving Australia with serious rainfall deficiencies (Jakob, 2010). This clearly had an impact on the Nattai River subatchment as water yield began to be overestimated in the GAM model due to its decline (especially at zero flow). This is evident in both the PI graph (Figure 3) and in the error plot as the smooth line drastically declines (Figure 4). This change in climate also impacted the catchment vegetation as all vegetation indices values declined for summers of 2008/2009 and 2009/2010. Therefore, such changes are not due to the wildfire event, but the environment responding to external climatic factors.

To further develop a better relationship between water yield and vegetation additional studies need to be conducted to compare other burnt catchments and unburnt catchments within the Sydney Basin to determine if a similar response is found. However, due to the limitations of the availability of Landsat data, statistical analysis to assess the relationship between water yield and vegetation is complicated. Therefore, another option could be to assess Moderate Resolution Imaging Spectroradiometer (MODIS) imagery over the same period as it is more readily available. From this possible statistical methods could be implemented to assess this relationship. Findings from such studies could provide environmental agencies and stakeholders with significant information about the response of catchments post-wildfire, which could help develop and plan future strategies in post-wildfire events.

Conclusion

In conclusion, the Nattai River subcatchment did not produce a smooth spline curve which had a similar trend to the Kuczera curve, suggesting it had very short recovery period. Further to this, the vegetation indices used in this study demonstrate that a significant degree of modifications within vegetation communities occurred immediately post-wildfire and was further exacerbated by the effects of El Niño. However, a steady increase in vegetation indices suggests a quick recovery of vegetation, achieving close to pre-wildfire values within 3-5 years. This in effect shows that the Sydney Basin water supply catchments obligate resprouter species have a much faster recovery time than the Melbourne water supply catchments obligate seeder species (Langford, 1976; Kuczera, 1987). Therefore, information provided from such a study can help catchment management agencies and stakeholders understand the response of a catchment after a wildfire event and help further develop new strategies for future wildfire events.

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Aurora: Enhancing the capabilities of Landgate's FireWatch with fire-spread simulation

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Abstract

Predicting probable fire spread is vital to the success of fire suppression and protection of lives and property. Fire authorities responsible for deploying resources gain a valuable advantage if they know in advance where the fire is likely to be by the time resources arrive. Researchers at the University of Western Australia (UWA) have developed software, called *Australis*, to simulate bushfire spread over the various fuel types found within Australia. The Western Australian Government's Statutory Authority Landgate has been detecting fire hotspots (FHSs) from the Moderate Resolution Imaging Spectroradiometer (MODIS), onboard the Terra and Aqua satellites, in near real-time for over 10 years using both US National Aeronautics and Space Administration (NASA) software and algorithms developed in-house. *Aurora*, a new web based system developed by Landgate in partnership with UWA and the Western Australian Government's Department of Fire and Emergency Services (DFES), uses these satellite-derived FHSs as ignition points for the UWA simulator. Other variables are also used including real-time gridded weather forecast data and gridded drought-factor data from the Australian Bureau of Meteorology (BoM). This allows simulations of up to 24 hours to be activated automatically each time a set of FHSs from MODIS are detected. The output from each simulation is sent to the Aurora website. This secure website allows fire controllers to overlay the bushfire spread simulations on other Geographical Information System (GIS) datasets to determine what infrastructure is threatened and what access is available to enable suppression of the fire. Armed with this valuable information, a fire controller can then deploy resources with maximum efficiency. The fire controller is also able to run simulations using a combination of his/her own information (including firebreaks) and pre-existing data. This allows the testing of various ignition points and weather conditions in order to determine the best days for carrying out prescribed burns or to run a series of scenarios quickly to optimise fire-suppression outcomes.

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Introduction

One of the advantages of fire is that it helps to stimulate new vegetation growth. Even though the processes contributing to fire spread are not completely understood, there are relationships between the observable elements affecting fire behaviour that can be used to predict fire spread. These relationships, or fire-spread models, have been constantly improved upon since the mid 1940s (Pastor *et al.* 2003). Fire-spread modelling has gone from paper-based calculations to cardboard wheel meters and hand-held calculators in the 1970s and then personal computers (PC) in the 1980s. With the growth in popularity of Geographical Information Systems (GISs) and advances in computing power visualisation of the output of fire-spread modelling has become easier. There are now many PC-based software systems that allow the simulation of fire spread over time, including some that have been designed for Australian conditions (Pastor *et al*. 2003). These systems all require the user to manage the underlying datasets needed to run a fire-spread simulation. For those users who are unfamiliar with GIS this can make their use of such systems more difficult and time consuming and become a point of resistance. Having a web-based fire-spread simulator with preprocessed spatial data can remove some of these problems.

Background

The University of Western Australia (UWA) designed fire-spread simulator *Australis* uses a cell-based approach with an underlying irregular grid. The irregular grid approach minimises the distortion of fire shape as the direction to the immediate neighbouring cells of a given cell are different from those of any other cell. It also uses an efficient discrete-event simulation methodology to propagate the fire over the landscape. The advantage of this technique is that the computational time is proportional to the number of cells that are ignited (Johnston *et al.* 2008). The Australis simulator has been written in Java so that it is portable across operating systems.

Landgate's FireWatch system was developed during the mid 1990s to assist in the management of bushfires occurring in Australia. Originally it only used data from the Advanced Very High Resolution Radiometer (AVHRR) on the US National Oceanic and Atmospheric Administration (NOAA) polar orbiting satellites (Smith *et al*. 1998). However, in late 2001, the Western Australian Satellite Technology and Applications Consortium (WASTAC) installed an X-band satellite receiver at Murdoch University, Perth, in order to receive Moderate Resolution Imaging Spectroradiometer (MODIS) data (Pearce *et al*. 2005). Landgate has been detecting fire hotspots (FHSs) from the MODIS sensor in near real-time using US National Aeronautics and Space Administration (NASA) software and also algorithms that were developed at Landgate optimised for Australian conditions.

Funding from the Australian Government's Department of Broadband, Communications and the Digital Economy, through the Digital Regions Initiative (DRI), has enabled Landgate, UWA and the Western Australian Government's Department of Fire and Emergency Services (DFES) to work together and develop a web based system using the Australis simulator.

Design

Landgate has designed a complete fire-simulation system, called *Aurora*, consisting of web, map, database and backend processing servers, all using open-source software or software developed as part of the DRI project. On the backend processing server, two processing streams have been developed that use the Australis fire-spread simulator as their engine.

The first stream (called MODIS FHS simulations) uses the FHSs detected from each MODIS pass as ignition points for the simulator. MODIS passes received in Perth are processed as well as passes sent from the X-band satellite receivers in Alice Springs and Townsville. This gives complete coverage of Australia at least twice a day. The time taken from the start of receiving a MODIS pass to the time at which the output simulation appears on the website is about 45 minutes for a pass received in Perth. This extends out to 87 minutes for passes from Townsville and 3 hours for passes from Alice Springs. This is a function of the different processing at the X-band satellite receivers, internet speeds and polling of File Transfer Protocol (FTP) sites. The output from each simulation is sent to the Aurora website with the ignition time set to the start time of the MODIS pass. In some cases the same pass will be received at two or more different stations and the start time will either be the same or within a few minutes. The advantage of having multiple stations receiving the same pass is that a loss of data at one station may be covered by another station. Currently these MODIS FHS simulations are predicted out to 24 hours.

The second stream (called user-defined simulations) allows the fire controller to run simulations using a combination of his/her own information and pre-existing spatial data and fire-behaviour models. This allows the testing of various ignition points, firebreaks and weather conditions in order to determine the best time for carrying out prescribed burns or to run a series of scenarios in order to optimise fire-suppression outcomes for a current fire event.

For use in an operational scenario, Landgate has also designed a PC version that uses Environmental Systems Research Institute's (ESRI's) *ArcGIS* software as its base platform. The main advantage this version has over the web based version is that the user can use his/her own data (and possibly create higher-resolution simulations). This use of the PC version of the simulator is probably more suited to a fire agency's operations centre responsible for a live fire event.

Inputs

Static Datasets

Several static datasets are required to run the simulator. All of these input datasets must be converted to Albers Equal Area Conic Projection (Kelso and Mellor 2012). As Australia is a mid-latitude country and extends predominantly east-west, this type of map projection is ideal for equal-area mapping (Snyder 1987). To define the landscape a set of tiles, with each tile containing points, is generated. This set of irregular points is generated using a Poisson disk distribution. An approximation of the Voronoi diagram and Delaunay triangulation is then calculated to determine the polygon boundaries and neighbours of each cell (Johnston *et al.* 2008). The point spacing and size of the tiles is arbitrary, but ideally a single tile should be at least big enough to cover the area of a large fire. For the MODIS FHS simulations, a point spacing of 1 km with tiles sizes of 100 km is used. As the MODIS FHSs are derived from the 1-km resolution bands and have a spatial error in the order of ±1.5 km, using a point spacing less than 1 km would result in a locational fallacy. For the user-defined simulations, a point spacing of 250 m with tiles sizes of 25 km is used. This represents a trade-off between the processing time taken to generate a simulation for fires under extreme weather conditions and the visual aesthetic of the resulting fire-simulation spread.

Once the tiles have been generated, they are spatially intersected with three different datasets. The first intersection is with a resampled version of the 1-second (30-m) smoothed digital elevation model (DEM–S) derived from the Shuttle Radar Topographic Mission (SRTM) data. This DEM has undergone several processes in order to remove noise and its vertical accuracy is approximately 5 m (Geoscience Australia and CSIRO Land & Water 2010). The second intersection is with the Major Vegetation Subgroups (MVS) dataset taken from the National Vegetation Information System (NVIS). This dataset contains 67 groups that represent the dominant vegetation occurring in each 100 m x 100 m cell across Australia (ESCAVI 2003). The third intersection is with the Time Of Last Burn (TOLB) dataset generated from the NOAA-AVHRR derived fire scar maps. Landgate has mapped fire scars every nine days at 1-km resolution from the NOAA satellites going back to January 1989. At the end of each calendar month, the most recent nine-day datasets are added to the TOLB dataset. To keep the two sets of tiles (250 m and 1 km) current, the intersection with the TOLB dataset occurs within one hour of it being updated.

A vegetation mapping file is used to map the vegetation codes in the NVIS MVS dataset to a set of fire spread and fuel accumulation models. There are currently 30 different fire-spread models that can be used within the simulator. These include the McArthur forest and grassland meters and models developed as part of Project Vesta (Gould *et al.* 2007). Some models employed for shrublands and mallee-heath use the TOLB to determine the fuel load (Kelso and Mellor 2011).

Dynamic Datasets

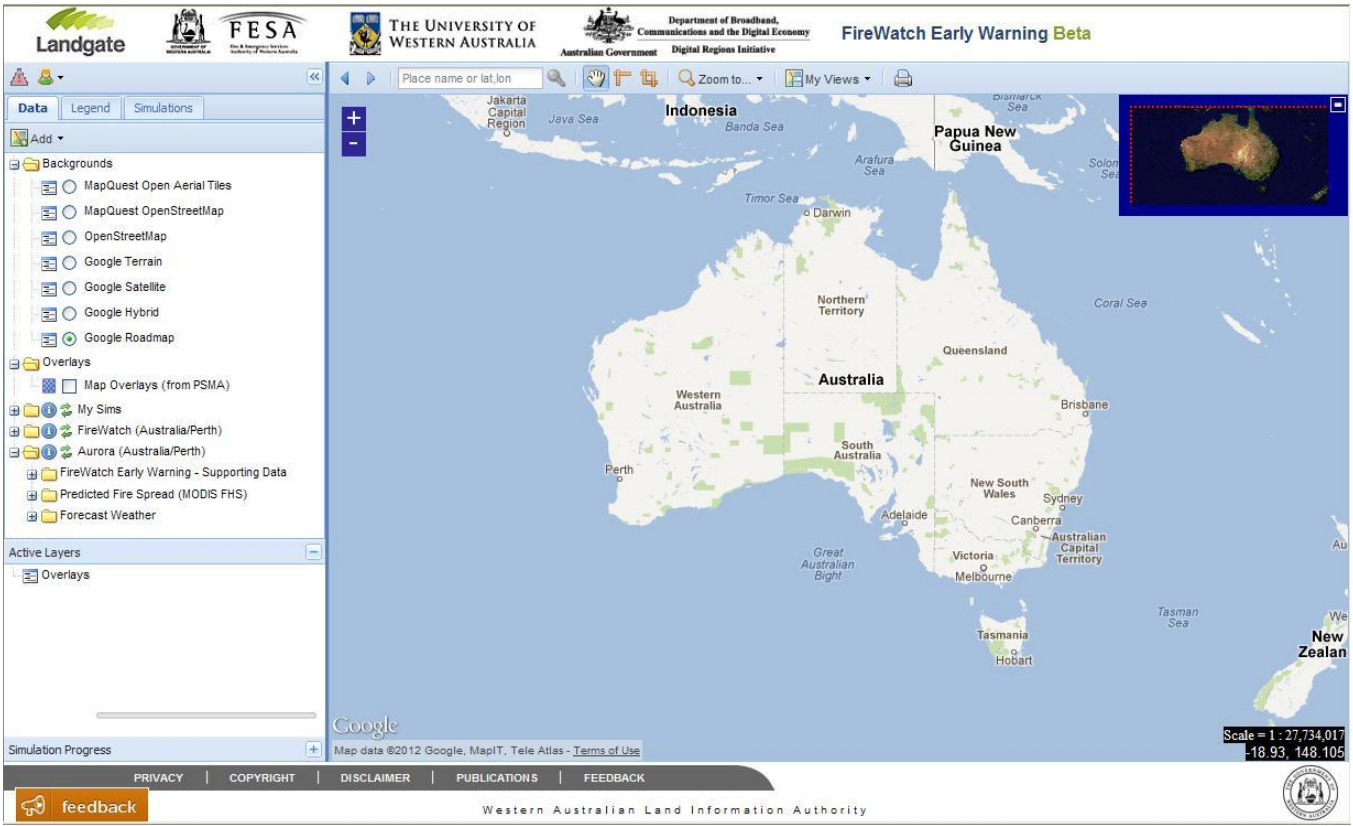
There are currently two dynamic datasets that help propagate the state of the whole fire system being simulated. The first is the gridded weather forecast from the Bureau of Meteorology. This dataset is created using the Australian Community Climate and Earth-System Simulator (ACCESS) Numerical Weather Prediction (NWP) systems and is supplied in NetCDF format with hourly forecasts up to 48 hours into the future. Each hourly forecast has a set of weather attributes for each 0.11°×0.11° cell across Australia. These files are created four times per day and the last file is usually available within three hours of the base times (00:00, 06:00, 12:00 and 18:00 UTC) (NMOC Operations Bulletins 2010). The screen-level air temperature, relative humidity and wind vectors at a height of 10 m are extracted from each forecast file and written to a comma-separated variable file (CSV) based on the latitude and longitude.

The second dataset is the drought factor (DF) using the Keetch-Byram Drought Index (KBDI). This dataset is generated on a daily basis for each 0.25°×0.25° cell across Australia. The KBDI DF is converted to a CSV file based on the latitude and longitude. It is used in the McArthur forest and grass meters to modify the rate of spread based on fuel moisture (Kelso and Mellor 2012).

Operation

To be granted access to use the Aurora website (http://aurora.landgate.wa.gov.au), a user needs to firstly lodge a web request to create an account which then has to be approved by DFES. If the user has been approved, an email is sent stating that access has been approved. After logging in, the default screen view (Fig. 1) has:

1. Three tabs at the top left:
   a) Data – the list of all layers that are available;
   b) Legend - a legend for each layer that can be classified in some form; and
   c) Simulations – a series of panels that enable a user to run customised fire-spread simulations.
2. Two expandable layers at the bottom left:
   a) Active Layers – the list of all layers that are turned on; and
   b) Simulation Progress – the status table for active user simulation.



3. A map window on right-hand side with tools along the top.

The "Simulations" tab is used to run a customised simulation. There are six panels of information that can be populated:

1. Duration
2. Ignition Sources
3. Fuel Load Adjustments & Firebreaks
4. Weather
5. Annotations
6. Run Simulation

The "Duration" panel allows the user to enter the start date, time and duration of the fire-spread simulation. The "Ignition Sources" panel allows the user to enter either a set of ignition points and/or a set of ignition lines. At least one ignition source must be entered and each one can have a different time and date as long as it fits within the duration of the simulation. The "Fuel Load Adjustments & Firebreaks" panel allows the user to draw a polygon and assign a fuel load for that polygon. This is useful for when a simulation is being run on a live fire and part of the landscape has already been burnt and mapped. This can be entered so that the simulation does not burn over parts of the landscape that have already been burnt. This panel also allows the user to place a polyline representing a firebreak. The

Figure 6. Default view of Aurora website after login.

"Weather" panel has a default setting which uses the gridded weather forecast. However, the user can also enter his/her weather information. This is useful if the user has access to an automatic weather station close to the fire or has been provided with a spot fire- weather forecast. If the user-provided information does not extend to the full duration of the simulation the weather forecast is used to fill any gaps. The "Annotations" panel allows the user to mark points of interest on the landscape. If the fire spread reaches that point the ignition time is added to the list of attributes for that point of interest. The "Run Simulations" panel allows the user to enter a name for the simulation and any notes that need to be attached to the simulation. The user can then click on the submit button and the "Simulation Progress" layer at the bottom left of the screen is activated. This table is updated with a green tick when each of the five steps; submitted, pre-processing, running, post-processing and complete is successful. These five steps are carried out on the backend processing server using the user defined simulations stream. All fire spread points generated are added to a *PostGIS* database on the database server.

If an error occurs during one of the five steps, a red cross appears in the table and an error message window will appear. This error message can then be submitted using the "Feedback" icon at the very bottom left of the screen. A simple simulation, using a few ignition sources and benign weather conditions, can run in less than 10 seconds. More complex simulations, with extreme weather conditions, may run for more than two minutes.

The new simulation will appear in a folder with the same date as the simulation start date under the folder called "My Sims". This layer can be turned on and will appear in the map window as a series of coloured points with each colour representing the hour at which the point was ignited. An attribute table can be activated by clicking on any point.

Improvements

There are several improvements to the Aurora website and Australis simulator that are currently being implemented or planned for the near future.

Currently, the simulator does not incorporate any form of road network. This means that roads do not act as barriers to the spread of the fire. However, for the user-defined simulations, firebreaks can be added that mimic the barrier that a road provides for the fire spread.

Even though there are 30 fire-spread models within the Australis simulator less than a quarter of these are currently used. Expert knowledge has been used to map the various vegetation codes for Western Australia, used in NVIS, to the most appropriate fire spread and accumulation models. This same level of expert knowledge needs to be applied to the other states of Australia.

A point spacing of 250 m is used for the user-defined simulations. With the DEM and NVIS datasets having cell resolutions substantially better than this, there is the possibility of using a point spacing of 100 m. The trade off is that the Australis simulator will have to calculate the fire spread across 6.25 times as many points which may increase the time taken to process a simulation. Likewise the map server has to read 6.25 times the number of points from the PostGIS database, which may increase the time taken to display large fire-spread simulations.

The TOLB dataset currently only uses NOAA-AVHRR data. The burnt area from which the TOLB is derived is manually digitised, and only burnt areas larger than 4 km^2 are mapped (Marsden *et al*. 2001). However, burnt areas mapped from higher-resolution satellite data, such as Landsat, could be easily incorporated. Fire agencies may have their own burnt-area mapping taken from aerial photography. Combining these types of datasets would produce a more accurate picture of the burnt area and thus produce more accurate fire-spread simulations.

Even though the website looks easy to use there are many underlying concepts that need to be understood to make the best possible use of the fire-spread simulator. Short training courses are currently being run with operational staff from DFES. As a result of these training courses, a training manual is currently being developed.

Conclusion

The Aurora website is an extension of the present capabilities of Landgate's FireWatch website to include fire-spread simulation. Aurora can help fire controllers quickly test various ignition points and weather conditions in order to determine the best days for carrying out prescribed burns or to run a series of scenarios to optimise fire-suppression outcomes for a live fire event. With this web-based system the user does not have to concern himself/herself with the management of the underlying datasets needed to run a fire-spread simulation. It can be run without the need for any software other than an up-to-date web browser. There is also no need for expensive hardware or a high-speed network. This means that Aurora can be used to benefit fire management in regional and remote areas where internet connectivity is often limited but is being upgraded under the Australian Government's National Broadband Network (NBN) program. The provision of improved emergency services to regional and remote areas, using new communications infrastructure, of the kind described in this paper, is a key objective of the Digital Regions Initiative through which this work has been funded.

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The hydrogeomorphic sensitivity of forested water catchments to wildfire

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Abstract

Wildfires are a strong driver of change in many landscapes (e.g. south-eastern Australia, western USA, Canada, and the Mediterranean). Vegetation removal and changes to soil properties by wildfire result in altered surface hydrology and erosion rates. When wildfire occurs in a water catchment these changes can cause negative impacts on water quality, supply, and treatment. Therefore, being able to predict the potential response of a landscape to wildfire is important in informing resource management decisions.

This research project investigates erosional response of catchments following the 2009 fires in Victoria. This paper details methods and results of preliminary work undertaken on this project. Field surveys were used to quantify error associated with remote identification of channel initiation points (CIP) from aerial photographs. Movement in the CIP is one way of measuring erosional response and post-fire sensitivity. Error in estimating the CIP was found to depend on vegetation cover. The average distance errors for increasingly denser vegetated classes (0-24%, 25-49% and 50-100%) were 23.0m ± 5.5m, 11.1m ± 1.9m and 23.2m ± 4.8m.

A difference in the morphology (area and slope) between catchments exposed to high and low annual average radiation was found. Catchments exposed to higher radiation were found to have, on average, steeper slopes and smaller catchments (16.2° and 16150m^2) compared with lower radiation sites (9.6° and 39015m^2).

The wider research project will explore the link between dryness (radiation), morphology and post-fire response in future work. These future project outcomes and benefits to resource managers are discussed.

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Introduction

Wildfire within a catchment can result in severe downstream impacts on soil and water resources, infrastructure, and lives (Nyman et al., 2011; Emelko et al., 2011). Altered hydrological flow and erosion rates occurring after wildfire (Shakesby and Doerr, 2006) pose a risk through large sediment inputs into water courses and flooding (Emelko et al., 2011). These hydrogeomorphic changes can vary depending on the landscape properties, burn severity and rainfall following the fire (Shakesby and Doerr, 2006).

A number of large wildfires over the last decade have prompted increased focus on wildfire and forest management, emerging from this, one area of concern is the effects of wildfire on water quality (Ellis et al., 2004; Parliment of Victoria, 2008; Victorian Bushfires Royal Commission, 2009).This issue is particularly pertinent in south-eastern Australia, where a large proportion of the water supply comes from forested catchments or surface water sources (Marsden and Pickering, 2006). Post-fire erosion events increase the amount of suspended sediment in streams and may hinder or prohibit water treatment (Smith et al., 2011a).

Potential hydrological and erosional response to wildfire is difficult to predict as not all landscapes react in the same way or to the same degree. A review of the literature reveals the hydrogeomorphic changes after wildfire in south-eastern Australian landscapes can be highly variable (Prosser and Williams, 1998; Lane et al., 2006; Sheridan et al., 2007; Smith and Dragovich, 2008; Smith et al., 2011a; Nyman et al., 2011). Thus, some landscapes appear more sensitive to wildfire.

There is a need to quantify the potential response of landscapes in order to provide information to resource managers. The risk of post-fire impacts is an important consideration for management in planning risk mitigation activities. It is also an important consideration for incident controllers. For example, resource coordinators need to weigh risks and benefits of protecting particular assets (like water supply catchments) when determining where to place resources during an operation. Thus, knowing the consequences of a particular catchment being burnt is very important.

Differences among landscape responses are dependent on the properties of the landscape that enable it to resist, adapt to, or bounce back from change (Phillips, 2009). Through investigating the cause of an observed wildfire response we can gain greater understanding of the relationship between landscape properties and hydrogeomorphic sensitivity. With this information the research can also be used to begin to predict the potential response of other landscapes.

This project aims to increase understanding of the relationship between landscape properties and post-fire hydrogeomorphic processes. The project will quantify post-fire erosional response (indicative of hydrogeomorphic processes) of two burnt areas and connect these data to catchment properties. Results will identify properties which cause the sensitivity of a given landscape to wildfire.

Measuring Sensitivity

Hydrogeomorphic sensitivity can be measured by investigating the degree of change in water flow and erosion processes following wildfire. These processes require a certain threshold of energy input to be reached before initiation. Due to changes in vegetation and soil after wildfire, erosion processes can be initiated with less rainfall energy input, thus, the thresholds are lowered by wildfire (Prosser and Williams, 1998). The observed magnitude of hydrogeomorphic response will therefore provide information on the lowering of process thresholds and sensitivity. Some visible signs of erosion include movement in the position of channels, scouring of channels and sediment deposits.

The initiation point of a channel at the head of a catchment shifts after wildfire as the threshold for sediment movement changes (Montgomery and Dietrich, 1992). Channel initiation points (CIP) occur where there is sufficient overland flow to cause erosion and channelization (Montgomery and Dietrich, 1992). CIP are dependent on the relationship between the catchment area above that point and the hill slope (Montgomery and Dietrich, 1994). The topographic threshold between channelled and unchannelled parts of the landscape marks a change in erosional processes from diffuse to more active sediment transport (Montgomery and Dietrich, 1994). Therefore, CIP may provide information about energy and process change after wildfire. After wildfire, the threshold for channelization is lowered causing channels to form higher in the catchment. The greater the change in the location of the initial point of a channel, the greater the shift in thresholds, and hence the greater the sensitivity.

In addition to fluvial erosion along channels, runoff generated post-fire debris flows may develop along drainage lines and scour a channel. The occurrence of debris flows in some Australian forests appears to be controlled by wildfire (Nyman et al., 2011). Debris flows can deliver a large amount of sediment to waterways and pose a serious threat to water quality (Smith et al., 2011b). The most commonly observed debris flows following wildfire are generated by runoff (Nyman et al., 2011) and develop due to a feedback process called ‘progressive sediment bulking’ (Cannon et al., 2003).

Research into the initiation and occurrence of post-fire debris flows in Australia is limited. By investigating the initiation point of channels which produce debris flows and channels which do not, features which make a particular area susceptible or sensitive to this process after wildfire can be determined. Channels in non-debris flow areas tend to begin lower down in the system due to lower energy (i.e. less overland flow) following wildfire. In systems that experience debris flows, it is hypothesised there should be some clear differences in terms of slope-area threshold for initiation.

Study site and methods

The sensitivity of post-fire hydrogeomorphic processes was investigated in the Kilmore-Murrindindi and Beechworth fire complexes (Figure 1). These areas in central and northeast Victoria were burnt in February 2009. The wildfire and subsequent rainstorms resulted in widespread erosion and debris flow activity in forested water catchments.

These wildfires burnt over 300 000 ha, providing study catchments with a wide variety of forest types, geologic background and soil types. The study area is part of the central uplands formation, located between 200 and 800 meters above sea level. Geology largely consists of sedimentary rocks (mudstone, sandstone and conglomerates) overlying a metamorphic gneisses and schist bedrock. (Jenkins, 1991).Vegetation is mixed eucalypt forest, mainly consisting of peppermint species (*E. dives*); and gums (*E. globulus, E. cypellocarpa, E. viminales*) with an understory of Acacia, shrubs, and bracken.

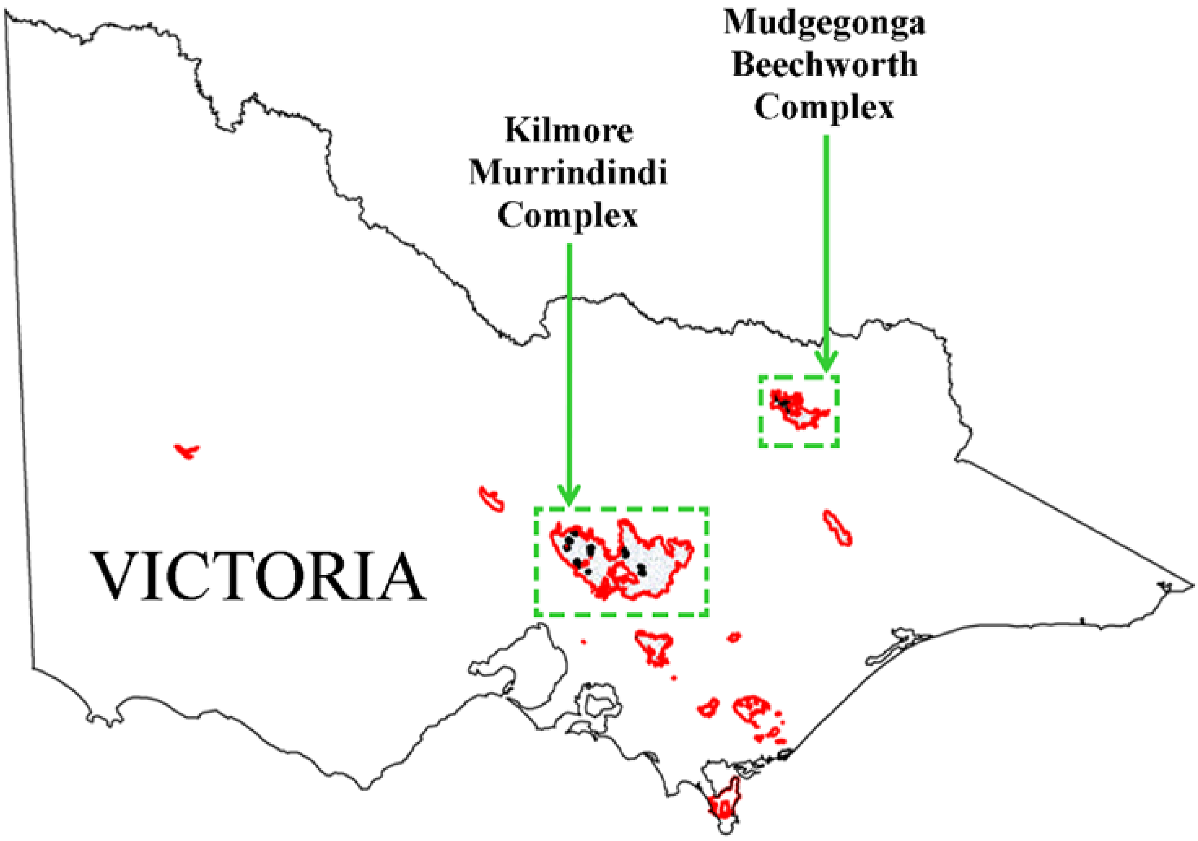

Figure 1: Approximate location and extent of Kilmore-Murrindindi and Beechworth fires in Victoria in February 2009.

Two aerial photos datasets will be used to investigate the magnitude of erosion following these wildfires. The first set, taken approximately 2 weeks after the fire, will be compared with photos taken approximately 10 months after the fire. As no rainfall occurred immediately post-fire, the first set shows a 'before' picture of the landscape (i.e. after fire, but before surface erosion processes). An 'after' picture is provided by the second set.

The photos will be used to identify movement in channel initiation points (CIP) and location of debris flow producing channels. This method of using aerial images for quantifying shifts in CIP after wildfire has not been previously reported in the literature.

Identifying channel initiation points

A set of rules were developed for identifying channel initiation points (CIP) in the aerial photographs (AP) and then tested for accuracy through a field investigation. A summary of

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the AP and field identification rules are given in Table 1. A selection of forested catchments within the burnt area, previously identified as having post-fire erosion by the Forest and Water Group of The University of Melbourne, were chosen for a preliminary study. All CIP within these areas were identified on AP, using the identification rules.

A field investigation was then carried out to quantify error associated with the AP identification method. CIP were identified in the field using the rules in Table 1. These rules were again based on channel literature, experience in the field and with the aerial photos. It was important that CIP could be identified on AP and in the field. Points in the field were recorded using a hand-held Sokkia GPS unit and transferred to ArcGIS 10 for further processing.

Aerial photo identification	**Field identification**
1:800 scale is used	The channel generally occurs at the lowest point between two hillslopes
The channel is a single, linear feature that extends more or less uninterrupted until its confluence with a creek or river	CIP is the starting point of an incision that has a minimum depth of 20 cm
Channels show lighter than their environment, except for shadows projected by the banks	The incision will clearly be an area where concentrated water flow occurs, with evidence of erosion
From the drainage divide, follow the channel until the first position it meets these criteria for at least 5 m	From the drainage divide, follow the channel until the first position it meets these criteria for at least 5 m
A debris deposition is not a CIP	
Upstream of a fork, each branch is treated as a separate feature that has to qualify the above criteria to identify as a channel	

Table 1: Summary of AP and field rules for identification of CIP.

ArcGIS analysis

CIP identified in the field and using AP were compared in ArcGIS 10. Sokkia Spectrum Survey software imported GPS data directly from the GPS unit. The AP consisted of three-band true colour 7 cm resolution TIFF-files.

ArcGIS tool Near (Spatial Analyst) was used to calculate the distance between the CIP identified in the AP and the CIP identified in the field. Contributing catchment areas above the CIP were delineated by hand, using the DEM (20m) contour lines and AP as a guide. The error between the AP and the field identified catchments was then calculated for each channel. Within the catchment areas mean slope, aspect, and average annual radiation was also calculated using the ArcGIS 10 tools (Slope (Spatial Analyst), Aspect (Spatial Analyst), Area Solar Radiation (Spatial Analyst) and Zonal Statistics (Spatial Analyst)).

The fractional vegetation cover around the CIP was estimated by placing a 40x15 m rectangle above and below the CIP identified on AP. Vegetation cover within the rectangle was estimated into three categories of cover; 0-24%, 25-49%, and 50-100%. An independent t-test was performed to test whether vegetation cover had a significant difference on the mean distance error.

For analysis of catchment morphology, catchments were grouped into North (315° to 45°) and South (135° to 225°) aspect groups. An independent t-test was used to determine if there was a significant difference in mean catchment slope and area between these groups.

Future methods

This preliminary study aimed to quantify the error associated with identifying the CIP from AP. The intent is to use this method to analyse a large number of catchments across the 2009 fire area as part of the wider research project. A second method for the identification of debris flow producing channels will also be developed and tested.

An automated GIS script will then be written to automatically identify catchment areas and associated properties. GIS layers containing information on vegetation, soil, geology, rainfall, and burn severity will provide variables which are important in post-fire erosion response. Collection of data through remote sensing is considerably less resource intensive and time consuming than other methods and presents a way to collect data efficiently.

This data will be used to create a logistic or multiple regression model (depending on the variables used) to predict erosion response following wildfire. Post-fire studies to date suggest that some components of a landscape are more sensitive to wildfire than others and may therefore contribute more to overall landscape response (Shakesby et al., 2007). This model will be used to test the contribution of various components of the landscape to the post-fire erosion response. This knowledge will contribute to our understanding of what causes different responses.

Results and discussion

Channel initiation point identification

The comparison of 56 CIPs identified on AP and in the field showed an average error of 20.1m in distance along the channel, a median error of 10.0m, and a standard deviation of 23.0m.

This error was found to differ according to the percentage of vegetation cover immediately surrounding the CIP. As shown in Figure 2, the average distance errors in meters for increasingly denser vegetated classes (0-24%, 25-49%, and 50-100%) are 23.0 ± 5.5 (n = 5), 11.1 ± 1.9 (n = 20), and 23.2 ± 4.8 (n = 31). Independent t-test results show that the differences between these classes are statistically significant (class 1 and 2 p = 0.0471, class 2 and 3 p = 0.0248).

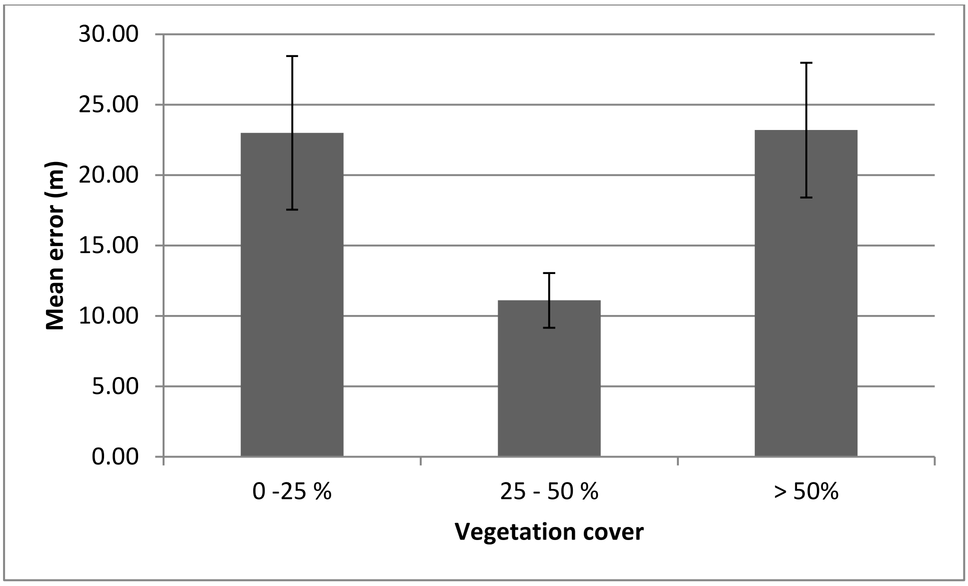

Figure 2: Average error associated with vegetation cover.

A difference in error between vegetation classes was expected as the method used was based on visual identification. Results indicate the lowest error in CIP identification occurs in the moderately vegetated channels. This suggests that some vegetation is helpful in identifying the channel incision. It appears a high amount of vegetation obscures the view of the channel, both with physical plants and shadows. A low amount of vegetation seems to allow observation of too greater detail and results in rills being mistaken for channels. A moderate amount of vegetation seems to cover the rills and the flatter area above the channel, making the CIP more obvious.

Part of the error could also be due to CIP movement in the time between the AP being taken (2009) and the field work (2012). However, any movement would likely be negligible. The AP were taken 10 months after the wildfire and as major winter storms occurred during this period it is likely all post-fire CIP movement occurred during this time. Prosser and Soufi (1998) found that channel movement stabilised after 1 year following clearing of eucalypt forest for conversion to pine plantation, and that channels were generally stable under forested conditions.

Morphology and dryness

Preliminary field investigations suggest that dryness, a measure of radiation and precipitation balance (Budyko, 1958), may be an important variable in predicting the sensitivity of landscapes to post –fire hydrogeomorphic changes. When contributing catchment size and slope are considered for north facing (higher radiation) and south facing (lower radiation) catchments a clear difference can be seen. Figure 3 illustrates this considerable difference in the morphology of headwaters with different radiation inputs or dryness. Drier channels with high radiation are characterised by smaller, steeper contributing catchments than wetter ones with low radiation. Table 2 gives a summary of average slope and catchment size by aspect, along with t-test results.

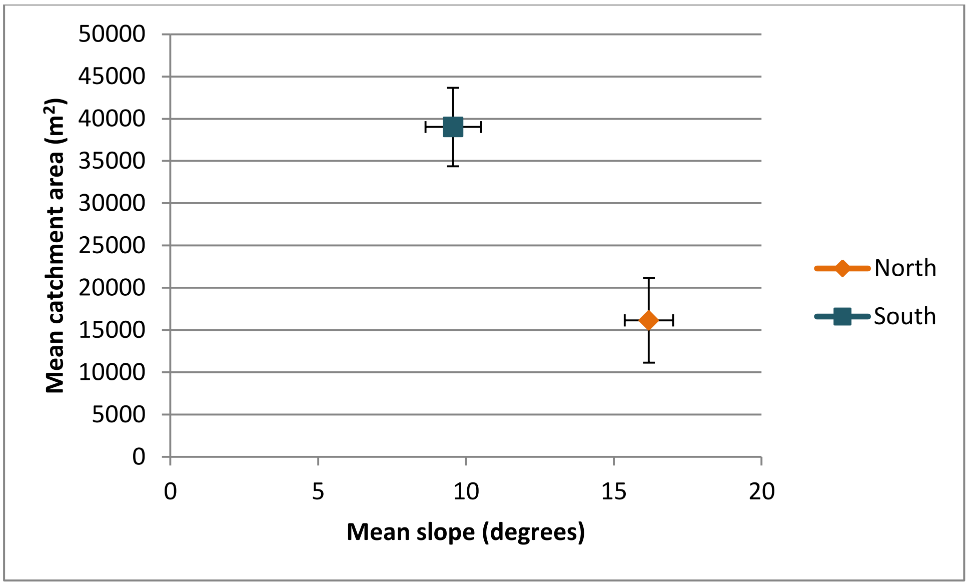

Figure 3: Catchment area and slope contributing to channels in high and low radiation catchments.

	Solar radiation (kWh/m^2)	Slope (degrees)	Area (m^2)
North	1608.49	16.18	16149.77
South	1441.20	9.56	39015.53
Significance (2 tailed)	*0.000*	*0.000*	*0.002*

Table 2: Average annual solar radiation (kWh/m^2), slope (degrees), catchment area (m^2) and t-test results (p values) for north and south aspect catchments. n=45.

Drier headwater catchments generally have poorly developed soils that are more likely to generate runoff and erosion, resulting in steeper slopes and channel heads that extend further upslope than sites with more structured and permeable soils (Wittenberg et al., 2007). If this research project can link a measure of dryness to post-fire hydrogeomorphic sensitivity, land and fire managers can use this to better predict potential post-fire risks associated with erosion.

Conclusion

The identification of potentially sensitive or high risk catchment areas is essential for decision making about resources and land management. This research project will investigate the relationship between landscape properties and post-fire response, to increase our knowledge of the causes of sensitivity. The project has progressed through the development stage and is now entering a phase of intensive data collection. Data collection, analysis, and modelling are expected to continue for the next 12-18 months.

Preliminary results suggest channel initiation points can be identified from aerial photography, with some margin of error. This error is lowest when vegetation cover is moderate (25-50%). An examination of catchment morphology (slope and size) reveals differences between catchments exposed to lower and higher long term radiation. These results suggest a measure of radiation-precipitation balance (dryness) could be important in determining catchment morphology and consequently post-fire sensitivity.

Findings of the project will be adapted into a format suitable for use by resource managers and other end users. Sensitivity prediction will provide important information to aid in three levels of decision making; 1) before a wildfire: Where will mitigation practices be best placed? Should we put resources into fire breaks or fuel reduction? 2) during a wildfire: What is the value of protecting a particular asset (e.g. water supply)? What is the real risk to an asset if the area associated with it is burnt? 3) after a wildfire: Is remediation (e.g. building log dams) needed? Where will it be most effective?

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Modelling the fire weather of Black Saturday

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Abstract

As part of the Centre for Australian Weather and Climate Research's contribution to the Bushfire Cooperative Research Centre's *Fire Impact and Risk Evaluation – Decision Support Tool* project, high-resolution and very-high-resolution simulations of the meteorology across Victoria on Black Saturday (7 February 2009) have been performed. These simulations are described and validated against available observational data.

Introduction

Black Saturday (7 February 2009) saw many large bushfires across Victoria, resulting in the deaths of 173 people, far exceeding the loss of life from any previous bushfire (VBRC 2010). The weather conditions on that day were particularly severe, from fire-weather and public-weather perspectives. All-time daily maximum temperature records were broken in many places across Victoria, including the Melbourne Regional Office site (46.4°C) and the Melbourne Airport site (46.8°C) (BoM 2009a). Black Saturday also followed a heat-wave at the end of January 2009 (BoM 2009a) which saw the Melbourne Regional Office site's temperature exceed 43°C for three consecutive days (28-30 January). Over the period 26 January to 1 February 2009, there were 374 excess deaths over what would be expected (VGDHS 2009).

This article describes high-resolution (0.012° to 0.036° resolution) and very-high-resolution (0.004° to 0.008° resolution) modelling undertaken within the Centre for Australian Weather and Climate Research (CAWCR) to reconstruct the meteorology across Victoria and southern New South Wales on Black Saturday, as part of its contribution to the Bushfire Cooperative Research Centre's (BCRC) *Fire Impact and Risk Evaluation – Decision Support Tool* (FIRE-DST) project. Results from this modelling also feed into the BCRC's *Understanding Complex Fire Behaviour: Modelling Investigation of Lofting Phenomena and Wind Variability* project. The modelling is performed using the Australian Community Climate and Earth-System Simulator (ACCESS), and in particular the UK Met Office's (UKMO) atmospheric model (version 7.5).

Meteorological gridded outputs from the modelling will be fed into fire-spread models (e.g. Phoenix RapidFire; Tolhurst et al. 2008), to facilitate fire-spread-model upgrading from single automatic weather station (AWS) meteorological inputs to fully four-dimensional inputs. This will permit explorations of the sensitivity of fire outcomes to (i) fire-ignition location and timing relative to the "observed" weather on the day, and (ii) the timing of significant aspects of the meteorology (e.g., wind changes).

Black Saturday represents the first of several case studies to be undertaken as part of the FIRE-DST project, and analogous very-high-resolution meteorological reconstructions have been performed for the Margaret River fire (November 2011, southwestern Western Australia) and the Eyre Peninsula fire (January 2005, South Australia). The authors note that previous high-resolution and very-high-resolution simulations of the Black Saturday meteorology have been undertaken, including work by Engel et al. (2012) which uses similar modelling configurations to those described here.

The antecedent conditions and synoptic meteorology are described in Section 2. The model set-up is described in Section 3, with details of its validation against available observations given in Section 4. Aspects of the meteorology relevant to the Beechworth-Mudgegonga fire are described in Section 5, with concluding remarks in Section 6. Times are given in Universal Coordinated Time (UTC) and Australian Eastern Daylight Time (EDT = UTC + 11 hours).

Antecedent conditions and synoptic meteorology

Black Saturday occurred towards the end of a long period of drought (1997-2009), which represents the most significant period of sustained low rainfall across Victoria since 1900. 57 per cent of the State experienced rainfall at or below the 10th percentile for the 12 months ending January 2009 (Figure 7). November and December 2008 were wet months, with State-averaged rainfall totals at 134 and 175 per cent respectively of the 1961-1990 averages. January and February 2009, on the other hand, were very dry months, with State-averaged rainfall totals both at 13 per cent of the 1961-1990 averages. Several of the fires on Black Saturday were within the region of Figure 7 showing very much below average rainfall for the 12 months ending January 2009. These included the Kilmore-East, Murrindindi, Bunyip, Delburn and Churchill fires. In contrast, the Beechworth-Mudgegonga fire was outside this region.

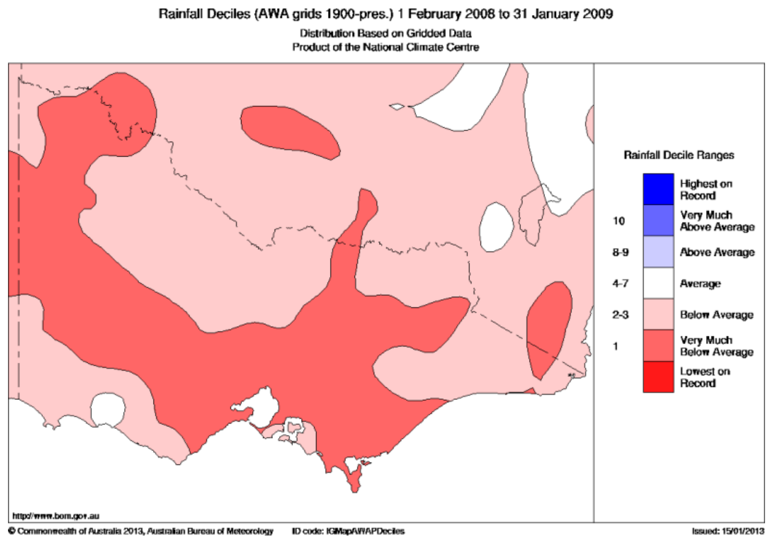

Figure 7. Rainfall deciles for Victoria, for the 12-month period February 2008 to January 2009. Based on the gridded monthly rainfall analyses of Jones et al. 2009.

State-averaged daily drought factors for Victoria are shown in Figure 8, calculated from the gridded national fields of Dowdy et al. 2009. These are non-dimensional numbers, ranging from 0 (very moist conditions) to 10 (very dry conditions), and are used as indicators of fuel dryness in forest fire danger index (FFDI) calculations (see for example the discussion in Lucas 2010). State-averaged values across Victoria rose from around 7 at the start of 2009, to around 9.5 in the first week of February. December 2008's rainfall across Victoria was concentrated into a small number of days, which resulted in the rain having little lasting impact on the drought factor, and in consequence the drought factor was higher at the end of December than at the beginning of the month. Large swings in the drought factor such as that seen in December 2008 are not unknown for this time of year; similar swings were seen in January and December 2007, and January 2008.

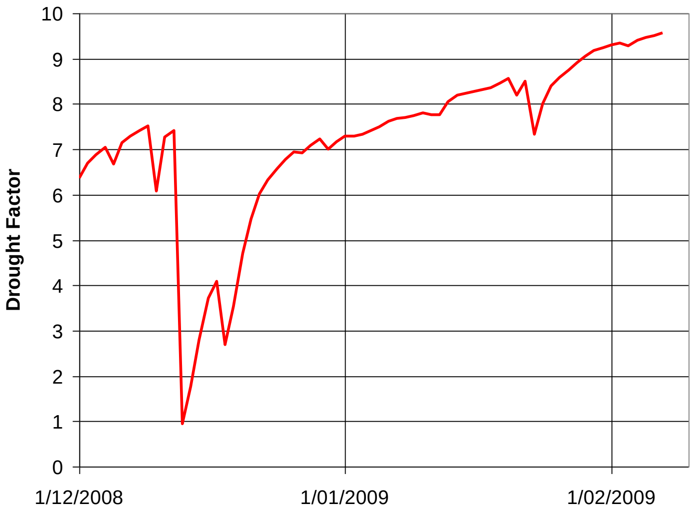

Figure 8. State-averaged daily drought factor for Victoria, for the period 1 December 2008 to 7 February 2009.

Synoptic mean-sea-level pressure (MSLP) analyses from the Bureau of Meteorology on Black Saturday (Figure 9) show a high-pressure system in the Tasman Sea off the west coast of New Zealand, together with an approaching low-pressure system located well to the southwest of Tasmania. The low-pressure system has an embedded cold front, but the principal relevant feature of the synoptic meteorology is a pre-frontal trough (indicated by the dashed line in Figure 9) which crosses Victoria through the course of the day (bringing rapid falls in temperature and significant wind changes). Wind changes such as these constitute major risks for fires in the Victorian summer.

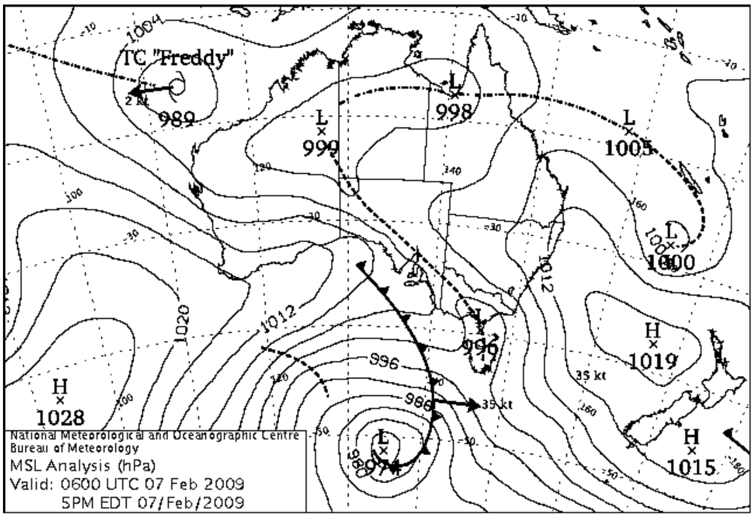

Figure 9. Mean sea level pressure at 06:00 UTC (5 pm EDT) on Black Saturday. Analysis from the National Meteorological and Oceanographic Centre, Bureau of Meteorology.

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Model details

In order to reconstruct the weather conditions on Black Saturday, a sequence of nested model runs is employed. Five stages are employed, and the nesting is one-way, which means that information only flows from the coarser resolutions to the higher resolutions, and not in the opposite direction. The first stage is a global model run, with a longitude spacing of 0.5625° and a latitude spacing of 0.375°. The second stage has a latitude-longitude resolution of 0.11° for a wide region covering Australia and surrounding waters, while maintaining a 20° buffer to the south, 35° to the east and 35° to the north. The third stage has a resolution of 0.036° (approximately 4.00 km in the north-south direction and 3.16 km in the east-west direction at Melbourne's latitude) for a region covering Victoria, Tasmania and southern New South Wales. The fourth stage has a resolution of 0.012° (approximately 1.33 × 1.05 km) and covers Victoria and southern New South Wales. The last stage has a resolution of 0.004° (approximately 0.44 × 0.35 km) and covers central Victoria. Nesting boundaries have been chosen, in so far as possible, to avoid placing them over regions of elevated topography. The third, fourth and fifth stage domains are shown in Figure 10. The fifth stage of the nesting has also been replicated at resolutions 0.008° (approximately 0.89 × 0.70 km) and 0.006° (approximately 0.67 × 0.53 km), to test the sensitivity of the results to grid resolution.

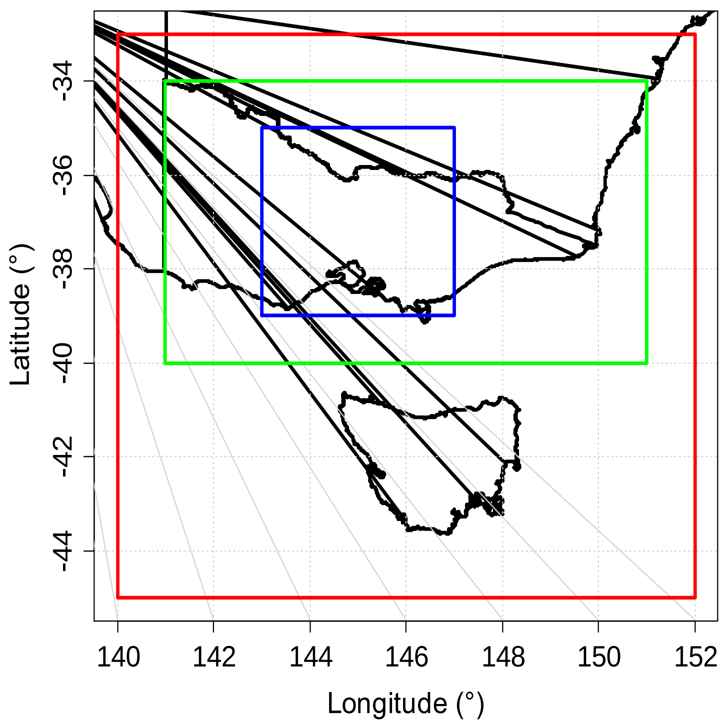

Figure 10. Boundaries of the third (0.036°, red), fourth (0.012°, green) and fifth (0.004°, blue) nesting levels for the Black Saturday model runs. Model boundaries are chosen, as far as is possible, to avoid areas of elevated topography.

The atmospheric model within ACCESS is non-hydrostatic, with an Arakawa-C grid in the horizontal and a Charney-Phillips grid in the vertical (BoM 2010). In consequence, regridding is required for the calculation of some fire-relevant meteorological quantities, such as wind

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speed and direction. All five stages of the nesting use 50 vertical levels, with the lowest model level being approximately 10 metres above the surface for some variables (e.g., the *u* and *v* components of the horizontal wind) and approximately 20 metres above the surface for other variables (e.g., potential temperature θ). The top level is around 60 km above sea level.

For the coarser resolutions (0.036° and above), the model uses a parameterised convection scheme. The lowest 13 model levels, approximately the lowest 3000 metres of the atmosphere, are treated as being boundary-layer levels. For the finer resolutions (0.012° and below), the parameterised convection is turned off. (Failure to do this in preliminary runs resulted in large-scale convection ahead of the front being modelled but not observed.) Also turned on at these finer resolutions is a sub-grid turbulence scheme applied in three dimensions for model levels 2 to 49. The whole vertical extent of the model domain is in effect treated as being potentially available for the boundary layer growth, and in fact boundary-layer depths of up to 5 km are seen in the simulations.

All model runs are initialised at 03:00 UTC (2 pm EDT) on 6 February 2009, using an initial condition obtained from the UKMO for the global model run, and re-configured versions thereof for the nest regional models. For February 2009, only one initial condition per day was available, with the next available initial condition being 03:00 UTC (2 pm EDT) on 7 February 2009 and therefore not well placed in time for the purposes of this study. Because all five nesting levels are initialised from the same time, 03:00 UTC (2 pm EDT) on 6 February 2009 as indicated above, little attention is paid to the first twelve hours of the simulations.

Surface outputs (e.g., screen-level air and dewpoint temperature, 10-metre wind speed and direction) are archived at five-minute intervals in these simulations, with upper-air outputs on the model levels being archived at fifteen-minute intervals.

Model validation

The simulations may be compared directly against independent observational data from automatic weather stations (AWSs) and radiosondes. The AWS data come from a network of one-minute-reporting and thirty-minute-reporting sites across Victoria and southern New South Wales, while radiosonde balloon-flight observations are available for five sites within the 0.036°-resolution simulation domain, two sites within the 0.012°-resolution simulation domain and one site within the 0.004°-resolution simulation domain. The radiosonde data allow a comparison between the observed and modelled vertical column data. The observational data are obtained from the Bureau of Meteorology's Australian Data Archive for Meteorology (ADAM) database.

Features of the simulations which may be validated using these data include the timing of the main wind change on Black Saturday, forecast screen-level maximum temperature and forecast maximum 10-metre wind speeds, and upper-level air temperature, dewpoint temperature and horizontal wind speed. Forecast maximum temperature errors are shown in Figure 11, with approximate timing errors in the primary wind change on Black Saturday being shown in Figure 12.

Forecast maximum temperatures in the 0.004°-resolution simulation are within 1°C of the observed values at most sites within the model domain. The timing of the primary wind change on Black Saturday in the 0.004°-resolution simulation is also well modelled, being only 30 to 60 minutes late across central Victoria, and with smaller timing errors closer to the coast. Timing errors aren't shown for the northeast of the State in Figure 12, because of difficulties in fixing the time of the change in both the simulation and the observations. A comparison of the 0.012°-resolution wind-change positions against the Bureau of Meteorology's observational analysis (BoM 2009b) not shown here gives similar results; the model wind change is slightly ahead of the analysed wind change as it crosses the southwest coast of Victoria, for the next few hours it tracks the observed wind change, but is behind the analysed wind change across central Victoria and the northwest of the State. During the evening the modelled wind change speeds up and catches up with the analysed wind change around midnight.

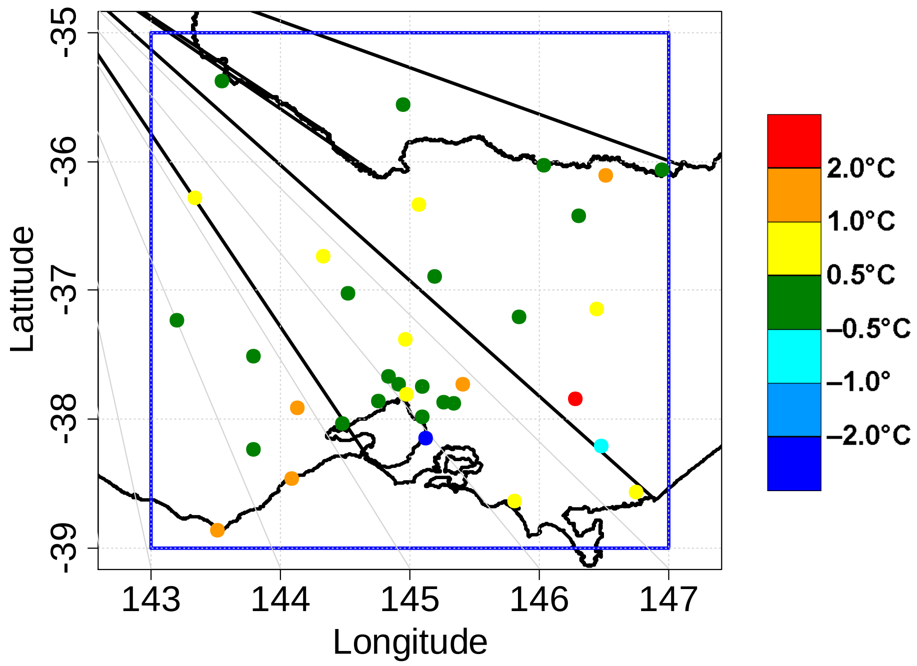

Figure 11. Forecast maximum temperature errors for the afternoon of 7 February 2009, from the 0.004°-resolution simulation. Positive (*negative*) errors mean the simulated maximum temperature is higher (*lower*) than the observed maximum temperature. The blue box denotes the model domain.

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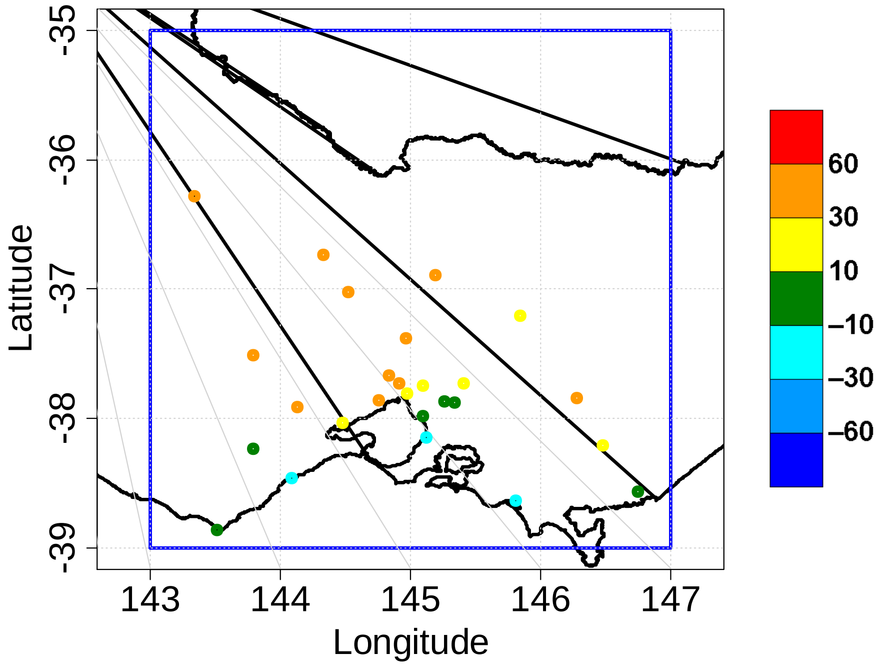


Figure 12. Approximate timing errors in minutes for the location of the primary wind change on Black Saturday. Positive (*negative*) values imply that the primary wind change in the 0.004°-resolution simulation is late (*early*) relative to the change at the indicated AWS locations. The blue box denotes the model domain.

Upper-level air temperatures are modelled very successfully in these simulations, with good results also being obtained for upper-level dewpoint temperatures and wind speeds (not shown). There is however a tendency in the simulations for 10-metre wind speeds to be underestimated, by up to 20 to 30 per cent in the periods of peak windiness on Black Saturday. The reasons for this are unclear at present and require further investigation, but may arise in part because large eddies (on the scale of hundreds of metres) and aspects of the surface roughness (trees, buildings, small gullies, etc.) simply cannot be resolved at the grid resolutions used here.

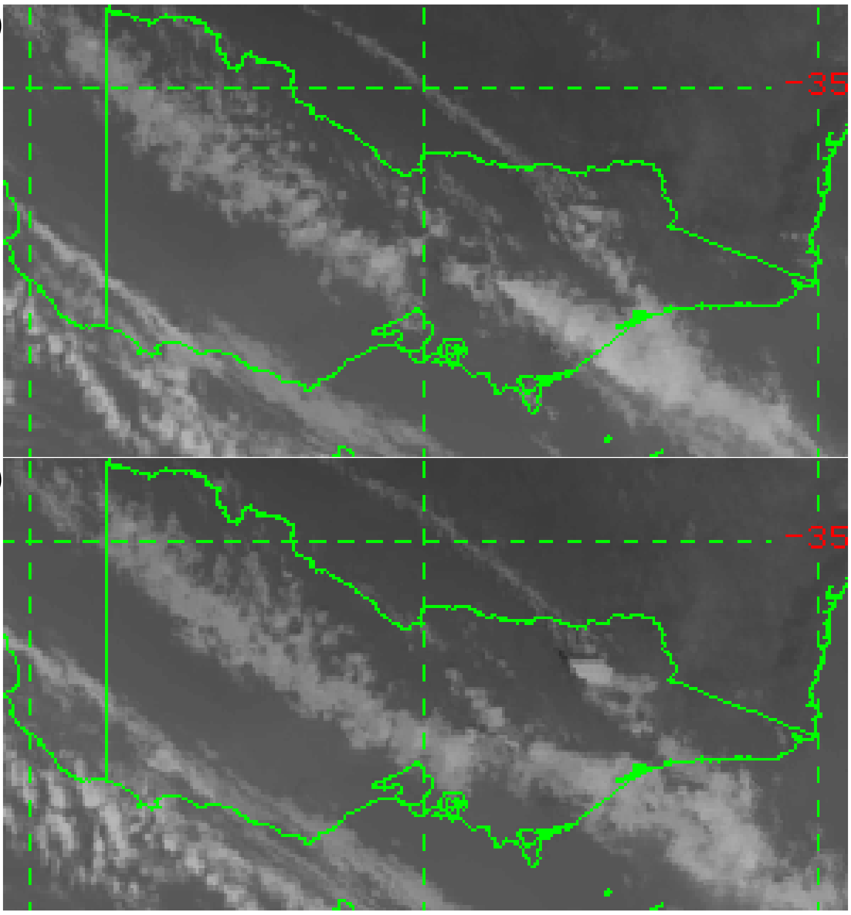
The simulations contain many interesting features, including boundary-layer rolls in the north-westerly flow preceding the primary wind change (features supported by visible satellite imagery in the form of cloud streets and data from the Yarrawonga radar), numerous small-scale vortices on the primary wind change itself, and an undular bore in the northeast of Victoria. The undular bore and the boundary-layer rolls were also seen in the simulations described in Engel et al. 2012 (although called nocturnal bores and horizontal convective rolls therein).

The undular bore in the simulations is particularly well-supported by the available observational evidence (infrared satellite imagery, one-minute data from AWSs at Albury and Yarrawonga, and data from the Yarrawonga radar), and there is persuasive evidence in the radar and satellite data of its impact on the Beechworth-Mudgegonga fire. It will form the main focus of the following section.

The Beechworth-Mudgegonga fire

The Beechworth Mudgegonga fire caused two fatalities, twelve casualties, destroyed 38 houses and burnt 33,577 hectares (VBRC 2010). Extreme fire behaviour with significant spotting was observed 1 km from Myrtleford in northeast Victoria at 23:34 EDT (12:34 UTC) (VBRC 2010). Radar data from the Yarrawonga radar (which is located to the northwest of the fire; the radar data are available at 20-minute intervals) indicate the passage of an atmospheric disturbance travelling in a northeasterly direction and crossing the radar location at around 12:00 UTC (11 pm EDT). Its passage over the fire is coincident with an intensification of the fire, as indicated by the smoke plume in the radar data. The atmospheric disturbance is also evident in the infrared satellite imagery (available at hourly intervals), as is the intensification of the smoke plume (
Figure **13**).

(a)
(b)



(c)

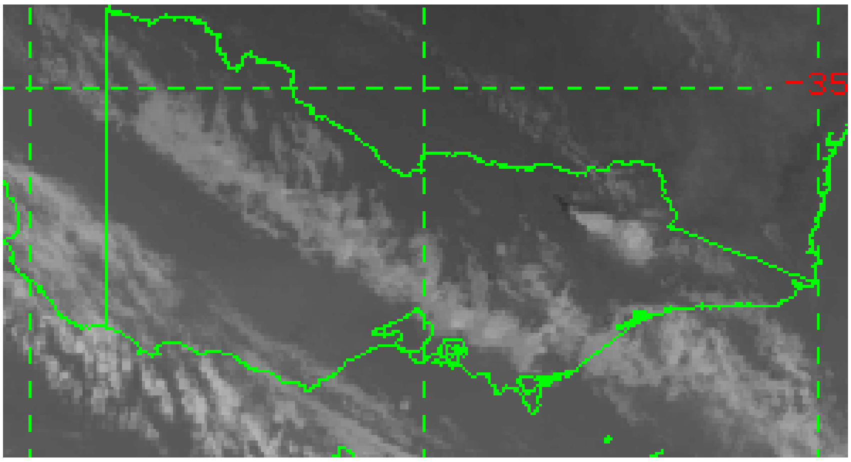


Figure 13. MTSAT infrared satellite imagery across Victoria for (a) 12:30, (b) 13:30 and (c) 14:30 UTC on 7 February 2009 (i.e., (a) 23:30 EDT on 7 February 2009, (b) 00:30 and (c) 01:30 EDT on 8 February 2009). The smoke plume from the Beechworth-Mudgegonga fire is evident on the right-hand side of the plot in each case, and is seen to intensify as the undular bore passes over it. In the first two plots, the undular bore is present in the form of a thin line of cloud.

When the atmospheric disturbance reaches the AWS at Albury around 1 am EDT on 8 February (Figure 14), it is evident as a slight but distinct temporary change in barometric pressure and air temperature (the change in barometric pressure, but not the change in air temperature is evident in the simulation), and a very substantial temporary change in wind direction from (near-northerly to near-westerly) lasting nearly ten minutes. The change in wind speed is much less significant. This feature is well captured in the 0.004°-resolution up to 0.012°-resolution simulations, and is even evident in the 0.036°-resolution simulation, although its speed of travel across the radar location at Yarrawonga is somewhat too fast. That speed is around 43 km hr^{-1} in the 0.004°-resolution simulation, compared with around 33 km hr^{-1} in the radar data, possibly due to the low-level stratification in the model being too strong, as indicated by the faster nocturnal cooling in the model at Albury (Figure 14) and Yarrawonga (not shown). Yarrawonga and Albury are the only two sites in the region available in ADAM reporting one-minute AWS data, and data were not sourced from outside the Bureau.

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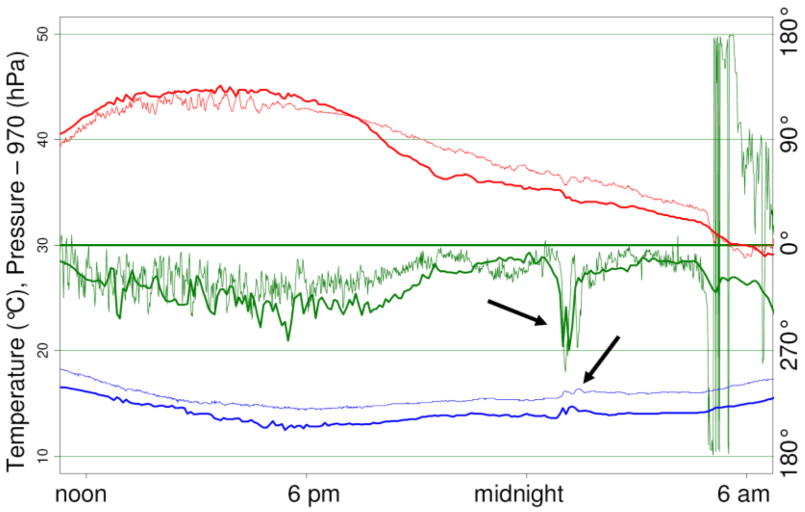

Figure 14. One-minute AWS screen-level air temperature (in °C, red, left axis), air pressure (in hPa relative to a 970 hPa base line, blue, left axis) and 10-metre wind direction (in degrees, green, right axis) for Albury 072160 (thin lines), together with five-minute nearest-grid-point data from the 0.004°-resolution simulation (thick lines), from midday EDT on 7 February 2009 to 6 am EDT on 8 February 2009. Air pressures are offset by 970 hPa. Wind directions run from southerly at the bottom of the plot, around through westerly, northerly (thick horizontal green line), easterly and southerly at the top of the plot. Black arrows indicate the undular bore.

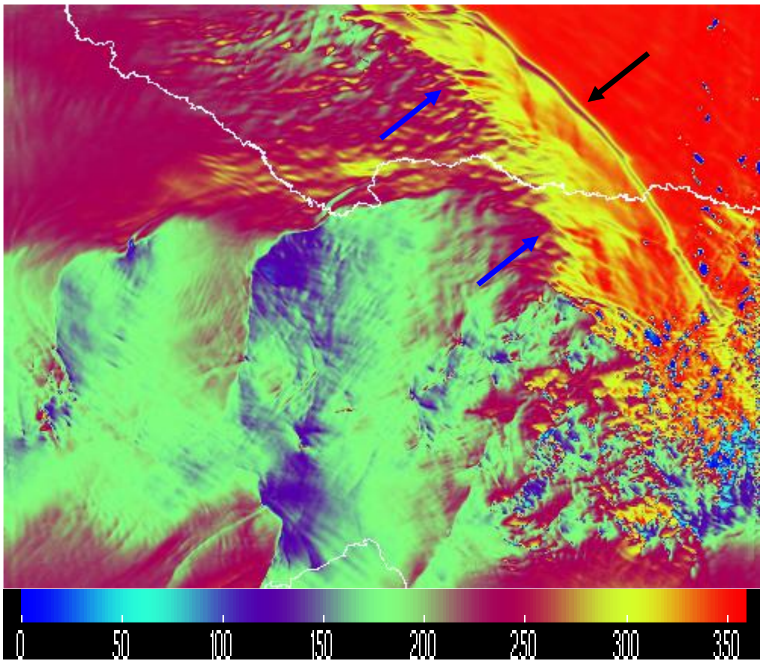

Figure 15. Wind direction in the 0.004°-resolution simulation at 13:00 UTC (midnight EDT) on Black Saturday. The primary wind change (indicated by the blue arrows) has stalled, leaving an atmospheric disturbance (indicated by the black arrow) to propagate towards the northeast into the existing pre-frontal northerly wind regime (top-right, red shades).

As the disturbance passes over the location of the Beechworth-Mudgegonga fire in the 0.004°-resolution simulation, it generates updrafts strong enough (of the order of 5 m s^{-1} in the simulation) to further loft any pieces of bark or other fire brands already raised to about 1000 metres by the fire plume (the fire itself not being modelled in the simulation).

There are two possible reasons for the increased fire activity and spotting as the bore passed over the fire. Firstly, the associated wind may have increased the fire intensity, due to the increased wind speed and possibly also due to the direction change pushing the fire into unburnt fuels on a temporarily broader front, although the change in wind speed was relatively small. A more intense fire would have a stronger plume, and therefore greater ability to raise embers into the strong winds aloft. Secondly, the updraft at the head of the bore, reaching 5 m s^{-1} well within 1000 m of ground level in the simulation, is itself strong enough to loft bark (Ellis 2011), although not from the surface. We propose that this updraft may have combined with the fire plume to provide strong, continuous lifting from the surface into the strong northwesterly winds aloft and thereby produced the observed major outbreak of spotting.

Discussion

Compared with the modelling technology available to reconstruct the weather of earlier significant fires (e.g., Ash Wednesday 1983, Mills 2005a; Canberra 2003, Mills 2005b), the new modelling technology contained within ACCESS includes improved numerics, improved physical parameterisations, developments in analysis formulations, and assimilation of new sources of data particularly from new satellite sounders (Puri et al. 2010). Added to this are the significantly higher grid resolutions now possible.

In addition to a direct comparison of the location of primary wind change in these new simulations against AWS observations (Figure 12) and observational analyses (BoM 2009b), comparisons have been also made against the results of other modelling experiments (not shown). One of these is against 0.036°-resolution (3600 m) and 0.012°-resolution (1200 m) simulations using the same ACCESS model configuration described in Section 3, but initialised from three different ERA-Interim (ERAI) global initial conditions; 00:00 UTC (11 am EDT), 06:00 UTC (5 pm EDT) and 12:00 UTC (11 pm EDT) on 6 February 2009. The other is against the real-time 0.125°-resolution (12.5 km) and 0.05°-resolution (5 km) operational MesoLAPS forecasts generated at the Bureau of Meteorology on 6 and 7 February 2009. The coarser-resolution MesoLAPS forecasts were initialised at 00:00 UTC (11 am EDT), 06:00 UTC (5 pm EDT), 12:00 UTC (11 pm EDT) and 18:00 UTC (5 am EDT, 7th Feb) on 6 February, while the finer-resolution forecasts were initialised at 00:00 UTC (11 am EDT) and 12:00 UTC (11 pm EDT) on 6 February, and 00:00 UTC (11 am EDT) on 7 February.

Amongst the ACCESS runs, the UKMO-initialised simulations generally provide a more accurate forecast for the location of the primary wind change than do the ERAI-initialised simulations, with the earliest of the ERAI simulations being up to two hours late relative to the analysed location (BoM 2009b) across central Victoria. This is not entirely unexpected, as the ERAI initial conditions (1.875°×1.25° horizontal resolution, 38 vertical levels) are less detailed than the UKMO initial condition (0.5625°×0.375° horizontal resolution, 50 vertical levels).

The operational MesoLAPS forecasts tend to be more accurate than the new ACCESS simulations with respect to the timing of the primary wind change across central Victoria, but less so earlier in the day. Also, the real-time operational forecasts were much less successful at resolving the pre-frontal boundary layer rolls and the nocturnal undular bore.

It should however be noted though that while it is indeed possible to compare two or more sets of simulations for a particular case study and decide that on balance one is better than the others, the relative merits of the various simulation approaches can only be properly assessed through comparisons across a suitably large number of examples comprising many different weather regimes.

Concluding remarks

High-resolution and very-high-resolution simulations of the meteorology on Black Saturday have been performed and validated successfully against available observational data. Many aspects of the simulated meteorology have implications for fire behaviour; the primary wind change itself, pre-wind-change boundary-layer rolls within the overall hot dry northerly flow, the bore across northeastern Victoria (and adjacent parts of New South Wales) which arises out of the stalled wind change, and the small-scale vortices on the primary wind change. In significant respects, the new ACCESS simulations perform better than the Bureau's operational MesoLAPS forecasts at the time.

These features are present at the simulation resolutions of 0.004° up to 0.012°, although the smaller-scale features (e.g., the boundary-layer rolls and small-scale vortices) are not as successfully represented in the 0.036°-resolution simulation (which is of the order of current operational high-resolution numerical weather prediction in the more densely populated parts of Australia). Integrating increasingly high-resolution simulations such as these into the fire-weather forecast process will provide an interesting challenge to the Bureau of Meteorology and fire agencies, although it should be noted that the finest model resolutions employed in this study will likely be restricted to research applications for some years to come.

High-resolution model simulations such as those used in this study provide a route to explore in great detail meteorological aspects of fire weather which are otherwise unobtainable with conventional observations, and allow for more detailed interpretations of features (such as the undular bore) seen in the observational data.

Acknowledgements

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Assessing the validity of tympanic temperature to predict core temperature of firefighters in different environmental conditions

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Abstract

The present study examined the validity of tympanic temperature measurements as a predictor of core temperature on the fireground in different environmental conditions. Fifty-one volunteer firefighters participated in the study across four different conditions, the conditions consisted of; 1) passive (i.e., no intervention) cooling in cold ambient temperatures (0-6°C); 2) cooling (through water immersion) in cool ambient temperatures (10-12ºC); 3) cooling (through water immersion) in warm ambient temperatures (21.5°C); and, 4) passive cooling in warm ambient temperatures (22°C). Firefighters wore full structural personal protective clothing while performing common firefighting duties including search and rescue tasks for 20-40 minutes. There was no difference between core and tympanic temperature immediately post-exercise across any condition. However, for all conditions, tympanic temperature dropped significantly faster than core temperature from 0 minutes, and remained significantly lower ($p < 0.05$) than core temperature from nine to 20 minutes post-training. The results show that there is no consistent difference between core and tympanic temperature during recovery from a simulated firefighting task across a range of different ambient conditions. Agencies should, accordingly, prioritize investigating other practical markers of core temperature as part of a broader heat stress management plan for firefighters.

Introduction

Firefighting is a physically demanding occupation, in which firefighters are required to perform short bouts of intense physical activity for extended periods of time (Barr et al. 2009; Rhea et al. 2004). Upon deployment to a fire, firefighters face life-threatening dangers including flames, radiant heat and collapsing structures, as well as physiological hazards in the form of smoke inhalation and heat stress (IAFF, 2003). In Australia, heat stress is one of the top three leading causes of injury for firefighters from South-Eastern Australian fire agencies (Aisbett et al. 2007). Factors influencing firefighter heat stress include; high physical demand of tasks, exposure to radiant heat and flames, and the retention of body heat due to wearing of personal protective clothing (IAFF, 2003).

Monitoring heat increases in firefighters is a health and safety priority, as heat stress can severely impair the physical and mental performance of firefighters (Pryor et al. 2011). Under high ambient temperatures, the body may experience exhaustion, mental confusion, disorientation, loss of consciousness, heart attack and in extreme cases, death (Binkley et al. 2002). Measurements of core temperature need to be obtained in order to identify the rapidly rising body temperature of firefighters at an incident (Pryor et al. 2011). Direct measurements of core body temperature using rectal thermometry is seen as the most accurate measurement for monitoring and assessing changes of core temperature (Mazerolle et al. 2010; Casa et al. 2007; Binkley et al. 2002). While using rectal thermometers may provide the most accurate measurement of core temperature, these devices are invasive and impractical to administer on the fireground. Gastrointestinal (GI) tablets, commonly known as core temperature tablets, are frequently used in research environments to transmit GI temperature readings to wireless data recording devices (Byrne & Lim 2007; Domitrovich et al. 2010; Casa et al. 2007). A study by Casa et al. (2007) compared common core temperature measuring devices including oral, gastrointestinal, axillary, aural, and temporal measurements to the well-validated measure of rectal temperature before, during and after exercise. It was concluded that ingestible GI tablets were the only measurement device that accurately predicted core body temperature (Casa et al. 2007). However, some studies suggest that core temperature tablets may produce inaccurate core temperature values when fluids are consumed (Domitrovich et al. 2010; Byrne & Lim 2007). To prevent such errors from occurring, the manufacturers instruct users to ingest the GI tablet at least six hours prior to the work bout in order for it to pass through the stomach and reach the small intestines, which is known to accurately reflect core temperature (HQinc, Palmetto, FL). This approach will limit false readings occurring with the consumption of cool fluids (Goodman et al. 2009; Wilkinson et al. 2008). Despite its ability to accurately measure core temperature, particularly when ingestion instructions are adhered to, core temperature tablets may not be the most practical way of obtaining core measurements on the fireground. The device requires advanced notice, limiting its use in emergency settings, as deployment times cannot easily be predicted. Further, the use of core temperature tablets may not be a cost effective strategy for monitoring firefighter's heat stress given the expense of each tablet (approximately AUD $70 per tablet).

In contrast to the limitations of the GI temperature device, tympanic temperature measurements taken by inserting the device into the ear canal is an inexpensive, commercially available and practical method of assessing body temperature (Ganio et al. 2009). Using tympanic temperature devices allows medical personnel on the fireground to take quick and easy temperature measurements when firefighters temporarily exit a hazardous environment. Currently, ambulance officers and medical personnel use tympanic temperature devices on the fire ground to predict the core temperature of firefighters (Ambulance Victoria, 2012). The use of these devices in predicting core temperature has been questioned by a number of studies (e.g., Casa et al. 2007; Pryor et al. 2011; Gagnon et al. 2010; Ganio et al. 2009). The existing literature from the medical, sporting and emergency service fields suggests that tympanic temperature measurements commonly underestimate core temperature (Ganio et al. 2009; Pryor et al. 2011; Amoateng-Adjepong et al. 1999). Therefore, this study aims to quantify the extent of this under-prediction to evaluate whether tympanic temperature has any utility as a core temperature marker device on the fireground.

Methods

Participants

Volunteer firefighters from the Country Fire Authority (CFA) participated in this study. The CFA is the overarching volunteer firefighting organization responsible for fire suppression throughout Victoria. The participants were recruited through flyers distributed at CFA brigade meetings by local Health and Safety advisors. The requirements and potential risks associated with the study were explained to each participant prior to the commencement of testing. Written informed consent was required of each participant. To be included in the study, participants had to be active members of the CFA, without cardiovascular or gastrointestinal conditions, and have no plans for magnetic resonance imaging (MRI) or airplane travel three days post testing (the latter two criteria being contraindications for the core temperature tablets; BMedical, 2010). Ethical approval for all procedures was secured from the Deakin University Human Research Ethics Committee prior to the commencement of testing.

Procedure

Each participant attended a one-hour pre-training briefing on the day of experimentation. Once informed consent was provided, each participant was given a core temperature tablet to ingest (Jonah™ Tablet, Respironics, Bond, Oregon). The core temperature tablet was provided at least six hours prior to the beginning of the training session to ensure the tablet had moved through the stomach and into the lower intestines (Byrne & Lim 2007). Participants returned to the experimentation site between 5:00 pm and 6:00 pm and were fitted with the remaining equipment (see Measurements and Equipment section, below). Participants wore full personal protective equipment which consisted of structural ensemble (PBI Gold and Nomex, Stewart & Heaton, Australia), FirePro fire resistant gloves (Allglove Industries, Australia), treated leather work boots (Taipan, Australia) and a structural helmet (Pacific, Australia), with a net weight of approximately 10 kg. Participants also carried, and may have used, fire safety goggles (UVEX, Germany). Clothing worn under personal protective equipment was not recorded. Participants were divided into four different post-work subgroups to determine the efficacy of tympanic temperature measurement across a range of different conditions. The conditions consisted of; 1) passive (i.e., no intervention) cooling in cold ambient temperatures (0-6°C); 2) cooling (through water immersion) in cool ambient temperatures (10-12ºC); 3) cooling (through water immersion) in warm ambient temperatures (21.5°C); and, 4) passive cooling in warm ambient temperatures (22°C). In the 'cooling (through water immersion)' conditions, participants sat with their arms submerged in water (12-15°C) for either 15 or 20 minutes (see Measurements and Equipment section, below) post-exercise. It should be noted that the same cohort of participants participated in conditions three and four. After being fitted with equipment, participants were fitted with self contained breathing apparatus (SCBA) and air cylinders. Participants in condition one were divided into pairs by site commanders and entered a smoke filled building where they performed common firefighting duties for between 20 and 40 minutes. Participants were required to exit the building when their (or their partner's) air cylinders signaled 'low'. The remaining three conditions (two, three and four) were divided into teams of five, where they then performed common firefighter search and rescue tasks for 20 minutes in a heated building, temperature range 60°C to 124°c. In these instances, teams were required to exit the building between 20 and 22 minutes of exposure. For all groups, the time at which the firefighters exited the building was labeled '0 minutes' and reflects when post-training measurements commenced.

Measurements and Equipment

Weight and height were measured using standard body weight scales (A and D, Japan) and a portable stadiometer (SECA, Brooklyn, New York), respectively. In condition one, core temperature was recorded on a wireless data logger (Vitalsense, Respironics, Bond, Oregon), which received measurement of core temperature from the ingested tablet at one minute epochs throughout the training simulation and post-training. The data logger was carried in the firefighter's pockets through the duration of the training simulation. The remaining three conditions utilized a wireless CorTemp Data Recorder, which also tracked heart rate from a Polar chest strap (Polar RSD 800sd, Polar Electro, Oy, Finland). Researchers documented manual core temperature and heart rate readings from the recorders at set intervals. Participants in condition one wore a heart rate monitor chest strap and receiver watch (Polar RSD 800sd, Polar Electro, Oy, Finland) during- and post- training. Heart rate data in all trials was concealed from participants throughout the trials to ensure heart rate was not consciously manipulated (e.g., through self-pacing, slower breathing). In the post-exercise cooling in cold ambient temperatures group (condition one), tympanic temperature was measured post-training at three-minute intervals until 15 minutes had elapsed, using the Braun Thermoscan® Pro 4000 tympanic thermometer (Braun, United Kingdom). The remaining three groups recorded tympanic temperature every five minutes for 20 minutes post-exercise. All measurements were taken from the participants left ear by the same researcher to ensure consistent collection techniques. In condition one, each participant also wore a global positioning unit (GPS; Spi Elite, GPSports, Australia) in order to measure activity, heart rate and distance travelled every second. As SCBA was carried on the back, the GPS harness was retrofitted to be worn on the chest in a harness which looped around the participants' shoulders.

Statistical Analysis

A two-way repeated measures analysis of variance (ANOVA) test, with time and device (core or tympanic temperature) as the within participant factors, was used to detect differences between the device at each time point post-training. If the ANOVA detected a difference, simple effects analysis was used to identify where the differences lay. All statistics were calculated using Statistic Package for the Social Sciences (SPSS, V.18, Champaign, Illinois). Statistical significance was set at $p \leq 0.05$ and all data was presented as mean ± standard deviation unless otherwise stated.

Results

Participant Demographics

	Condition One	Condition Two	Conditions Three and Four
Age (years)	39 ± 10	27 ± 11	47 ± 10
Height (cm)	177.4 ± 6.0	176.6 ± 7.7	178.0 ± 7.0
Weight (kg)	88.3 ± 14.1	85.69 ± 19.41	91.6 ± 15.2
n	16	22	19

Values are mean ± standard deviation.

Table 1. Participant Demographics

Firefighting training simulation

In condition one, each participant spent approximately 30 – 40 minutes performing the firefighting training simulation in which a number of common firefighting duties, including search and rescue, were undertaken. Individual time spent during the simulated training varied due to rate of air consumed and the subsequent need to exit when their air cylinder signaled low. For the remaining three groups (conditions two, three and four), 20 to 22 minutes was spent in the heated simulated firefighting environment.

Detailed activity data was also obtained for condition one, and serves as a reasonable estimate of the work performed across all four conditions. While the individual tasks during the simulation could not be captured, the intensity of the work simulation as a whole was predominantly above 70% of age predicted heart rate maximum (HR_{max}). The American College of Sports Medicine (ACSM, 2000) classifications of work intensities would categorize the in-simulation heart rates achieved as moderate- to hard- intensity work (above 50% HR_{max}). Small periods of hard to maximal and very light work intensities were also recorded. Average heart rate throughout the entire training simulation was 128 ± 25 beats·min^{-1}. The distance travelled throughout the simulation was 2.1 ± 0.7 km.

Post-Training

Relationship between core and tympanic temperature at specific time points

In condition one, core temperature remained constant between 37.5°C and 38°C across all of the six recovery time points (Figure 1). In contrast, tympanic temperature steadily dropped across the 15 minute rest period, and was significantly lower than core temperature at the nine-, 12, and 15 minute time points. The differences between core and tympanic temperature increased at each successive time point up to 12 minutes, ranging from 0.7 ± 0.9°C immediately post-exercise to 2.2 ± 1.3°C at 12 minutes post simulation. At 15 minutes post-simulation, the tympanic temperature was 2.0 ± 1.1°C lower ($p < 0.001$) than the corresponding core temperature. In conditions two, three and four, there was a significant interaction between temperature measuring device and time ($p < 0.001$). There was no difference between core and tympanic temperature immediately post-exercise ($p = 0.578$, 0.445 and 0.908, respectively). However, for all conditions, tympanic temperature dropped significantly faster than core temperature from 0 to 5 minutes, and remained significantly lower than core temperature at time points 5, 10, 15 and 20 ($p < 0.05$; Figure 1). In condition two, the biggest difference between devices arose at the 5-minute mark, with core temperature being 1.1 ± 0.5°C higher than tympanic temperature. The magnitude of this difference then slowly decreased across the remaining 15 minutes so that at 20 minutes core temperature was 0.6 ± 1.0°C higher ($p = 0.023$) than tympanic. In condition three and four, the discrepancy between the two devices remained relatively constant between 5 and 20 minutes, ranging between 0.6 ± 0.4°C and 0.7 ± 0.5°C ($p < 0.001$).

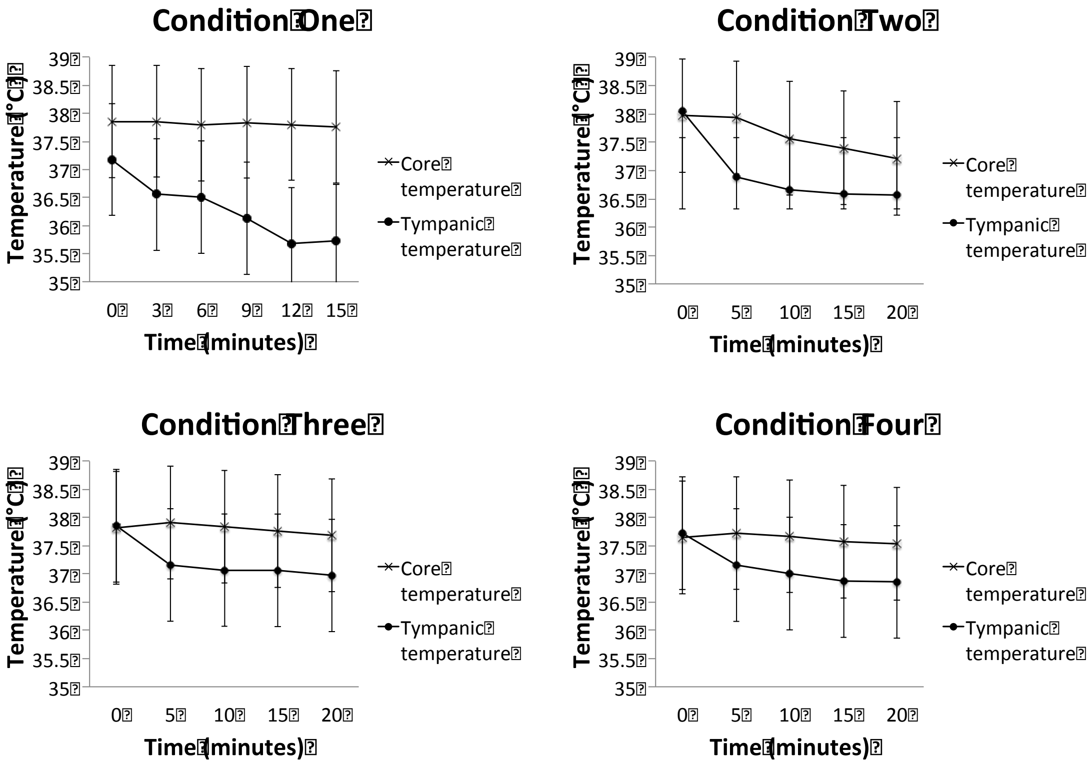

Figure 1: Tympanic and core temperature following 20-40 min of simulated structural firefighting work. Please note that tympanic and core temperatures differ significantly after minute nine in Condition One and from five minute s of Conditions two to four.

Discussion

The major finding of this study was that there was no consistent difference between core and tympanic temperature during recovery from a simulated firefighting task across a range of different ambient conditions and with or without limb cooling. The variations in the difference between core and tympanic temperature measurement post-training severely undermines the utility of tympanic temperature for heat stress detection in firefighters.

Firefighters in all conditions had lower tympanic temperature readings than core temperature for the majority of the post-training period (Figure 1). However, tympanic measurements were temporarily not different to core temperature immediately after exiting the hot environment. This could be due to the 0-minute tympanic measurement being recorded prior to the ear canal being cooled by a cooler external environment (Pryor et al. 2012; Byrne & Lim 2007). Indeed, significant differences between core and tympanic temperature were identified from 5 minutes post exit from the training simulation.

Previous literature suggests that tympanic temperature readings are commonly below that of core temperature as the device is influenced by external factors such as ambient temperature, air movement and sweat (Gagnon et al., 2010; Hansen et al. 1993). The four conditions used in the research utilised different resting ambient temperatures and wind speeds, thus, we were able to observe differences in the variation between tympanic temperature and core temperature. In the present study, condition one had the lowest ambient temperature (0-6ºC and 10-12ºC, respectively) and higher wind speeds when compared to the other conditions, which may explain why the discrepancy between core and tympanic temperature was most exaggerated here. In conditions three and four, firefighters rested in a warmer ambient environment (21.5-22ºC) with no wind, which may explain why the magnitude of the difference between the two temperature measurement devices was slightly smaller (although still significantly significant). Limb cooling (in conditions two and three) did not appear to impact tympanic temperature any differently to the passive-cooling conditions.

The results indicated a consistently lower tympanic temperature ranging between 0.6ºC to 2.2ºC below recorded core temperature. Thus, using tympanic temperature as a guide for returning firefighters to active duties could be placing firefighters at risk (Pryor et al., 2012). Casa et al. (2007) found that peak tympanic temperature occurred at the same time as rectal temperature, but was 1.6ºC ± 0.6ºC lower. The study also showed a large mean difference of 1.9ºC between tympanic and rectal temperature for one subject (Casa et al. 2007). More recently, different study evaluating cooling methods in the Northern Territory reported that firefighters' tympanic temperature was, on average, 1.3ºC below GI temperature (Brearley et al. ND) following performing an outdoor work circuit. Given the variable level of under-prediction of core temperature by tympanic measures, it is possible that fire agencies who use tympanic measurement as to guide the re-deployment of firefighters could be putting personal at increased risk of heat stress. For instance, un-prediction of core temperature (by tympanic devices) could lead to firefighters being allowed to re-enter hazardous environments with dangerously elevated core temperatures. This has the potential to put the firefighter at risk of developing heat illness, which may subsequently impact the performance of their fire suppression duties and place other firefighters at undue risk. Therefore, other measures that could serve as a more accurate proxy for core temperature need to be considered. Heart rate, blood pressure and subjective ratings have been recently disregarded as accurate individual predictors of core temperature (Talbot 2012; Brearley et al. ND; Armstrong et al. 2010), so pursuing other indicators of thermal stress should be a top priority. Until a suit a reliable proxy measures have been developed, firefighters (and their health and safety advisors) will continue to rely on a range of markers together with their own professional judgment.

In conclusion, the current findings show that tympanic temperature devices do not accurately reflect firefighters' core temperature across different conditions. While tympanic temperature devices are easily implemented on the fire ground, true reflections of core temperature are not attainable from the device. Unfortunately, an accurate proxy measure of core temperature is not yet evident, so fire agencies must prioritize investigating other practical markers of core temperature as part of a broader heat stress management plan for firefighters.

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The Stress of Firefighting: Implications for Long-term Health Outcomes

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Abstract

Fire and rescue staff routinely endure significant psychological and environmental stress exposure on the job. While much has been done to improve understanding of the physiological effects of exposure to these conditions, little has been done to quantify the inflammatory stress response that firefighters are exposed to during wildfire suppression. Therefore the aim of the present study was to explore whether firefighters experienced a change in inflammatory markers following one day, and across two days of wildfire suppression tasks. Twelve male fire-fighters participated in two consecutive days of live-fire prescribed burn operations in Ngarkat National Park, South Australia. Typical work tasks included lighting burns, patrolling containment lines, supressing spot fires, and operating vehicles. A number of the inflammatory markers changed significantly across the course of a shift and several presented with an attenuated response across the second day. This finding implies that there was a compounding effect of repeated exposure to these stressors which could have considerable implications for managing fire-fighters health and wellbeing over a multi-day campaign. Further research is required to see which fire ground stressor, or combination of stressors is causing these changes in the inflammatory markers across consecutive work shifts.

Introduction

Each year thousands of volunteer and career staff from fire and rescue emergency services routinely endure significant psychological and environmental stress exposure on the job to ensure public safety. While much has been done to improve our understanding of the physiological effects of exposure to these conditions (e.g. Heart rate, core temperature: Aisbett *et al.* 2012), little is known about the implications of repeated exposure to these stressors on firefighter health. Across each shift, firefighters are required to perform intermittent, intense physical labour (Cuddly *et al.* 2007; Aisbett *et al.* 2007), often in hot (Black 1987; Hancock *et al.* 2007), and smoky (Reisen and Brown 2009) conditions. Other environmental stressors may also include exposure to dust and pollutants (Carlisle and Sharp 2001), toxic chemicals (Miranda *et al.* 2010), and excessive noise (Pepe *et al.* 1985). In addition, firefighters may also work for extended periods of time, across both day and night shifts, and often with little rest between consecutive shifts (Cater *et al.* 2007). In isolation, these factors such as heat, smoke (or its constituent elements), and sleep disruption may have a detrimental impact on cognitive and physical work capacity (Carlisle and Sharp 2001; Hancock *et al.* 2007; Lim and Dinges 2010; Nybo 2008). However the impact of these stressors in combination, and effect of repeated exposure to these stressors on the (long-term) health of personnel has yet to be determined.

Just as firefighters work to protect people and property, fire agencies strive to keep their personnel safe and healthy. For example the use of personal protective clothing (PPC) and personal protective equipment (PPE) serve to physically protect personnel from some of the hazards of wildfire suppression. Similarly the implementation of work to rest guidelines have been designed to protect firefighters against injury and even death resulting from fatigue related errors. However while many of the workplace stressors these personnel face have been documented; far less evidence is available on firefighter's inflammatory response to these stressors. Among the scientific community there is emerging evidence supporting the principle that psychologically (and physiologically) stressful events lasting anywhere from minutes to years are associated with changes in the immune system (Sergerstrom & Miller, 2004), for which inflammatory cytokines such as Interleukin (IL)-1β, IL-6, and Tumor Necrosis Factor (TNF)-α, appear to be the major messenger molecules in this network. Activation of these immune cells produces an array of physiological, behavioural, affective, and cognitive changes in response to stress exposure. For example, a decrease in mood state, influencing the desire to withdraw from social engagement, and increased perceptions of fatigue, which it is reasoned have evolved to promote recovery following exposure to a stressor (Maier & Watkins, 1998).

This acceptance that stress can influence and manipulate the release of circulating inflammatory markers has lead to the suggestion that chronic exposure to these stressors may actually have a long term negative impact on individual's health and well-being (Gouin, 2011; Maier & Watkins, 1998). For example, by initiating changes in the hypothalamic-pituitary-adrenal axis and the immune system, chronic stress has been cited as a trigger for depression, cardiovascular deregulation, and diseases such as cardiovascular disease (Grippo & Johnson, 2009; Leonard, 2010). Disturbances to inflammatory markers have been observed following a 90-minute live-fire simulation of structural firefighting (Smith, 2005) and after 37-minute of cycling ergometer exercise whilst performing firefighting tactical decision making (Huang *et al.* 2010; Webb *et al.* 2011). Extrapolating the findings from these environments to the immunological changes observed after a 10-12 hour day of wildfire suppression is problematic due to the differences in work duration, work to rest profiles, and environmental conditions. Further, the available literature provides no insight into the possible cumulative effect of a second day on wildfire suppression on firefighters' immune response. This information is particularly useful given the prevalence of multi-day deployments for Australian rural firefighters. Therefore the aims of the current study were to: 1) investigate whether an inflammatory response was mounted following a day of wildfire suppression tasks; and 2) investigate the effect that a second day of wildfire suppression tasks has on the same inflammatory markers.

Methods

Participants

Twelve male fire-fighters (age 29 ± 11 yr) participated in two consecutive days of live-fire prescribed burn operations in Ngarkat National Park, South Australia. Typical work tasks included lighting burns, patrolling containment lines, suppressing spot fires, and operating vehicles. Standard, fire-retardant PPC designed to shield the firefighter from environmental hazards and injury was worn throughout the shift as per fire agency guidelines. Approval for the project was obtained from the University Ethics Committee for human research. All participants received written and verbal explanation of the study informing them of the risks and benefits associated with participation. Written informed consent then was obtained from the participants prior to commencement of the study.

Testing Procedures

Upon arrival to the prescribed burn site pre-shift (0 h), participants were asked to sit for two minutes prior to providing a 10 mL venous blood sample from an antecubital vein. Following data collection, the firefighters assembled for their daily briefing and then commenced firefighting work. The end-shift data (12 h) were obtained at the on-site location, while the two hours post-shift data were obtained upon their return to the staging area (14 h). During hours 12 to 14, firefighters drove from the fire-ground to the staging area, showered, ate and rehydrated freely. This testing procedure was replicated for both days.

Blood sampling and analysis

Blood samples were obtained from each firefighter at 0hr, 12 h and 14 h. Following each testing session, all samples were centrifuged at 10,000 rev•min-1 for four minutes at room temperature, and then the plasma was separated into aliquots. These samples were stored at -20°C for up to three days whilst out in the field before being transferred into a -80°C freezer. Upon completion of the study, a selection of cytokines (IL-1β, IL-2, IL-4, IL-5, IL-6, IL-7, IL-8, IL-10, IL-12p70, IL-13, IFNγ, GM-CSF, & TNFα) were simultaneously quantified using a High Sensitivity Cytometric Bead Array Human Inflammation Assay kit (CBA Kit: #HSCYTO-60SK). These assay kits provide a mixture of 13 micro-bead populations with distinct fluorescent intensities and were pre-coated with capture antibodies specific for each cytokine. All had inter and intra-assay variability's of <10%. Analysis of the cytokines were done according to the instructions of the manufactures of the Bioplex 200 array reader (V.5.0, Bio-Rad Laboratories, Hercules, CA).

Statisyical Analysis

Due to the relatively small sample size, a Linear Mixed Modelling (LMM) approach with the SPSS Mixed Procedure (IBM SPSS Statistics for Windows, Version 20.0. Armonk, NY: IBM Corp.) was used for the analysis. Specifically, multilevel models were used to measure the effect of 'time of shift' and 'day of shift' on both mood disturbance and each of the inflammatory cytokines measured. The method of estimation used was restricted maximum likelihood, as this method is less biased than the full maximum likelihood with small sample sizes (Peugh & Enders, 2005). To ensure homogeneity of the data, log transformations were performed where necessary prior to statistical analysis. All analyses were performed using SPSS and $p<0.05$ was used to indicate statistical significance.

Results

Within-days: Results indicated that across the course of a shift, there were significant changes in IL-1β, IL-5, IL-7, IL-10, and TNFα ($p<0.01$). Both IL-1β and IL-7 increased over the 12h of controlled burn tasks (average increase 44% and 21% respectively). Following the end of the shift there was a general return towards baseline (0 h) measures, however only the 53% drop in IL-1β between 12 h and 14 h was significant.

In comparison, IL-5, IL-10 and TNFα all significantly decreased over the 12 h of controlled burn tasks (average decreases of 23%, 40%, and 12% respectively). While there appeared to be some return towards 0 h levels all 14h measures for IL-5, IL-10 and TNFα were still significantly lower than 0 h levels ($p<0.01$).

Between-days: There was a significant effect of performing repeated shifts on a number of the inflammatory cytokines. More specifically, IL-1β ($p=0.005$), IL-7($p=0.004$), IL-4 ($p=0.048$), IL-6 ($p=0.036$), IL-8 ($p=0.045$), and IL-13 ($p=0.050$) all presented with an attenuated response across the course of the second day. The mean changes for the inflammatory cytokines within and between the two consecutive days of wildfire suppression are presented in Table 1.

	Day 1			Day 2		
pg/µl	0h	12h	14h	0h	12h	14h
IL-1β	0.17 (0.06)	0.32 (0.07)	0.20 (0.06)	0.16 (0.07)	0.16 (0.07)	0.05 (0.04)
IL-4	2.98 (0.66)	3.27 (0.98)	2.70 (0.62)	2.39 (0.56)	2.78 (0.76)	2.26 (0.79)
IL-5	0.27 (0.11)	0.24 (0.09)	0.26 (0.09)	0.34 (0.11)	0.22 (0.09)	0.25 (0.12)
IL-6	2.84 (0.89)	5.57 (1.34)	3.86 (1.17)	2.67 (0.67)	2.28 (0.52)	3.70 (1.99)
IL-7	0.43 (0.06)	0.59 (0.06)	0.40 (0.08)	0.37 (0.06)	0.39 (0.09)	0.28 (0.07)
IL-8	2.88 (0.78)	2.83 (0.39)	2.66 (0.35)	2.19 (0.34)	1.97 (0.34)	2.61 (0.51)
IL-10	11.99 (3.77)	8.49 (1.91)	8.41 (2.24)	15.82 (6.06)	7.88 (2.07)	9.87 (2.64)
IL-13	0.88 (0.15)	1.03 (0.18)	0.96 (0.15)	0.91 (0.14)	0.75 (0.14)	0.69 (0.23)
TNFα	5.39 (0.71)	5.22 (0.55)	4.87 (0.55)	5.83 (0.68)	4.58 (0.81)	4.32 (0.81)

Table 1: Mean (± SE) values for those inflammatory cytokines which responded significantly to consecutive days of wildfire suppression.

Only one cytokine, IL-6, presented with a significant interaction effect for *time* and *day of shift* (p=0.037). On day 1 IL-6 increased over the 12h of controlled burn tasks (average increase of 96%), which was followed by a marked decrease between 12h and 14h (31%). However on the second day, IL-6 appeared to decrease (-15%) over the 12h of controlled burn tasks, before returning towards day one 14h levels at the end of day two (14h; Figure 1).

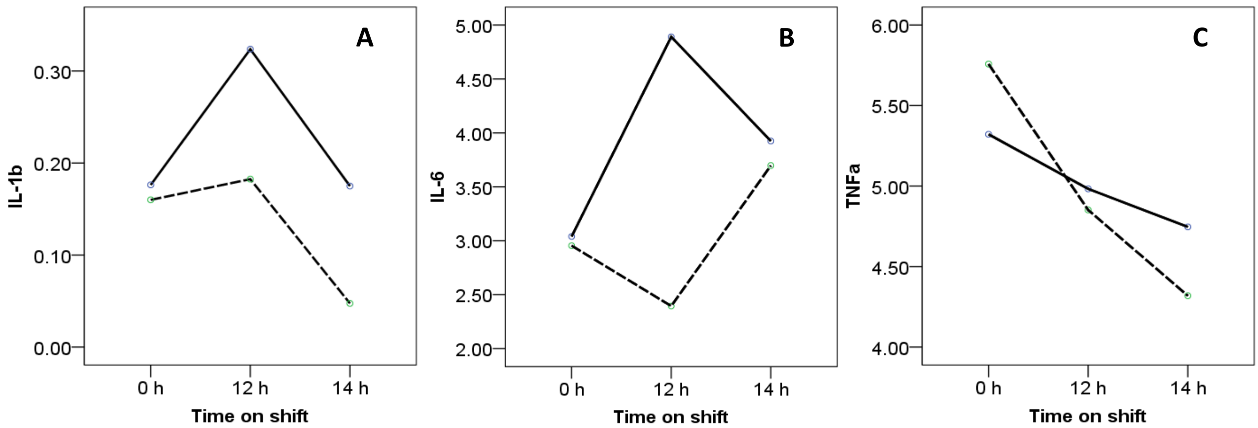

Figure 1: Mean changes in IL-1β, IL-6 and TNFα over the course of each shift.

Note: Day one is indicated by the solid line, and day two the dashed line for IL1β (A), IL-6 (B) and TNFα (C) respectively.

Discussion

While much has been done to improve our understanding of the physiological responses to physical work and exposure environmental stressors (e.g. Huang *et al.* 2010; Smith, 2005; Webb et al, 2011); the impact of these stressors in combination, and effect of repeated exposure to these stressors on circulating inflammatory factors has yet to be determined. Therefore the main objective of the current study was to investigate whether an inflammatory response was mounted following a day of wildfire suppression tasks; and investigate the effect of a repeated day of wildfire suppression tasks on the same inflammatory markers.

The three primary cytokines that have been associated with the acute-phase inflammatory response (to exercise) are IL-6, IL-1ß and TNFα (Smith 2004). In the current study, IL-6 increased over the course of a single day of wildfire suppression. Increases in IL-6 concentrations have been implicated with behavioural changes during periods of both physiological and psychological stress (Owen and Steptoe 2003; Pedersen and Febbraio 2005). More specifically, in both work and exercise settings (Lancaster, 2006; Nehlsen-Cannarella *et al.* 1997) elevations in IL-6 levels, as much as five times greater than baseline measures, have been observed (Brenner *et al.* 1999; Yang *et al.* 2011). Therefore while acknowledging the dearth of literature specifically in the emergency services context; the observed changes in IL-6 following a single 12h shift of wildfire suppression tasks in the current study are consistent with previous exercise based research, supporting the premise that wildfire suppression is physiologically stressful task.

Similarly, the observed elevations of IL- ß and IL-7 following 12 h of wildfire suppression tasks in the current study provides further support for the hypothesised activation of the stress system to adjust homeostasis and increase chances for survival (Chrousos and Gold, 1992). IL-1B is an important mediator of the inflammatory response, while IL-7 has a key role in modulating immune responses (Fry and Mackall, 2002). Although TNFα was not significantly elevated, and in fact decreases were observed in the current study, it remains one of the more problematic cytokines to measure and as such further research is required to substantiate this finding.

Interleukin-5 and IL-10 were the other two cytokines which significantly decreased following a single 12 h shift of wildfire suppression tasks. While the effects of exercise on inhibitory cytokine IL-10 have not yet been widely reported, this anti-inflammatory cytokine is known to increase markedly in the circulation following exercise (Suzuki *et al.* 2000a). It has been hypothesized that its release could limit the release of the pro-inflammatory cytokines IL-1β and TNFα after exercise (Suzuki *et al.* 2000b). In the current study IL-10 concentrations decreased on average 40% over the course of the 12-hour shift. However notably, there was a marked increase during the 2-hour recovery phase on day two which may be indicative of an up regulation of this cytokine to mediate the inflammatory response to the repeated day of wildfire suppression tasks. The exact role that IL-5 plays is unclear; however it has been identified as a key player in the coordination and orchestration of white-blood cells in inflammatory processes (e.g. Hirai *et al.* 1997).

Despite the intermittent and repetitive physical nature of emergency services work, no study to date has investigated the inflammatory or hormonal response to repeated days of physical work. Findings from the current study suggest that a number of inflammatory markers were significantly altered on day two of their suppression work. This suggests one of two things: One, it may imply that there was an adaptive or conditioning response to the work on the second day, such that it was less stressful. The alternative interpretation of the results suggests a compounding effect of repeated exposure to these stressors may have occurred, which could have considerable implications for managing fire-fighters health and wellbeing over a multi-day campaign. The required duration of rest between repeated bouts to prevent carryover effects from a first bout it is as yet unknown, although research by Degerstrøm and Østerud (2007) suggests that a 4 h rest period is insufficient.

Conclusion

Collectively the findings of the current study suggest that there was an inflammatory response to a 12 h shift of wildfire suppression; and that this response was altered following a second day of work. It must be acknowledged, that while a number of the inflammatory markers were significantly altered across the course of a shift, there was a high degree of variability between participants. With such a small sample size it is hard to account for this variance, however it is possible that some participants may have already had an attenuated resistance to the environmental stressors. Nevertheless, the findings of the present study are unique, and represent a novel contribution to our understanding of the impact of wildfire suppression on the acute-phase stress response and circulating inflammatory markers. Further research is required to see which fire ground stressor, or combination of stressors is causing the rise in firefighters' inflammation across consecutive work shifts. Similarly, we don't know how these inflammatory markers change in emergency situations. Moreover, given chronic exposure to these stressors may actually have a long-term negative impact on individual's health and well-being, we need to improve our understanding of how an individual's inflammatory response to a stressor is correlated with long term health outcomes.

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Cardiovascular risk screening of volunteer firefighters

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Abstract

Background: The work demands involved in firefighting place significant stress on the cardiovascular system. This study investigated the application of the AHA/ACSM Health/Fitness Facility Preparticipation Screening Questionnaire in volunteer Country Fire Brigade (CFA) firefighters. **Methods:** Cardiovascular disease (CVD) risk factors were measured in 3777 CFA firefighters and entered into a modified version of the American Heart Association (AHA)/ACSM Health/Fitness Facility Preparticipation Screening Questionnaire to stratify individuals as low, moderate or high risk. **Results:** Just over half (50.8%) of female and more than two thirds (68.2%) of male CFA firefighters were classified as moderate risk. The questionnaire further stratified 2.6% of female and 5.2% of male CFA firefighters as high risk while the remaining 46.6% and 26.6% of female and male firefighters, respectively, were classified as low risk. **Conclusion:** The majority of firefighters screened were at moderate risk and therefore, would be advised by AHA/ACSM guidelines to undertake and pass a detailed medical examination and a medically supervised exercise test prior to initiating vigorous intensity physical activity. However, considering the financial and practical implications (e.g., reduced emergency response capacity) the introduction of mandatory screening may cause, fire agencies should focus screening for high risk personnel only, while promoting agency wide CVD health education.

Keywords: Cardiovascular disease; risk factors; preparticipation; firefighting; screening

Introduction

Firefighting involves periods of moderate-intensity work interspersed with irregular bursts of high-intensity work performed in a potentially hazardous environment (i.e., extreme heat and carbon monoxide exposure; National Institute for Occupational Safety and Health 2007). The physical and environmental demands associated with firefighting place significant stress on the cardiovascular system. Indeed, acute myocardial infarction are a significant risk for firefighters (Balady *et al.* 1998; Kales *et al.* 2007). Furthermore, cardiovascular disease (CVD) related deaths are the leading cause of on-duty death among firefighters in the United States of America (USA; Kales *et al.* 2007). The majority of these deaths occur in firefighters with a higher prevalence of CVD risk factors or pre-existing CVD (Kales *et al.* 2007). The precipitation of acute cardiac events for personnel with pre-existing CVD risk factors performing hard work (Balady *et al.* 1998; Thompson *et al.* 2007) have compelled firefighting associations in the USA to devise mandatory medical screening strategies to protect the health and safety of firefighting personnel (National Fire Protection Association 2007). Such strategies have proven to accurately identify volunteer firefighters (Gaetano *et al.* 2007), soldiers (Flynn *et al.* 2009) and emergency medical service (EMS) personnel (Gaetano *et al.* 2007) at high risk of adverse work-related cardiac events. Moreover, screening strategies have proven successful in motivating emergency service personnel to seek further health care services (Gaetano *et al.* 2007; Flynn *et al.* 2009). Although effective, the existing emergency service based screening and stratification research is limited to only a few USA based studies.

In contrast to the USA, no national CVD-related mortality data exists for the ~ 250,000 volunteer and career Australian firefighters who protect people and property from a range of natural and manmade disasters. Recently, however, we have shown that Country Fire Authority (CFA; Victorian) volunteer firefighters have similar risk factor profiles to age-matched Australian population norms which lead to an absolute CVD risk greater than that documented for emergency service workers in other countries (Wolkow *et al.* in press). Despite similar occupational demands and on-duty CVD risk (Kales *et al.* 2007) volunteer firefighter recruits may not be subject to the same stringent health-related employment procedures as their paid counterparts (Fahy 2005). For instance, paid Australian firefighters are required to meet minimum pre-employment health standards to become an active firefighter (Country Fire Authority 2012). Without routine screening measures in place for volunteer firefighters, personnel with multiple CVD risk factors and therefore, at high risk of on-duty CVD related events are less likely to be identified.

The introduction of health screening and stratification adds to routine health and safety costs for the respective fire agency. Therefore, to reduce costs it is important the selection of any health screening tool be both time-efficient and accurately identify individuals at high risk (Sharkey and Davis 2008). To aid in correctly selecting a cost effective screening tool prior to large-scale application, it is important to trial the screening intervention on a small sample with an analyses of consequence. Such an evaluation can provide quantitative data to show the effect the screening tool has on participants (e.g., the number of people screened at high risk), from which associated financial costs can be determined (e.g., cost of further medical testing and evaluation etc; Sharkey and Davis 2008).

The physical work-rates involved in firefighting would be considered 'moderate' to 'very-hard' by the physical activity intensity classifications endorsed by the American College of Sports Medicine (ACSM; American College of Sports Medicine 2009; Balady *et al.* 1998). Moreover, the physical work intensities associated with firefighting are comparable to those required when performing exercises such as vigorous weightlifting and circuit training (e.g., push-ups, pull-ups and sit-ups; Ainsworth *et al.* 1993). Given the comparable physical demands and established cardiovascular risks associated with both intense firefighting and exercise related activities, the application of an exercise based preparticipation screening and stratification device could aid in the protection of volunteer firefighters from on-duty CVD-related risks. Indeed, screening and stratification strategies have proven to accurately identify health and fitness facility members at heightened risk of an adverse CVD event occurring during physical exertion (Shephard *et al.* 1991; Sharkey and Davis 2008). The American Heart Association (AHA)/ACSM Health/Fitness Facility Preparticipation Screening Questionnaire is among the most widely used and recognised preparticipation screening measures (Balady *et al.* 1998). This device uses CVD history, symptoms and risk factors to stratify individuals according to a certain level of risk (i.e., low, medium and high) prior to participation in low to high-intensity exercise (American College of Sports Medicine 2009). Although the effectiveness of the AHA/ACSM questionnaire in reducing CVD has not been investigated directly, this device uses evidence-based risk factor guidelines established by the National Cholesterol Education Program (NCEP). Furthermore, the AHA/ACSM questionnaire is a time-efficient and easily applied tool, and therefore potentially suited for application to large firefighting populations such as the CFA (i.e., 58,000 volunteer members; Country Fire Authority 2009). To the author's knowledge, only one study overseas (Gaetano *et al.* 2007) and no studies in Australia have investigated the application of CVD risk screening among firefighters. Therefore, by applying a time and cost-efficient CVD screening tool (i.e. AHA/ACSM Health/Fitness Facility Preparticipation Screening Questionnaire), this study aims to assess the cardiovascular health of a volunteer firefighter population and determine those who present with low, moderate and high CVD risk. Furthermore, this study aims to provide an insight into the usefulness of this particular screening tool among firefighters and contribute to an evidence-base from which agencies can make informed decisions regarding further implementation of CVD risk screening.

Methods

Participants

In total, this descriptive cross-sectional study evaluated 3777 volunteer CFA firefighters (3011 males, 766 females). The study cohort represented a convenience sample of volunteer firefighters drawn from Victorian CFA brigades. Following an expression of interest, research staff travelled to each of the participating fire brigade locations and provided on-site CVD risk factor measurement services. Research staff also recruited volunteer firefighters at non-emergency firefighting championships (The Urban and Rural Firefighting Championships). To be eligible for inclusion, participants had to be a volunteer CFA firefighter aged between 18 to 74 years and had fasted for six hours prior to the assessment. Participation in this study at both non-emergency events and individual brigades was voluntary and signed written informed consent from each participant was obtained prior to data collection. All procedures were approved by the Deakin University Human Research Ethics Committee prior to commencing the study.

Cardiovascular Disease Risk Factor Measurement and Collection

Each participant had their waist circumference (WC) measured, and body mass index (BMI) calculated from height (cm) and body mass (kg) measurements. For each of these anthropometric measurements, participants had their shoes and any heavy clothing and/or personal accessories (i.e., wallet, mobile phone, CFA pager etc.) removed. Firefighters' resting systolic blood pressure (SBP) and diastolic blood pressure (DBP) were measured using an automatic blood pressure (BP) cuff (Microlife 3AC1-1PC, Microlife Corporation, Switzerland). Participants then provided a fingertip blood sample for analysis of; low-density lipoprotein cholesterol (LDL-C), high-density lipoprotein cholesterol (HDL-C) and blood glucose. Participants were required to fast for a minimum of six hours prior to providing the blood sample. In contrast, a 10-to 12-hour fast was used in other studies which investigated similar CVD risk factors among USA firefighters (Byczek *et al.* 2004; Swank *et al.* 2000). As CFA firefighters can be on-call 24 hours a day, the authors felt it was unrealistic to insist on an extended fast, thus a shortened fasting period was adopted. Previous studies have demonstrated no significant difference in HDL-C (Emberson *et al.* 2002) and only minimal difference in mean LDL-C (- 0.2 $mmol{\cdot}L^{-1}$) between fasting and non-fasting values (Langsted *et al.* 2008). Therefore, it is unlikely the shortened fasting period had a major impact on these risk factor measurements. Nevertheless, glucose levels have been observed to continue to fall beyond six hours of fasting (Emberson *et al.* 2002). As a result, the number of CFA firefighters identified with impaired fasting glucose (IFG) may be slightly elevated.

The blood sample was obtained using a disposable lancing device (Accu-Chek Safe-T-Pro Plus, Roche Diagnostics, Australia), from which 35 μL of whole blood was collected with a capillary tube (Cholestech LDX Capillary Tube, Hayward, CA). The blood sample was analysed on-site using the Cholestech LDX (Cholestech Corporation, Hayward, CA) device to determine the amount of LDL-C, HDL-C and glucose in the blood sample. The Cholestech LDX point-of-care testing (POCT) device has been used to assess blood lipids and glucose among both USA rural firefighters (Gaetano *et al.* 2007) and Victorian rural community residents (Shephard *et al.* 2005). The device has been validated in reference to classification standards for total cholesterol, triglyceride and HDL-C (Bard *et al.* 1997; Shemesh *et al.* 2006) and the analytical performance of this device has been recently validated in Australian rural community settings (Shemesh *et al.* 2006; Shephard *et al.* 2005).

Following the collection of BP, blood lipids and glucose data, each participant entered their results and personal data (i.e., age, sex, family history of CVD, diagnosed type 1 or 2 diabetes, smoking and exercise habits) into an online database. It should be acknowledged that contrary to AHA/ACSM risk factor classification criteria (American College of Sports Medicine 2009), both BP and blood glucose results in the current study were taken from one-off measurements, and as such, are not a diagnosis of hypertension or IFG, respectively

(Table I). An actual medical diagnosis of hypertension or diabetes is based on multiple measurements taken on several occasions (American College of Sports Medicine 2009). Furthermore, AHA/ACSM risk factor criteria classify individuals as hypertensive and/or dyslipidemic if on antihypertensive or lipid-lowering medications, respectively (American College of Sports Medicine 2009; Table I). In contrast to AHA/ACSM guidelines, the current study did not record current medication use in the sample of CFA firefighters (Table I). The relative impact of these practical limitations of the POCT method could result in the misclassification of hypertension, dyslipidemia and/or IFG should POCT results be mistakenly used as proxies for medical diagnoses.

Cardiovascular Risk Stratification

To determine the CFA firefighters' cardiovascular risk stratification, a slightly modified version of the AHA/ACSM Health/Fitness Facility Pre-participation Screening Questionnaire was applied. This particular screening model was selected because it is an easily administered tool that uses basic risk factor information and has clear cut criteria (i.e., low, moderate or high risk) to specifically risk stratify people planning to begin physical activity (American College of Sports Medicine 2009). Therefore, this tool is more likely to be used as a pre-firefighting work screening tool than other risk functions (e.g., Framingham Risk Score) focussed on medium term disease risk prediction (i.e., 5 or 10 year risk; Wilson *et al.* 1998).

Participant's results for the risk factors age, sex, smoking, exercise/sedentary lifestyle, family history of CVD, SBP, DBP, BMI, WC, LDL-C, blood glucose and diabetes were entered into the AHA/ACSM risk stratification function. One point was allocated for each risk factor above the recommended NCEP risk factor guidelines, except for HDL-C (American College of Sports Medicine 2009; Table I). Risk factor points were then totalled to determine the individual's AHA/ACSM overall risk stratification point score (American College of Sports Medicine 2009). To account for the protective effects of high HDL-C on the cardiovascular system, one risk factor point was deducted from the participant's sum of risk factors if their HDL-C level was > 1.55 $mmol \cdot L^{-1}$ (American College of Sports Medicine 2009; Table I). Conversely, one risk factor point was added if the participant had an HDL-C level < 1.04 $mmol \cdot L^{-1}$ (American College of Sports Medicine 2009; Table I). If an individual had no more than one CVD risk factor they were stratified as low risk (American College of Sports Medicine 2009). Individuals with two or more CVD risk factors were stratified at a moderate risk for CVD (American College of Sports Medicine 2009). Individuals classified at high risk were those with known cardiovascular, pulmonary or metabolic disease (American College of Sports Medicine 2009). However, contrary to AHA/ACSM guidelines (American College of Sports Medicine 2009), the questionnaire used in the current study only inquired about the incidence of diagnosed diabetes (type 1 or type 2). Hence, individuals with other known CVD-related diseases (i.e., cardiovascular, pulmonary and/or metabolic diseases other than diabetes) were not identified and as a result, the percentage of CFA firefighters stratified at high risk could be underestimated in this sample.
It should also be noted that the CVD risk factor classification criteria for the risk factors 'Exercise/Sedentary Lifestyle', 'Smoking' and 'A Family History of CVD' used in the current study differed from their respective AHA/ACSM risk factor criteria (refer to Table I). In

comparison with the AHA/ACSM questionnaire, the criteria used to classify these risk factors in CFA firefighters (Table I) were more lenient (e.g., the current study classified an individual as a smoker if they currently smoked while AHA/ACSM criteria classify a smoker if the individual is a current smoker or has quit in the last six months or is exposed to environmental tobacco smoke) and therefore, may underestimate these particular risk factors among the sample of firefighters.

Positive Risk Factors	**Risk Factor Classification**
Age	Men ≥ 45 years; Women ≥ 55 years
Family History of CVD	CVD related death in two or more close relatives (i.e. father, mother, brothers, sisters); **Myocardial infarction, coronary revascularization, or sudden death before 55 yr of age in father or other male first-degree relative, or before 65 yr of age in mother or other female first-degree relative*
Hypertension	SBP ≥ 140 mm Hg and/or DBP ≥ 90 mm Hg; **as stated, but measurements confirmed on at least two separate occasions or taking antihypertensive medication*
Dyslipidemia	LDL-C ≥ 3.37 $mmol{\cdot}L^{-1}$ (130 $mg{\cdot}dL^{-1}$) *or* HDL-C < 1.04 $mmol{\cdot}L^{-1}$ (40 $mg{\cdot}dL^{-1}$); **as above, but also classified as dyslipidemic if on lipid-lowering medication*
Impaired Fasting Glucose	Fasting blood glucose ≥ 5.50 $mmol{\cdot}L^{-1}$ (100 $mg{\cdot}dL^{-1}$) but < 6.93 $mmol{\cdot}L^{-1}$ (126 $mg{\cdot}dL^{-1}$); **as above, but also classified as pre-diabetic if impaired glucose tolerance = two hour values in oral glucose tolerance test ≥ 7.70 $mmol{\cdot}L^{-1}$ (140 $mg{\cdot}dL^{-})^{1}$ but < 11.0 $mmol{\cdot}L^{-1}$ (200 $mg{\cdot}dL^{-1}$) confirmed on at least two separate occasions*
Obesity	BMI ≥ 30 $kg{\cdot}m^{-2}$ *or* WC > 102 cm (40 inches) for men and > 88.0 cm (35 inches) for women
Exercise/Sedentary Lifestyle	30 min of vigorous intensity exercise at least three days per week or moderate intensity exercise two to three times a week or physically active occupation but complete no regular exercise; **Not participating in at least 30 min of moderate intensity (40%-60% VO_2R) physical activity on at least three days of the week for at least three months*
Smoking	Current cigarette smoker; **as stated, but also classified as a smoker if individual has quit in the last six months or exposure to environmental tobacco smoke*
Negative Risk Factors	**Risk Factor Classification Criteria**
High HDL-C	HDL-C ≥ 1.55 $mmol{\cdot}L^{-1}$ (60$mg{\cdot}dL^{-1}$)

Table I. Cardiovascular disease risk factor classification criteria used in risk stratification of CFA firefighters

** AHA/ACSM risk factor classification criteria different to risk factor classification criteria in current study* (American College of Sports Medicine 2009)

SBP = Systolic Blood Pressure; DBP = Diastolic Blood Pressure; LDL-C = Low-Density Lipoprotein Cholesterol; HDL-C = High-Density Lipoprotein Cholesterol; BMI = Body Mass Index; WC = Waist Circumference; mm Hg = millimetres of mercury; $mmol{\cdot}L^{-1}$ = millimoles per litre; $mg{\cdot}dL^{-1}$ = milligrams per decilitre

Statistical Analyses

To determine CFA firefighter's AHA/ACSM risk stratification, risk factor measurements were entered into a custom recorded macro created in Microsoft Excel (Microsoft Corporation, Redmond, WA). All data was presented as means ± standard deviation (SD) unless otherwise stated.

Results

Three thousand and eleven firefighters tested were male (i.e., 79.7%) and 766 (i.e., 20.3%) were female. The age of both male and female firefighters ranged from 18 to 75 years and the average age of the male and female firefighters was 46 ± 15 yr and 43 ± 15 yr, respectively. On average, female and male firefighters had 2 ± 2 and 3 ± 2 CVD risk factors, respectively. Just over half (50.8%) of female participants had two or more CVD risk factors and therefore classified as at moderate risk. In contrast, 68.2% of male participants were classified as at moderate risk with two or more CVD risk factors. Furthermore, 2.6% of female firefighters and 5.2% of male firefighters were stratified as high risk (i.e., diagnosed diabetes) while the remaining 46.6% and 26.6% of female and male firefighters, respectively, were classified as low risk (≤ 1 risk factor). When the sexes were combined, 30.7% of participants in this study were classified as low risk with one or less CVD risk factor, 64.7% of participants could be classified as at moderate risk with two or more CVD risk factors and 4.7% had diagnosed diabetes (i.e., diabetes type 1 or type 2) and were consequently, stratified as high risk (Figure I).

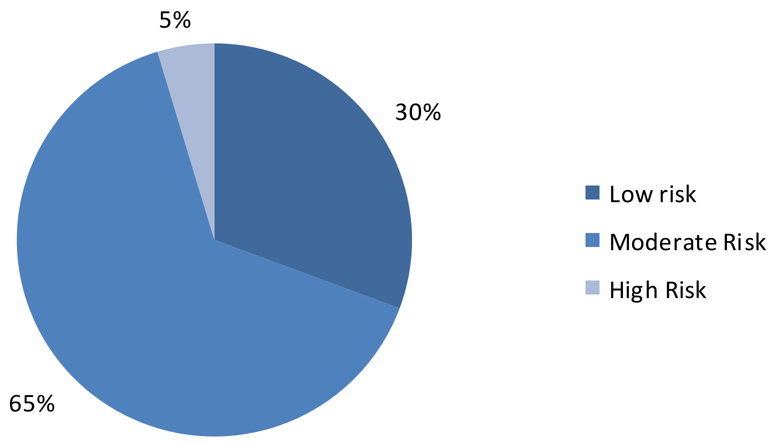

Figure I. Percentage of CFA firefighters with low, moderate and high risk stratification

Discussion

This study investigated the application of a modified AHA/ACSM preparticipation risk screening questionnaire in volunteer CFA firefighters. The questionnaire identified diagnosed diabetes (type 1 or type 2) in 2.6% of female firefighters and 5.2% of male firefighters, as a result, these individuals were stratified as high risk. A further 50.8% of female firefighters and

68.2% of male firefighters were identified as having two or more CVD risk factors and were therefore stratified as moderate risk. In total, 64.7% of the studied CFA firefighters could be stratified as at moderate risk with two or more CVD risk factors.

To the author's knowledge, the current study is the first to have investigated the use of the AHA/ACSM risk screening questionnaire in firefighters. Using similar risk factor thresholds based on Framingham data, Gaetano *et al.* (2007) evaluated the CVD risk factor prevalence of 1,456 volunteer firefighters and EMS personnel in the USA following a mandatory health surveillance examination. From this sample, Gaetano *et al.* (2007) further risk stratified volunteer firefighters and EMS personnel ≥ 45 years (n = 315). Seventeen percent of this cohort had a risk factor score ≥ 9 points which identified unacceptable risk and as a result were assigned a 'C' classification (Gaetano *et al.* 2007). These individuals had their responsibilities limited to tasks of low physical intensity and were only allowed to return to normal duties following the satisfactory completion of a graded exercise test (GXT) or cardiologist examination (Gaetano *et al.* 2007). In comparison, 64.7% of the CFA firefighters' tested presented with moderate CVD risk and therefore, would be advised by AHA/ACSM guidelines to undertake and pass a detailed medical examination and a medically supervised GXT prior to initiating vigorous intensity (70 to 85% of maximum heart rate) exercise or physical activity (American College of Sports Medicine 2009). Furthermore, if the risk stratification of CFA firefighters was narrowed to personnel ≥ 45 years, 77% would be stratified at moderate risk. Both these percentages are considerably higher than the 17% of USA volunteer firefighters and EMS personnel recommended for low activity work and testing (Gaetano *et al.* 2007).

The different risk profiles between CFA firefighters in the current study and EMS and firefighting personnel could be the result of variation in risk stratification methods. In particular, the modified AHA/ACSM stratification criteria could place a larger emphasis on age as a risk factor than the Framingham based model used by Gaetano *et al.* (2007). For example, in the current study male firefighters ≥ 45 years and women firefighters ≥ 55 years received one risk factor point. Therefore, any additional points would place them at a moderate risk. In contrast, Gaetano *et al.* (2007) allocated male and female EMS and firefighters ≥ 45 years either two or three risk factor points, respectively. As a result, male and female personnel required a further seven or six risk factor points respectively, to stratify them as an unacceptable risk (i.e., ≥ 9; Gaetano *et al.* 2007).

The contrast with Gaetano *et al.* (2007) demonstrates the larger emphasis the AHA/ACSM tool places on any one risk factor. The AHA/ACSM model also makes no distinction between someone with two or nine (for example) risk factors and more sensitivity is required. Indeed, evidence suggests that more than half of all Australian adults have more than two risk factors (O'Brien 2005) and therefore, like CFA firefighters, would most likely be stratified as moderate risk if the AHA/ACSM guidelines were applied. Given the large number of CFA firefighters identified at moderate risk, AHA/ACSM screening and stratification could also pose considerable financial cost to the CFA. Indeed, a medical examination and supervised GXT are likely to cost in excess of AUD $280 per person (Norton *et al.* 1998) and require the hiring of skilled staff. Medical and GXT testing of CFA firefighters could reduce the number of available volunteer firefighters in the CFA and consequently, reduce the emergency response across the state of Victoria. Therefore, despite the AHA/ACSM risk tool being widely used and recognised tool for pre-physical activity screening and stratification, it is possible that in its current form of strict application, it may not be the right tool for use among emergency service personnel such as firefighters. Instead, rather than testing (i.e., medical and GXT exercise tests) all firefighters who present at moderate and high CVD risk and excluding those from their duties who fail, the screening tool could be used to assign firefighters to specific, less physically demanding roles within their crew and/or brigade . The use of further medical and GXT testing could then be reserved for those firefighters who present with a moderate to high CVD risk but also play a more active role within their crew or brigade when on the fireground. Alternatively, BMI classifications have also been related to several parameters associated with cardiovascular health (e.g. blood pressure and cholesterol) among firefighters and could be used as a simple screening indicator of CVD risk for firefighters (Clark *et al.* 2002). However, further studies in this area are needed to explore screening options for firefighting and other emergency services.

Considering the financial and practical implications (e.g. reduced emergency response capacity) the introduction of mandatory screening and temporary exclusion of firefighters from physical work may cause, fire agencies should focus screening and stratification for high CVD risk personnel who are operationally active. If, however, volunteer fire agencies in Australia were to peruse mandatory job-screening and stratification of all firefighters, emerging evidence suggests that the assessment of firefighter's job related health and fitness be based on both a preparticipation health assessment (e.g., the AHA/ACSM questionnaire or similar) and their physical capacity to perform essential job functions (Gurkin *et al.* 1995; Pachman 2009; Serra *et al.* 2007). The latter involve describing and quantifying the physical demands relevant to the performance of common firefighting tasks (Serra *et al.* 2007). Furthermore, given the large percentage of firefighters' stratified at moderate CVD risk, fire agencies should aim to improve the CV health of their personnel through agency wide CVD health education interventions. Importantly, effective methodological design and implementation of CVD health education programs by emergency service agencies need to be set on a robust evidence base of previous or existing interventions (Rychetnik *et al.* 2002; Wolkow *et al.* in second review).

The application of a AHA/ACSM function to this sample of CFA firefighters has allowed for an in depth insight into the CVD risk in this population. However, the modifications of the AHA/ACSM model does have a number of limitations that must be considered. In comparison with the AHA/ACSM questionnaire, the modified criteria used to classify certain risk factors (i.e., Exercise/Sedentary Lifestyle', 'Smoking' and 'A Family History of CVD') were less strict and therefore, may underestimate these particular risk factors among the sample of firefighters. However, regardless of the modifications made, these particular risk factors are based on self report responses which may not correspond to actual physical activity, smoking level or CVD family history. A further limitation of the current study is the use of a non-random convenience sampling framework (i.e., voluntary participation of subjects). This method of recruitment may lead to a biased sample of the population as firefighters who are less concerned with their health or who have known health issues may be deterred from participating, while those firefighters who have a greater interest in their health may be more likely to take part. Consequently, selection bias may affect the degree to which the sample is representative of CFA firefighters. However, the large sample size and thus small standard error, enhance the ability to generalise the study's findings back to the wider CFA population as a whole.

Conclusion

A large percentage of volunteer CFA firefighters were classified as moderate risk and if the AHA/ACSM guidelines were applied, could require satisfactory completion of a thorough medical evaluation and medically supervised GXT prior to gaining clearance to undertake vigorous intensity firefighting work. The percentage at moderate risk is greater than the only comparable USA study, which is likely due to the older age of the current CFA participants. The high percentage of CFA firefighters at moderate risk should compel agencies to apply agency wide interventions regarding CVD health education and focus risk screening on personnel considered a high CVD risk and legally defensible job selection procedures around inherent task requirements.

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