ARE BIG FIRES INEVITABLE? Perspectives from the HighFire Risk Project

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Perspectives from the HighFire Risk Project

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Abstract

The HighFire Risk Project seeks to understand the drivers of bushfire risk in and adjacent to the high country. Using literature reviews, studies of large fires and field studies we are building a clearer picture of those drivers.

- The role of ruggedness as an initiator of fire, through influences of lightning ignition prevalence.
- Nocturnal low-level jets, subsidence inversions and other dew point anomalies, giving peak FFDIs at nighttime.
- Dry slots of dry upper air causing catastrophic fire expansion.
- Unusual combustion processes and landscape scale flashovers.
- Violent pyro-cumulonimbus development, with global-scale impacts
- Mountain wind waves with the potential to resonate with the landscape.
- Foehn winds, a little understood feature of Australian landscapes.
- Dynamic channelling, a process the can create landscape-scale flaming zones.
- Terrain chimneys, shown by European research to create exponential increases in rates-ofspread.
- Plume-driven fires, a phase-transition to totally different fire behaviour drivers.
- The role of ruggedness as a fire limiter, of significance for protection efforts.

The role of establishment of a suitable fuel-age mosaic is dicussed in the context of this risk picture.

We conclude that the High Country is a landscape that is prone to multiple ignitions in places where fire suppression is most difficult. Further it is a landscape that is prone to a range of processes that can affect the probabilities of fire escalation. It is also a landscape that stores the effects of past large fires in the landscape-scale fuel-age distribution – the last big fire primes the landscape for the next one.

This framework makes clearer the way to avoid the next catastrophic fire.

1. Introduction

In the aftermath of the extensive 2003 alpine bushfires the Commonwealth Government provided funding for the Bushfire CRC's HighFire project to investigate the various characteristics of high country landscapes that contribute to fire behaviour and bushfire risk. As a component of HighFire, the HighFire Risk Project seeks to gain a better understanding of the drivers of bushfire risk that operate in these landscapes. History shows that the high country is obviously prone to big fires and thus the question of whether such fires are inevitable in the high country naturally arises as part of the HighFire Risk agenda.

The question of the inevitability of big fires is a broad one that is likely to have different answers depending on the particular features of the region over which the question is framed. Therefore to properly pose such a question one must do so within a particular spatial context. In this note we consider the question in the context of high country landscapes, which can be loosely defined as those regions that are above a certain threshold elevation and that are sufficiently rugged, where ruggedness can be defined in terms of the local relief of the terrain.

Furthermore, to properly address the question "Are big fires inevitable?" one must also define what is meant by a "big" fire. The HighFire Risk Project considers a series of bushfire size classes: small, medium, large, very-large and extreme. Each of these classes can be defined in terms of characteristics such as the amount of landscape they involve and the effect they have on the surrounding environment. Given these different size classes one can then consider the set of possible transitions between them. These transitions can be described in terms of what might cause them, and what results from them occurring. Beginning with the fact that all bushfires start small; a big fire can thus be described as a small fire that has undergone a series of transitions, or escalations, with each transition taking place in response to the occurrence of a specific set of driving processes. The question of the inevitability of big fires then amounts to the likelihood of a particular sequence of transitions (escalations or decays) taking place.

A key goal of the HighFire Risk Project is to be able to predict the likelihood of a particular transition occurring. In section 2 we briefly describe the fire size transition model framework that allows for transition between fire size classes with varying likelihoods. In section 3 we go on to describe some of the interesting processes that affect the likelihood of transition between size classes. In section 4 we briefly discuss the role of fuel management in mitigating the risks that arise from big fires and the concept of a fuel-age mosaic as a means of reducing transition likelihoods.

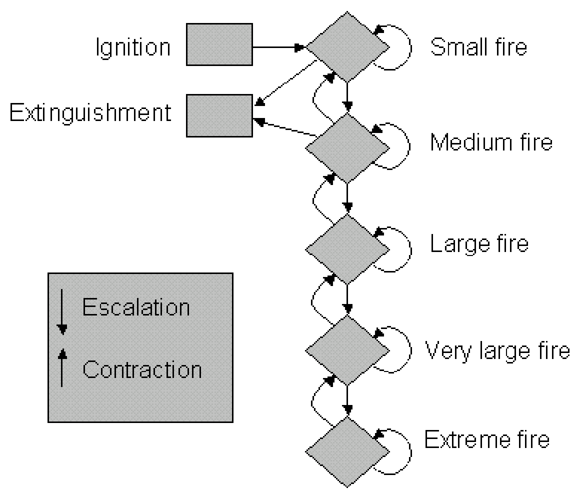


Figure 1. Summary of the fire size class transition model. Developed by Risk Management Section, ACT Emergency Services Agency, for the ACT's Bushfire Risk Assessment.

2. Fire Size Transition Model

The model addresses the transitions between size classes as a fire escalates or decays. A conceptual framework for the model can be seen in Figure 1. It is a Markovian process model in which the transition probabilities have to be determined through research in to the key processes that cause escalation or decay of a fire. The project will address all aspects of the process model and methodically analyse shortfalls in the understanding that should underpin it. Some of the key processes are already evident from past research and from material collected during the 2003 fires, while some will need to be investigated. A multi-disciplinary approach is being applied, spanning field data collection, physical modelling and analysis of fire data and risk methodologies. While much of the initial effort is necessarily meteorological, many aspects of fire management will be integrated.

A detailed description of the transitions and of the various processes that can affect the probability of transition between certain fire size classes is available from the authors on request.

3. Drivers of Bushfire Risk in the High Country

To begin to assign probabilities to the particular transitions between fire size classes it is critical to understand all of the significant processes that act to alter the size of a fire and, as a consequence, the risk it poses to a particular asset. Research into larger bushfires in the high country has led to the development of an interesting list of processes that have acted as drivers of the various transitions that occurred. Many of these have featured rather poorly in the existing bushfire research literature (Sharples, 2007):

- The role of ruggedness as an initiator of fire
- Nocturnal low-level jets, subsidence inversions and other dew point anomalies
- Dry slots
- Unusual combustion
- Violent pyro-cumulonimbus development
- Mountain wind waves
- Föehn-like winds
- Dynamic channelling
- Terrain chimneys
- Plume-driven fire
- The role of ruggedness as a fire limiter

On the 8th of January 2003 a series of dry thunderstorms started a very large number of fires in the alpine areas of mainland Australia. While many have noted this fact, it seems that a number of significant process controls have been overlooked. Figure 2 shows a map of lightning ignitions on the 8th of January along with the sites locally prone to lightning ignitions derived from a terrain model based on averaging the local elevation (McRae, 1992). Figure 3 shows the same lightning ignition data overlayed on a map of terrain ruggedness (defined in terms of the local relief of scaled elevation). The figures indicate that the lightning fires occurred in places that are intrinsically prone to lightning ignitions, as derived from the terrain model. The majority of these sites are difficult for fire crews to access and are only occasionally close to road networks. It is only in areas with a dense access network that there is a high probability of initial attack succeeding. The lightning fires also occurred preferentially in areas of the most rugged terrain. Rugged terrain prevents access road construction and also makes construction of helipads difficult.

In usual circumstances weather conditions at a fire ground must be estimated using measurements from sites that may be some distance away. At elevated sites this can often be adequately accomplished by applying adiabatic lapse rates, but in some cases the stratification of the atmosphere may produce rather different weather on high ground. Such stratification includes more than just the ‘thermal zone’ inversions that most fire fighters are trained to watch out for.

Subsidence inversions, associated with high pressure systems, can bring dry upper air down towards hilltops producing very low dew point temperatures between midnight and dawn. Nocturnal low-level jets, which generally produce stronger winds, may also be associated with these. Thus it is not unusual for the peak in fire danger on high ground to occur in the latter part of the night. This is counterintuitive and would act to compromise night shift strategies and tactics. These effects would mainly act to hinder decay transitions to smaller fire size classes, but nocturnal fire escalations can also occur.

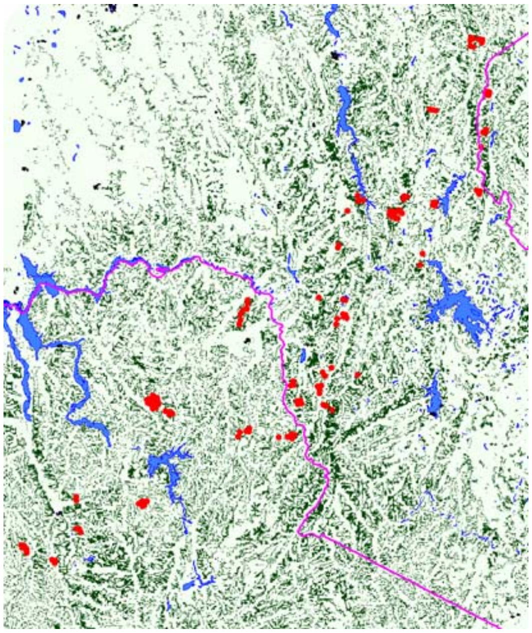


Figure 2. Map of ignitions on 8/1/2003 (red dots) overlayed on map of regions locally prone to lightning ignitions (dark green). The model here works well at a local-scale.

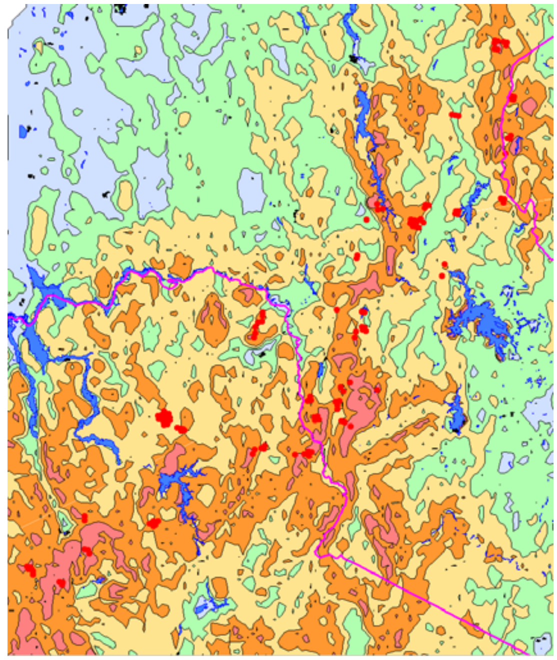


Figure 3. Map of ignitions on 8/1/2003 (red dots) overlayed on map of terrain ruggedness index

Dry slots (Mills, 2006) are upper atmospheric features that can be detected in water vapour satellite imagery (see Figure 4). If the thermal mixing zone around a fire is deep enough and a dry slot passes over the region, then very dry air can be brought down onto the fire and can cause explosive 'blow-up' conditions. Such an effect would make transitions to larger fire size classes much more likely.

Many anecdotal accounts of unusual combustion during fires have been recorded but few, if any, have been reliably documented. Examples of unusual combustion that have been recorded since 2003 include:

- Tornado driven fire behaviour, with erratic swings in ventilation rates
- Ember storms (see Figure 5) with the properties of 'fire balls'
- Terrain-scale flashover, igniting approximately 100 ha in a fraction of a second.
- Premixed combustion, resulting in fire behaviour that is independent of local fuel loads. Blue flames, horizontal flame sheets and other phenomena have been noted.

While these may not directly lead to escalation of a fire, they can prevent fire crews from attacking and thus affect the likelihood of transition to a smaller fire.

Intense fires can lead to violent pyro-cumulonimbus development, essentially producing a thunderstorm within the fire's smoke plume. Such instances have been noted in the Big Desert of Victoria in 2002 and in Wollemi National Park, NSW in 2006 (see Figure 6). The storms in Canberra in 2003 were well documented (Fromm, *et al*., 2006). Features of these thunderstorms can include lightning, which can start new fires, tornado development and precipitation (including black hail). These effects can often act to escalate a fire into the extreme size class, through new ignitions, downbursts, impeding air operations and reducing visibility.

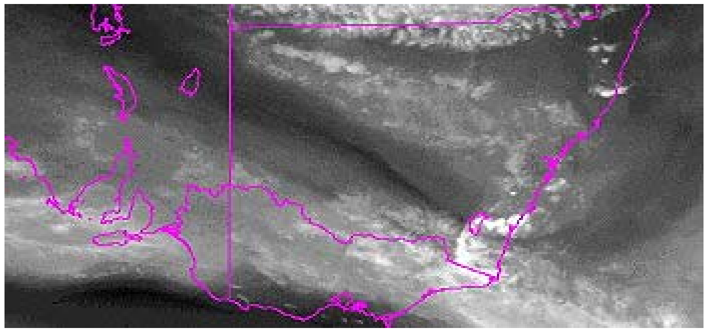


Figure 4. Water vapour imagery showing a dry upper air slot (black band) interacting with the 2003 ACT fires. (courtesy Graham Mills, BoM)

Figure 5. An intense ember storm at Duffy, ACT. WIN TV News footage.

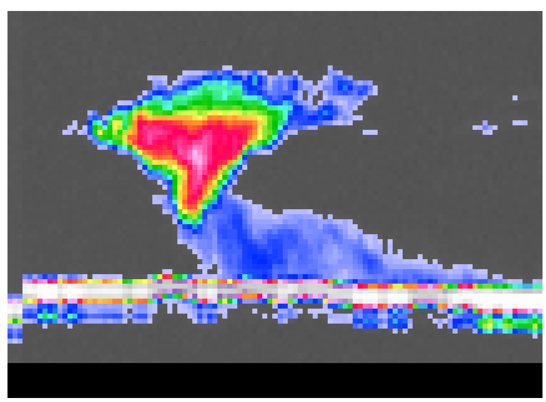
A.  B. 

Figure 6. Wollemi Fire, 22 November 2006. (A) MODIS image of a pyro-Cb, (B) CloudSat radar cross-section of the pyro-Cb (red indicates the most moisture).

A well known feature of mountain meteorology is the formation of mountain wind waves, which can occur when air movement is impeded by a transverse terrain barrier. This can result in vertical wind waves that are best detected if *altocumulus standing lenticularis* clouds develop. These have been detected in satellite imagery associated with severe fire behaviour. Resonant waves produce a quasi-periodic sequence of downdraughts and updraughts (Figure 7) that may lead to the drying out of air through the process of adiabatic compression. Mountain waves can also lead to an increase in the mixing zone above a fire. Both of these effects act to increase the likelihood of transition to larger fire size classes.

Föehn-like winds, which can occur on the lee side of mountain barriers, can also bring dryer air into the vicinity of a fire. These occur when air flowing over the barrier loses moisture through precipitation or when lower level moist air is blocked by the barrier allowing the dryer upper air to take its place on the lee side. Typically this results in lower dew points and stronger winds on the downwind side of the barrier. Temperatures can also be elevated due to adiabatic compression. The net effect is to increase the likelihood of fire escalation.

Terrain can also affect fires more directly. European work has shown that when fires encounter certain terrain configurations, such as canyons and steep slopes, approximately exponential increases in fire spread may occur (Viegas, *et al*., 2005). There are terrain features in the Australian high country that are conducive to this type of fire behaviour. This leads to a rapid escalation in fire behaviour that would likely threaten the safety of nearby fire crews.

Moreover, dynamic channelling of bulk winds by specific terrain features has been revealed, by detailed remote sensing, to be a major cause of fire escalation. An incised valley or steep lee slope (Figure 8) aligned roughly perpendicular to the main airflow can induce extraordinary fire behaviour:

- An entrained eddy, full of circulating embers, that can move laterally away from the fire at up to 5 km/hr
- A spill out of embers from the top of the eddy into the bulk air flow. This ember spill can produce a dense field of spot fire up to 12 km downwind of the eddy's extent.
- Coalescence of spot fires into a fire storm. Examples of this have been recorded as having an instantaneous extent of over 24 square kilometres.

Fires that escalate to the large or very large size class release a significant quantity of moisture from burning vegetation. The smoke plume can resist mixing with the air that it passes through for a height that reflects the depth of the flaming zone. As a fire escalates this depth grows and the plume resists mixing up to greater height. If this height exceeds the condensation level, then the latent heat of condensation is released into the plume and the vigour of its uplift is enhanced. Trentmann *et al* (2006) showed for that such a fire latent heat release may be three times that from the fire.

In the 2003 fires, mixing was resisted for more than 7 km above the ground (see Figure 9). Under these circumstances the plume can be pushed along by upper level winds. Any lofted embers remain within the plume. Surface fire behaviour, mainly due to ember storms, becomes less dependent on fuel loads and weather conditions at the surface as long as the plume's uplift can be maintained. Evidence suggests that a decay transition is only likely to occur if either atmospheric stability alters or if fuel loads fall below 5 t/ha for more than 5 km.

Terrain can have a remarkable effect on big fires. Many big fires seen in southeast Australia in recent years have started on the high ranges – as would be expected in light of the discussion on lightning ignitions above. Fires that start in the high ranges must undergo a net downhill run in order to leave the high country. Upon leaving higher country, traditional fire behaviour knowledge suggests that there should be an escalation in fire behaviour (as fires propagating downslope spread more slowly than those propagating across flat ground). In other words, there is an expectation of an escalation in fire behaviour as the fire leaves the rugged landforms. The evidence arising from these fires, however, suggests that the fires halt in these transitional parts of the landscape. Figure 10 shows Sentinel hotspot data overlayed on a map of ruggedness index derived from a scaled digital elevation model –it illustrates the tendency for large fires to constrain themselves to the rugged part of the landscape. It would thus seem that the largest fires in rugged landscapes 'prefer' to stay in the rugged landforms; they may spill over for some distance, however, and hazardous fuels such as densely planted pines and ill-informed backburns can carry the fire well into non-rugged lands. It may be that the constraints arise from processes correlated with the extent of the rugged landforms, such as mountain wind waves.

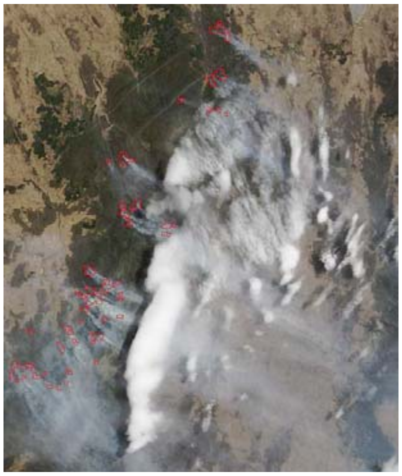


Figure 7. Wave clouds (lenticularis) indicative of resonant mountain wind waves over a fire.

Figure 8. A channelling event, moving the fire sideways (to the right in the photograph). Photo courtesy of Stephen Wilkes.

Figure 9. Plume of the McIntyres Fire on 18 January 2003, showing expansion against the surrounding air 7 km above the ground. Photo by Target Air Services Pty. Ltd.

We have provided a brief description of a set of processes that can drive transitions between fire size classes, many of which are terrain-dependent or scale-dependent. While more research is required to fully appreciate the significance of these processes and to better quantify their particular characteristics, the question of the inevitability of escalation of fire size class clearly has to consider the likelihood of any or all of these drivers occurring during the life of a fire. Given the likelihood of lightning ignitions occuring in rugged landforms, these drivers must be considered.

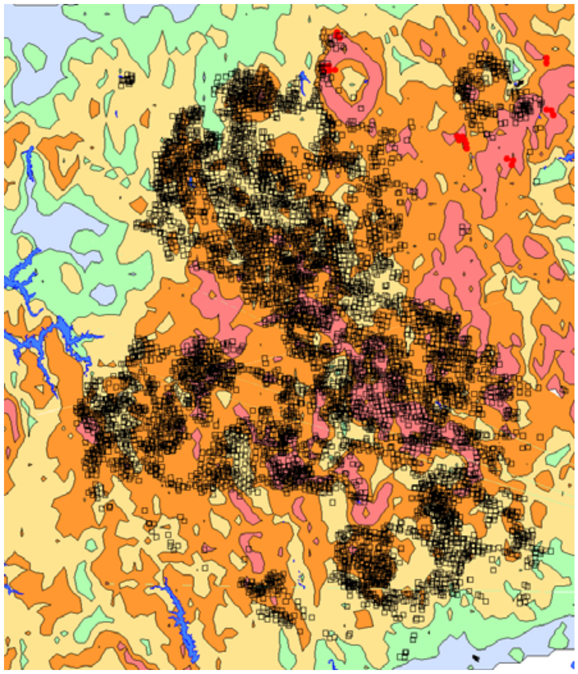


Figure 10. Terrain limiting of the December 2006 Victorian Alpine Fires. Rugged terrain is shown in yellow, orange or red. The southern margin made significant runs that produced some of the largest convection columns seen and yet failed to leave the rugged area.

4. Fuel-age Mosaics

The main tool used to assist fire suppression is fuel management. Most aspects of fire behaviour reflect the fuel load in some way. Prior reduction of fuels loads may provide additional strategic options for incident controllers; for example, a fire flank may become amenable to direct attack only within recently lowered fuel loads. When considering the issue of landscape-scale fires it is necessary to analyse fuel load issues on the same scale.

It must be remembered that management of fire regimes is a complex matter. Research (for example Bradstock and Carey, 2001) has shown that there are complex interactions between fire regimes and igniton rates, weather and landscapes.

The high country near the ACT has been experiencing large fires for many decades on a quasi-cyclic basis. If the time-sequences of distribution of fuel age in a set of classes is examined, these cycles are self-sustaining due to the presence of sufficient fuel over the landscape to facilitate fire growth to a large scale. Figure 11 shows a simplified fuel-age mosaic for Namadgi National Park. In 2002, when the fuel-age mosaic was first prepared (McRae, 2002), the spectrum had just entered a dangerous configuration. The next year was when the next catastrophic fire occurred, and 95% of the area reverted to the youngest fuel age class with the remainder being in the oldest.

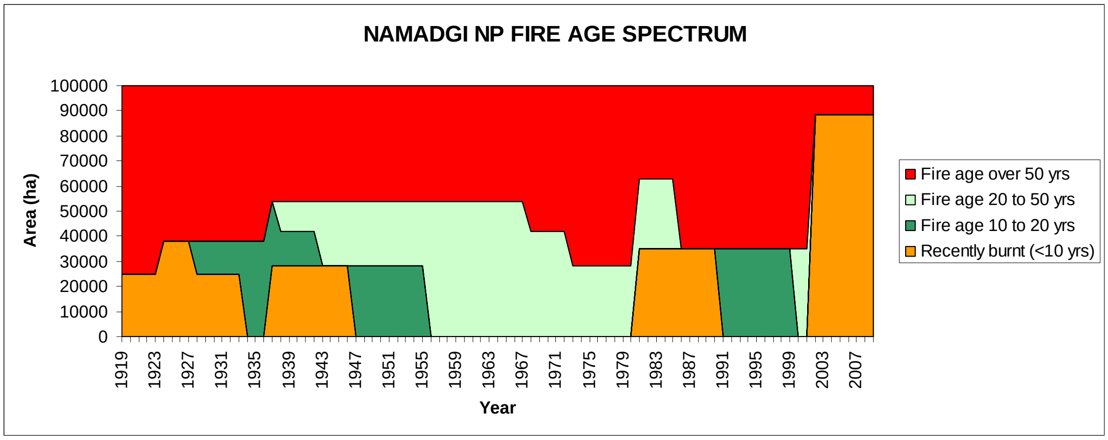


Figure 11. Simplified history and likely progression.

In terms of the time since last major fire at any site, management strategies need to factor in the following important considerations:

- Repeat fires within a time span of less than approximately 10 years could reduce biodiversity by removing species that have not recovered sufficiently to set seed, replenish lignotubers, etc.
- Excluding fire for more than approximately 50 years can result in some species becoming senescent or their seed becoming non-viable. Subsequent fire would remove them from the site until they are able to recolonise from off-site.
- Repeat fires within a time span of approximately 20 years reduces fire fuel loads and the ability for the site to carry a fire to full intensity.

A coherent spectrum of age classes is needed to maximise, across a time series, the proportion of sites in the 10-20 year age class. This strikes a balance between biodiversity maintenance and fire protection. When this spectrum is achieved, modelling indicates that a site will consist of approximately 20% in the 0-10 years age class, 20% in the 10-20 year age class, 30% in the 20-50 year age class and the remaining 30% in the over 50 year age class. This is shown in figure 12.

The main problem of fuel management now becomes one of how to transform a non-optimal fuel-age spectrum into an optimal one such as is seen in Figure 12.

Figure 13 shows the effects of burning too little of an area, on average, per annum: the system becomes unbalanced, with too much old fuel leading to biodiversity issues and making the next cyclic fire inevitably large. Figure 14, on the other hand, shows the effect of burning too much of an area, on average, per annum: The biodiversity management issues become paramount. While this may mitigate the large fire cycle, it is unacceptable for national park and water catchment managers.

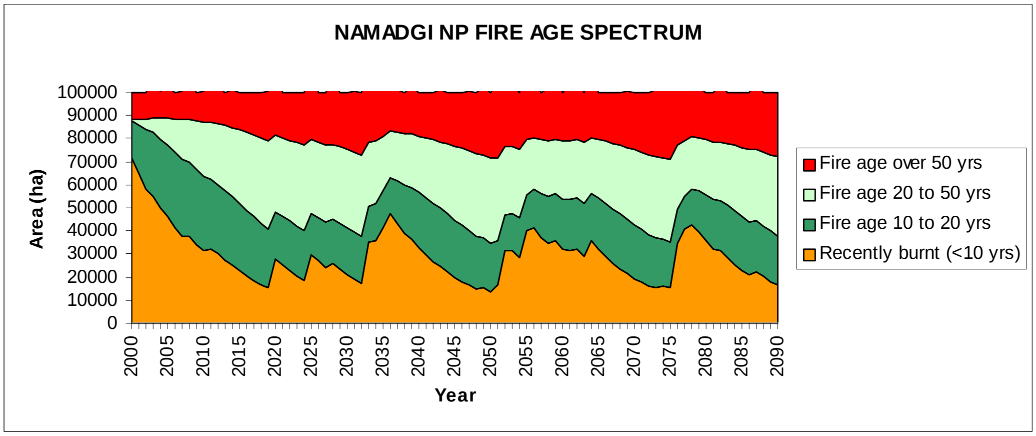


Figure 12. Effects of an optimised burning effort.

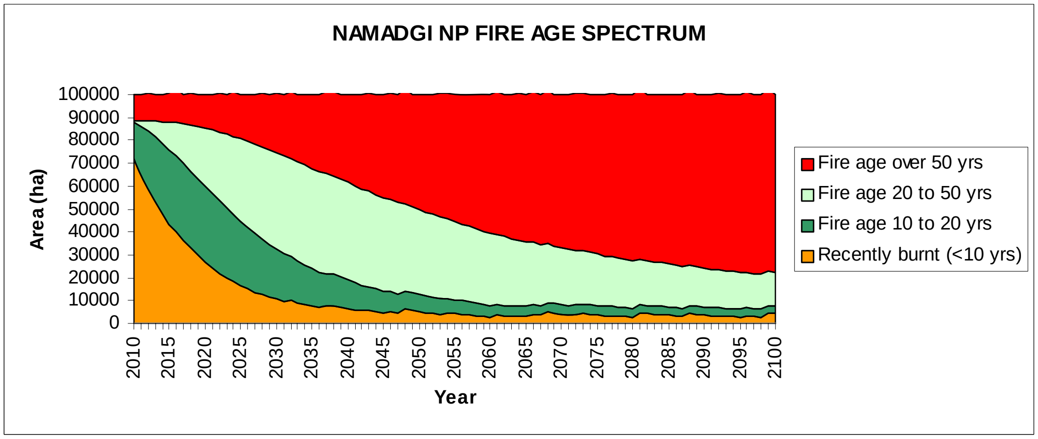


Figure 13. Effects of insufficient burning.

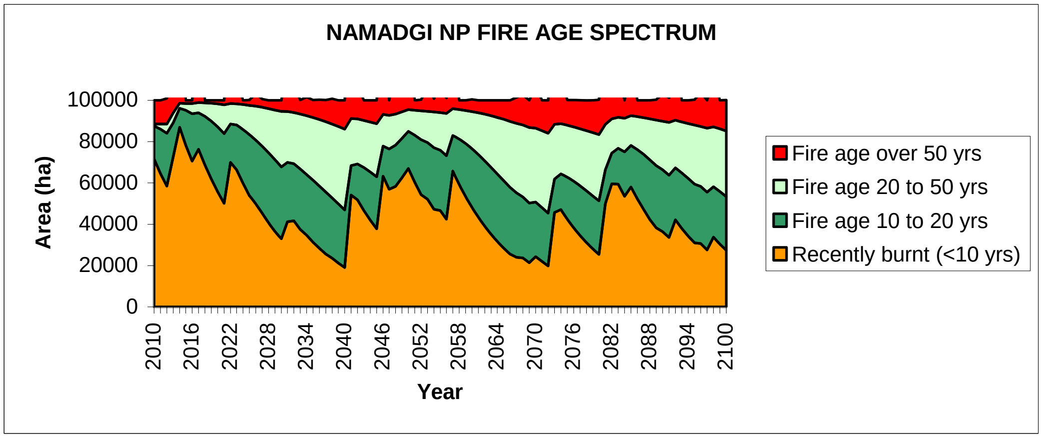


Figure 14. Effects of too much burning.

There are significant issues associated with striking the right balance between burning too much and too little of an area. These include:

- Resolution of policy conflicts, arising from the goals of the various pieces of legislation or of various agencies and companies.

- The ability of government land and fire management agencies to commit the required resources to achieve these goals.
- It takes upwards of thirty years to achieve the transition from quasi-cyclic jumps in fuel-age classes to a steady-state. This cannot be rushed; otherwise it simply results in a similar imbalance in the fuel-age spectrum, which again primes the landscape for the next large fire.

Summary

The foregoing discussion has outlined the concept of a fire size class approach to bushfire risk modelling and the likelihood of the various transitions between these classes occurring. Consideration of this framework in a high country setting led us to focus on some significant factors that have bearing on the question of the inevitability of big fires in high country landscapes. In particular, the high country exhibits the following characteristics:

- A landscape that is prone to multiple ignitions in places where fire suppression is most difficult.
- A landscape that is prone to a range of processes that can affect the probabilities of fire escalation.
- A landscape that stores the effects of past large fires in the landscape-scale fuel-age distribution – the last big fire primes the landscape for the next one.

Some background conditions must be met for big fires to occur in this landscape; most notably, a severe drought is required. Much of the literature on anthropogenic climate change and its impacts on the Australian region infer that the likelihood of such droughts may increase with time.

To avoid a big fire it appears that a narrow path must be followed. This includes prior effort to establish a sustainable fuel-age spectrum. Ideally this would also involve development of an extensive fire trail network to permit rapid initial attack. If fire escalation occurs it is feasible that in some circumstances a big fire is inevitable.

References

Bradstock, R. & Carey, G. (2001). What Governs Fire Regimes? *Proceedings Australasian Bushfire Conference*, Christchurch.

Fromm, M., Tupper, A., Rosenfeld, D., Severanckx, R. and McRae, R. (2006). Violent pyro-cumulonimbus storm devastates Australia's capital and pollutes the stratosphere. *Geophysical Research Letters* Vol **33** L05815

McRae, R. (1992). Prediction of areas prone to lightning ignition*. International Journal of Wildland Fire* **2**(3), 123-130.

McRae, R. (2002). *The Phoenix Imperative – some thoughts on the Namadgi Fire Age Bottleneck*. Unpublished report for ACT Bushfire Service.

Mills, G.A. (2006) On the sub-synoptic scale meteorology of two extreme fire weather days during the Eastern Australian fires of January 2003. *Australian Meteorological Magazine* **54**, 265-290.

Sharples, J.J. (2007). Review of Mountain Meteorology Relevant to Fire Behaviour and Bushfire Risk. (In Prep.)

Trentmann, J., Luderer, G., Winterrath, T., Fromm, M.D., Servranckx, R., Textor. C., Herzog, M., Graf, H.-F., and Andreae, M.O. (2006). Modelling of biomass smoke injection into the lower stratosphere by a large forest fire (Part I): reference simulation. *Atmos. Chem. Phys. Discuss*., **6**, 6041-6080

Viegas, D. X., Pita, L. P., Ribeiro, L. and Palheiro, P. (2005). Eruptive fire behaviour in past fatal accidents. In: Butler, B.W and Alexander, M.E. Eds. 2005. *Eighth International Wildland Firefighter Safety Summit: Human Factors - 10 Years Late*r; April 26-28, 2005 Missoula, MT. The International Association of Wildland Fire, Hot Springs, SD.