# Chapter 1

## General introduction and aims

Logs, bark and litter burning during a hazard reduction fire

# Chapter 1. General introduction and aims

## 1.1. BACKGROUND

Over the last 12 years, extensive bushfires in south-eastern Australia have destroyed thousands of houses and killed hundreds of people. Seven of my colleagues in the New South Wales (NSW) National Parks and Wildlife Service (NPWS) were among those who died fighting wildfires or carrying out hazard reduction burns during this period. Millions of hectares of forests and woodlands were burnt in these fires. Enquiries undertaken after the 2003 fires in the Australian Capital Territory (Ellis *et al*. 2004) and the 2009 Black Saturday fires in Victoria (Victorian Parliament 2010) have recommended large increases in the amount of hazard reduction burning on public land. The Victorian Royal Commission recommended that 5% of public land be burnt annually, as a rolling figure, to reduce the threat from fire to the community. This threat is forecast to grow as the incidence of fire and drought is predicted to increase due to climate change (Pittock 2003, 2005, Dunlop and Brown 2008).

Notwithstanding the loss of life and property caused by these fires and demands from the community for increased areas of hazard reduction burning, land managers need to be aware of the effects of fires on fauna, flora and habitat. The environmental impacts of fire, drought and other disturbances affect biological communities (Gill 1981, Fox and Fox 1986, Recher 1991, Bradstock *et al*. 1995, Keith 1996, Woinarski *et al*. 1997, Watson and Tran 2001, Gill and Catling 2002, Hobbs 2002, Kenny *et al*. 2004, Spencer and Baxter 2006, Penman *et al*. 2008, Montague-Drake *et al*. 2009, Whelan *et al*. 2009, Bowman and Murphy 2010, Croft *et al*. 2010a, 2012). This study investigates the relationships between species and habitat on the one hand and fire and drought on the other, through both experiments and field survey. The findings of this thesis are intended to apply to fire management of open forests and woodlands as well as to fire planning more generally. The current model for fire management in these communities is examined, especially in relation to decisions concerning the application of fire and the recommended upper fire thresholds for the vegetation types studied in northern NSW.

The following literature review concentrates on individual plant species' responses to fire, the compositional changes to vegetation communities at a landscape scale based on fire history and the derivation of recommended fire regimes based on this work. Gaps in knowledge required to conserve plant species, while applying fire management guidelines for vegetation communities, are identified. Similarly, studies of the impact of fire on the amount and quality of fauna habitat in open forests and woodlands are reviewed to determine the extent of knowledge on this aspect of fauna ecology and whether the needs of fauna have been incorporated into fire planning. Initially, however, papers highlighting the effect of climate on the incidence of fire are reviewed: first, to ascertain predicted changes to fire weather and the occurrence of wildfire, and second, how or if this has been factored into fire planning.

## 1.2. REVIEW OF THE LITERATURE

### 1.2.1. Fire, climate and drought

The evolution of Australian vegetation communities has been closely associated with changes in climate and fire regimes through geological time (Kemp 1981, Recher and Christensen 1981, Singh *et al*. 1981, Hall 1994, Whelan 1995, Fox 1999, Frakes 1999, Kershaw *et al*. 2002, Bowman 2003, Dovers 2003, Lindesay 2003). Coevolution over millions of years between fire and much of the Australian flora was contemporaneous with evolutionary adaptation to aridity and low levels of nutrients in soils (e.g. underground rhizomes and lignotubers), which pre-adapted plants to fire (Kemp 1981, Flannery 1994). Climate is one of the key factors that have influenced fire, which in turn was a major disturbance that shaped ecosystems (Williams *et al*. 1994, Bradstock *et al*. 1995, Gill and Bradstock 1995, Woinarski *et al*. 1997, Kershaw *et al*. 2002, Lindenmayer 2003, Lindesay 2003).

The role of climate over both ecosystem function and fire regimes has varied through time (McCarthy *et al*. 2001, Kershaw *et al.* 2002), although the extent and impacts of this control may be exacerbated by climate change (Pittock 2005, Young 2006, Dunlop and Brown 2008, Bowman and Murphy 2010, Clarke *et al.* 2011). Climate change scenarios and modelling predict increases in the frequency and intensity of fires due to the sensitivity of fire regimes to weather conditions (Pittock 2005, Dunlop and Brown 2008, Clarke *et al*. 2011). The environmental impacts of climate change on fire regimes are centred around increased temperatures, changes in rainfall patterns, increases in the amount of fuel, variation in moisture content of fuel and the increase in extreme events such as drought and wildfires (Pittock 2005, Dunlop and Brown 2008, Clarke *et al*. 2012).

The incidence of fire rises after a long drought (Lindenmayer 2003, Bowman and Murphy 2010) while the physiological response of plants to drought can be the same as to fire disturbance, such as resprouting and the depletion of starch reserves or the death of seedlings (Bond and Midgley 2003, Vesk *et al*. 2004, Wright and Clarke 2007). The individual responses of plants to fire alone are well known through the classification system of Gill (1981) where woody plant species are grouped in relation to fire as non-sprouters and sprouters. Non-sprouting plants are subdivided according to whether seed storage occurred on the plant or in the soil. The location of regenerative buds (subterranean or aerial) is the second subdivision of sprouters in Gill's (1981) classification.

Many authors have noted plant responses to different disturbances including fire, disease, herbivory, frost, wind damage and drought (Gill 1981, 1997, Vesk *et al*. 2004, Wright and Clarke 2007) ,while others have highlighted the drought resistance of plant species in more detail (Landsberg 1985, Davidson and Reid 1989, Heinze *et al*. 1998, Morgan 2004, van Nieuwstadt and Sheil 2005). Some of these adaptations include vegetative recovery capacity and soil seed stores (Gill 1981, Keith 1996), protection of epicormic buds by bark and in lignotubers and rhizomes, extensive deep root systems and epicuticular waxes (McArthur 1968, Davidson and Reid 1989, Williams and Gill 1995, Hill 1998). However, the cumulative effects of combinations of such disturbances have rarely been considered in fire planning despite the fact that drought is a prominent feature of the Australian climate, and predicted to become more frequent (Australian Greenhouse Office 2003, Pittock 2005). Keith (1996) and van Nieuwstadt and Sheil (2005) identified threats to plant survival and possible species extinctions from repeated disturbances such as fire and drought. Yet, there is no evidence in the literature that researchers or land managers have incorporated the synergistic impacts of fire and drought into fire regime guidelines.

### 1.2.2. Fire, habitat and habitat quality

An important factor when considering the effect of fire on the conservation of biodiversity is the concomitant change to the amount and quality of habitat associated with burning. A principal aim of this thesis was to investigate the impact of fire on habitat features of open forest and woodland. A combination of abiotic and biotic conditions determines the distribution and abundance of fauna and flora in these vegetation communities. This biodiversity is related to aspects of habitat heterogeneity, which needs to be defined precisely before it can be measured in the field. Whittaker *et al*. (1973) classified habitat in relation to environmental gradients with extensive spatial components and restricted to physical and chemical aspects of the environment, while Wiens and Graham (2005) considered habitat to be the biotic and abiotic conditions in which a species is able to persist. Knowledge of resource availability is important for understanding wildlife–habitat relationships (Hall *et al*. 1997) and examining the impact of fire on the abundance and quality of habitat attributes.

The range of variables that contribute to fauna habitat is summarised in Fig. 1.1 and includes:

- Landscape physical attributes referring to features such as elevation, slope, aspect, parent material, etc. (Whittaker *et al*. 1973).
- Site attributes referring to features such as logs, litter, bark type, shrub cover, grass cover, etc. (Whittaker *et al*. 1973, Kearney and Porter 2004).
- Functional resources referring to features such as water supply, food resources, nest sites, cover, etc. (Wiens and Graham 2005).
- Ecological interactions referring to issues such as biotic interactions including competition, predation, etc. (Mitchell 2005) along with disturbance processes.

Components of site attributes and functional resources contribute to the fuel of fires especially litter, bark, grass and shrubs (McCarthy 2002), but site and landscape variables and ecological interactions are also required elements for the survival and reproduction of wildlife. For example, Courtney and Debus (2006) showed that nest trees with hollows of specific dimensions and located within 2 km of flowering food trees are required for the survival of Little Lorikeets (*Glossopsitta pusilla*) and Musk Lorikeets (*Glossopsitta concinna*) on the North-West Slopes of NSW. These elements are examples of the ecosystem attributes that determine the status of biodiversity in forest and woodland ecosystems (Parkes *et al.* 2003, Oliver *et al*. 2007, Gibbons *et al*. 2009).

Habitat quality refers to the ability of the environment to provide conditions appropriate for population persistence (Hall *et al*. 1997) and can be critical in accounting for the incidence of species (Dennis 2007). It is possible to measure the amounts and kinds of resources available to animals (Hall *et al.* 1997) and use habitat assessments to indicate habitat quality. This is the foundation of wildlife habitat management, and Van Horne (1983) described a three-level hierarchy to assess habitat quality (Fig. 1.2). Information available at one level (e.g. species requirements from detailed ecological studies) allows predictions to be made at another level (e.g. indirect evaluation of habitat quality made from inferences from the results of detailed studies).

The level of assessment required to investigate the impact of fire on habitat attributes of forests and woodlands is included in Fig. 1.2. Mitchell (2005) noted that there is a potentially immense array of habitat variables that may affect species abundance and distribution. However, the key elements have been the subject of numerous habitat relationship studies or identified in habitat assessment methodologies for vertebrates and invertebrates (Parkes *et al*. 2003, Oliver *et al*. 2007, Gibbons *et al*. 2009). Variation in the quality of habitat attributes or the depletion of these resources (Fig. 1.1) can be critical to the occurrence and persistence of species.

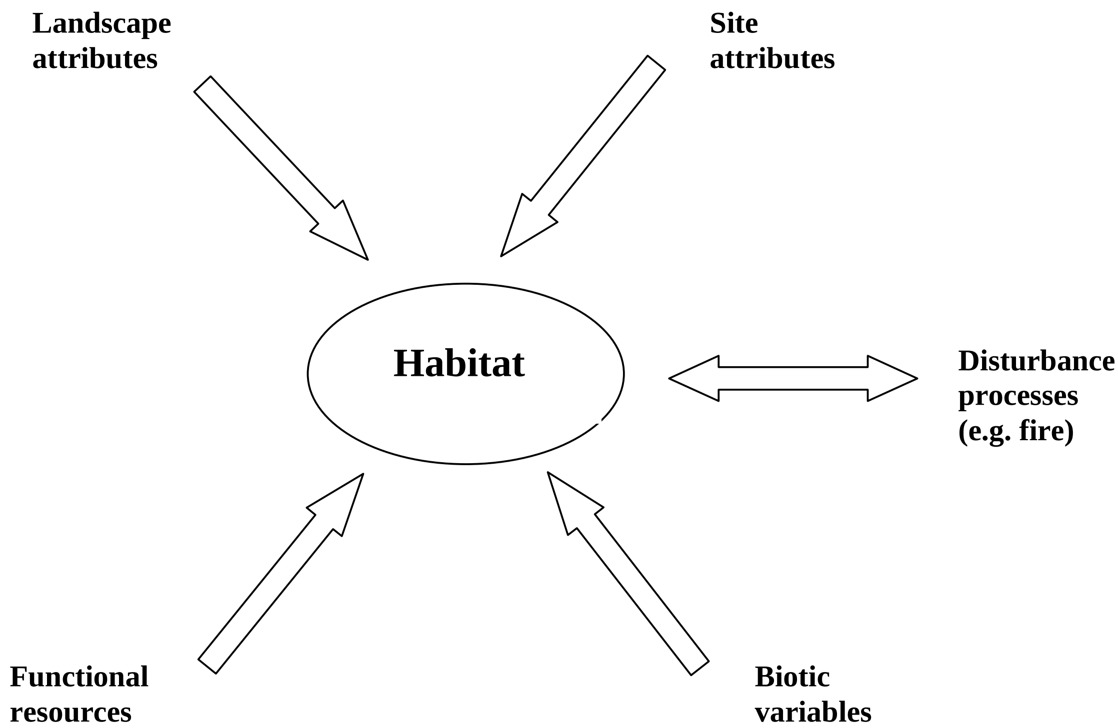


**Fig. 1.1**. Variables that contribute to a functional resource-based concept of habitat and that may be deleteriously affected by a habitat diminishing process. Fire disturbance removes major components of habitat but can also enhance habitat elements (e.g. initiating hollow development or adding to logs on the ground by causing tree fall).

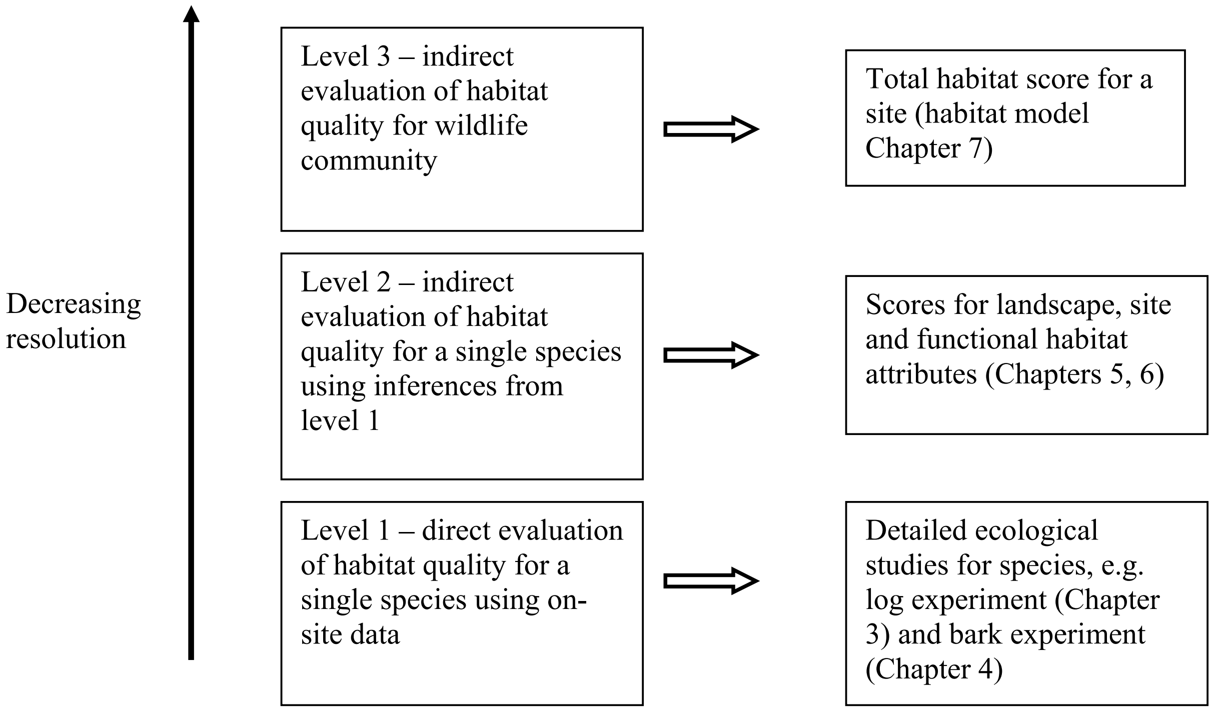


**Fig. 1.2.** Hierarchical description of habitat quality assessments after Van Horne (1983) and its application to the assessment of habitat attributes of forests and woodlands.

Fire modifies habitat characteristics, which in turn impact on fauna populations (Raison *et al*. 1986, Catling 1991, Gill and Bradstock 1995, Hobbs 2002, Whelan 2002, Montague-Drake *et al*. 2009). Habitat diversity is often seen as a surrogate for species diversity (McElhinny *et al*. 2006, Dunlop and Brown 2008). Elements of the habitat of vertebrate and invertebrate animals that can be affected by fire have been defined as tree, shrub and ground cover, litter, bark, woody debris, tree and log hollows, dead standing trees, vegetation structure and floristics, and often include fine details of many of these features such as hollow dimensions or different bark types (Nicolai 1986, Recher 1991, Bennet *et al*. 1994, Gill and Bradstock 1995, Coops and Catling 2000, Gill and Catling 2002, Lindenmayer *et al*. 2002, Parkes *et al*. 2003, Majer *et al*. 2006, McElhinny *et al*. 2006, Oliver *et al*. 2007, Gibbons *et al*. 2009).

Little is known concerning the impacts of wildfire or hazard reduction burning on habitat attributes of open forests and woodlands, with significant gaps in knowledge about the long-term effects and ecological implications of fire on fauna populations (Nicolai 1986, Christensen and Abbott 1989, Williams *et al*. 1994, Bradstock *et al*. 1995, Andrew *et al*. 2000, Hobbs 2002, Lindenmayer *et al*. 2002, Fernandes and Botelho 2003, Clarke 2008). McCarthy *et al*. (2001), Clarke (2008) and Whelan (2009) all suggested that the paucity of research on the effect of fire on fauna habitat and habitat quality should be addressed by field experiments, monitoring and adaptive management so as to reassess the fire response of fauna species.

### 1.2.3. Fire and plant species composition

Observing patterns of variation in species richness has been widely used to systematically appraise the response of vegetation to fire and to determine whether the passage of fire, or a succession of fires, affects the survival and reproduction of plant taxa or potentially causes population declines or extinctions of plant species (Purdie and Slatyer 1976, Gill 1981, Fox and Fox 1986, Christensen and Abbott 1989, Williams *et al.* 1994, Bradstock *et al.* 1995, Gill and Bradstock 1995, Bell and Williams 1997, Gill and Catling 2002, Whelan *et al.* 2002, Tolhurst 2003, Kenny *et al*. 2004, Spencer and Baxter 2006, Penman *et al.* 2008, Wittkuhn *et al*. 2009). Purdie and Slatyer (1976) considered that vegetation succession after fire was dependent on the species composition of the community prior to a fire and found that all species present in the first few years after fire were represented in the community before burning. The response of individual species to fire, whether sprouters or obligate seeders, and the interaction of plant species' responses with the intensity and temporal sequence of fires are also important in characterising the composition of post-fire vegetation communities (Gill 1981, Fox and Fox 1986, Keith 1996, Vesk and Westoby 2004).

In circumstances where there is only moderate or low intensity fire, Vesk and Westoby (2004) found a continuum of responses from plants after burning. Short intervals between fires may eliminate some species (Gill and Catling 2002), and Gill and Bradstock (1995) warned that plant species have become locally extinct due to both too frequent and too infrequent fire. Nonetheless, Christensen and Abbott (1989) recorded more species in regularly burned plots in eucalypt forests in Western Australia. They compared the frequently burnt plots in Karri forest to an adjacent control area unburnt for 40 years; the highest species richness occurred early after the passage of fire. This was similar to the findings of Fox and Fox (1986) and Penman *et al.* (2008). However, the latter authors also showed a general decline in species richness across their wider study area, possibly due to a response to time since the last wildfire (29 years) independent of more frequent burning at the plot scale.

The issue of the longevity and fate of species in long-unburnt eucalypt forests and woodlands has only been cursorily addressed in the literature, mostly in relation to setting upper fire thresholds for plant species and vegetation communities for fire management (Keith 1996, Burrows *et al.* 1999, McCarthy *et al*. 2001, Bradstock and Kenny 2003, Watson 2009). One reason for this is that long-unburnt eucalypt vegetation communities are rare in the landscape (Withers and Ashton 1977, Kenny *et al*. 2004). Nevertheless, models of plant species response to fire generally predict a slow decline in species richness as time since fire increases (Purdie and Slatyer 1976, Bell and Koch 1980, Noble and Slatyer 1981, Spencer and Baxter 2006) or extinction of species due to the senescence of fire-dependent species with long-term exclusion of fire (Gill and Bradstock 1995, Keith 1996). However, there is little empirical evidence that the supposed senescence of species occurs and Gill (1999) considered many of the generalisations concerning plant species' response to fire to be hypotheses only.

Gill and Catling (2002) were concerned with the time scale of observations used to make predictions of vegetation responses and highlighted the need for more case histories to study variation in patterns of plant species richness, taking into account site histories and the characteristics and distribution of regional flora. Such an approach is possible on the Northern Tablelands and North-West Slopes of NSW where the fire histories, including long-unburnt communities of open forest and woodland communities, have been determined (Department of Environment and Conservation 2005a, b 2006, 2007, Department of Environment and Climate Change 2008a, b) and the regional flora is well documented (Clarke *et al*. 1998, Hunter 2000a, b, 2008 a, b), thus enabling hypotheses concerning plant species richness in these communities to be tested.

However, there is a limitation in investigating only species richness per site (species density) as this gives a one dimensional and distorted understanding of diversity at a landscape scale in relation to fire. Cary *et al*. (2003) noted that the ability to scale understanding to broader spatial scales relevant for landscapes remains elusive. Despite this, fire is now moving from a single issue management tool that was once used sparingly to promote some species over others, to one that is now used in management at landscape scale (Kenny *et al*. 2004). Gill and Bradstock (2003) warn that people have incomplete control over fire regimes that can be structured by unpredictable large-scale events and suggested that any prescribed burning should be applied to less than the whole jurisdiction at any one time. In NSW there has been a change in policy to landscape-scale fire management (NSW Ministry of Police and Emergency Services 2012). The effects of such broad scale burning on fauna and flora are poorly understood and a central theme of this thesis was to investigate consequences of limited knowledge of the impact of burning at this scale and to test whether theories of fire management applied to small areas are applicable to changes in scale

### 1.2.4. Fire management, fuel and fire regimes

Fire management based on inappropriate fire regimes has contributed to the world-wide problem of the loss of biodiversity in temperate forests, particularly the species declines in Australian open forests and woodlands (Catling 1991, Gill and Bradstock 1995, Whelan *et al*. 2002, Dovers 2003, Montague-Drake *et al*. 2009, Whelan 2009, Whelan *et al*. 2009). Most Australian fauna and flora have persisted in fire-prone environments for millions of years (B0nd and Keeley 2005). However, interference in fire regimes through applied fire management can jeopardise species survival (Bradstock *et al*. 1995, Whelan 1995, Hobbs 2002, Kenny *et al*. 2004, Clarke 2008). Fire regimes and fire threshold concepts deal with the impacts of fire frequency on species abundance and floristic composition in vegetation types (Bradstock and Kenny 2003). Fire thresholds should vary within a lower and upper threshold to keep all species in a community (Tierney and Watson 2009). Lower thresholds are based on plant vital attributes including primary juvenile periods and regeneration modes while upper thresholds are based on longevity of adults and seed banks (Kenny *et al*. 2004).

Human influence on the fire regime of eucalypt forests and woodlands has been dictated by the community's need to ameliorate the impact of wildfires especially at the urban interface, the aim to conserve fauna and flora in reserved land, or to assist in primary production in grazed lands and managed forests (Good 1981, Catling 1991, Hall 1994, Whelan 1995, Andrew *et al*. 2000, Keith *et al*. 2002, Whelan 2002, Bradstock and Kenny 2003, Fernandes and Botelho 2003, Gill and Bradstock 2003, Penman *et al*. 2008, Whelan 2009). Components of the fire regime that may be affected by land managers include inter-fire interval, fire intensity and season and possibly type of fire (e.g. surface or crown), and manipulation is often attempted by managing fuel loads and fire frequency, as fire hazard is often associated with fuel (McCarthy *et al*. 2001).

McCarthy *et al*. (1999) defined the overall fuel hazard as a combination of the hazard posed by bark, elevated and surface fine fuels. Litter accumulates after the passage of fire to reach a steady state in different vegetation types after approximately 5 years (Watson 1977, Pressland 1982, Raison *et al*. 1986, Cary and Golding 2002). Similarly, fuel in the shrub layer increases for a few years, after which shrubs thin as short-lived species die as time since fire increases (Bell and Koch 1980, Clark 1988, Catling 1991, Catling and Burt 1995, Coops and Catling 2000, Watson and Tran 2001, Bickel and Tasker 2004, Watson 2009).

Despite the documented evidence that fuel does not endlessly build up but plateaus in most vegetation communities as time since fire increases towards the long-unburnt situation, there are still demands for more frequent and widespread prescribed burning after bushfire seasons with loss of life and property (Whelan 2002, Fernandes and Botelho 2003, Victorian Parliament 2010, Ministry of Police and Emergency Services 2012). Research into the fuel dynamics of open forests and woodlands, especially determining trends in fuel loads in long-unburnt vegetation, is essential to plan and implement fire policy and management to achieve community protection and conservation (Dovers 2003) when the ecological effects of frequent hazard reduction burning are not well understood. The effectiveness of prescribed burning for wildfire hazard abatement has been questioned by Fernandes and Botelho (2003) given that the advantages of such burning on a large scale are not proven. Whelan (2002) warned that frequent broad-scale fire will reduce biodiversity and recommended strategic burning instead in specific zones.

The ecological consequences of high frequency fire and inappropriate fire regimes have been listed as a key threatening process under the *NSW Threatened Species Conservation Act, 1995*. The nature and extent of this threat on habitat features of open forests and woodlands on the Northern Tablelands and North-West Slopes of NSW is unknown. The guidelines for ecologically sustainable fire management prepared by Kenny *et al.* (2004) noted that there are considerable uncertainties in the estimation of upper thresholds for vegetation communities, which in turn are used as surrogates for maximum recommended intervals for fauna conservation. In particular, the habitat attributes of long-unburnt vegetation have not been considered in fire management guidelines for open forests and woodlands. Haslem *et al*. (2011) found the density of fallen timber, bark and hollows to be higher in long-unburnt mallee and they considered the fuel of fires, including hazard reduction burns, to equate to the habitat of fauna. It appears that not only do fire management guidelines not incorporate the requirements of fauna, some burning practices may compromise fauna habitat (Inions *et al*. 1989, Catling 1991, Recher 1991, Irvin *et al*. 2003, Clarke 2008).

## 1.3. THE STUDY REGION

### 1.3.1. Survey and experiment sites

National parks, nature reserves and state conservation areas were selected for survey and field experiments on the western edge of the New England Tablelands and adjacent North-West Slopes in north-eastern NSW (Fig. 1.3). Reserved land often supports relatively undisturbed vegetation communities (little or no evidence of clearing, logging or grazing) and fire histories (wildfires and hazard reduction burns) over the past 50 years are generally known and have been mapped.

The study region extended across the Nandewar bioregion and part of the New England Tableland bioregion. Average annual rainfall decreases from east (Glen Innes, 840 mm) to west (Warialda, 700 mm), with a slight dominance of summer–autumn rainfall due to subtropical anticyclones bringing moisture into northern NSW at that time of the year (RACAC 1996). Anticyclones can also direct hot dry north-westerly winds into north-west NSW from the inland, and this is usually the source of fire weather on the Northern Tablelands and North-West Slopes. Droughts recur at approximately ten year intervals. Variation in average annual temperature across the region is correlated with elevation, with cooler temperatures at higher altitudes. For example, at Kings Plains National Park at 840 m a.s.l., the average warm period maximum is 27.2ºC while at Warialda at 460 m a.s.l., the average warm period maximum is 32.0ºC.

The geology of the region is complex with an underlying basement of Palaeozoic and Mesozoic rocks including consolidated and deformed sediments and igneous and volcanic rocks. The landscapes that are formed on the acid volcanic and igneous rocks usually have rounded profiles with convex slopes and outcrops (Morgan and Terry 1999). The survey locations were situated on parent materials such as granite, monzogranite, rhyolite and sandstone that form shallow loams or shallow and stony lithosols with minimal profile development, low water-holding capacity and low fertility (National Parks and Wildlife Service 2000). The vegetation communities surveyed were New England Dry Sclerophyll Forest and Northern Tableland Dry Sclerophyll Forest according to Keith (2004), which are the dominant vegetation types in the study region. Survey and experimental research sites were classified as open forest and woodland communities based on detailed vegetation mapping of reserves by Hunter (1999, 2000a, b, 2008a, b) and Clarke *et al.* (1998).

### 1.3.2. Previous fire research in the study region

There has been increasing fire research in open forests and woodlands on the Northern Tablelands and North-West Slopes of NSW. Clarke and Fulloon (1997) determined the fire response attributes of 45 rare plants growing in rocky terrain on the Northern Tablelands in order to provide fire management guidelines for vegetation communities with these plants. Hunter (2000a, b, 2008a, b) reviewed the fire response of individual taxa in conservation reserves across the tablelands and slopes of NSW and recommended burning regimes for all the vegetation communities that were described. Similarly, Croft *et al.* (2006) determined the fire response of four rare plant species in the Gibraltar Range on the Northern Tablelands and made fire management recommendations for these species. However, none of this research concentrated specifically on the habitat features of the forests and woodlands in relation to fire, although consideration of the impact of fire on habitat may have been implicit in fire regime recommendations.

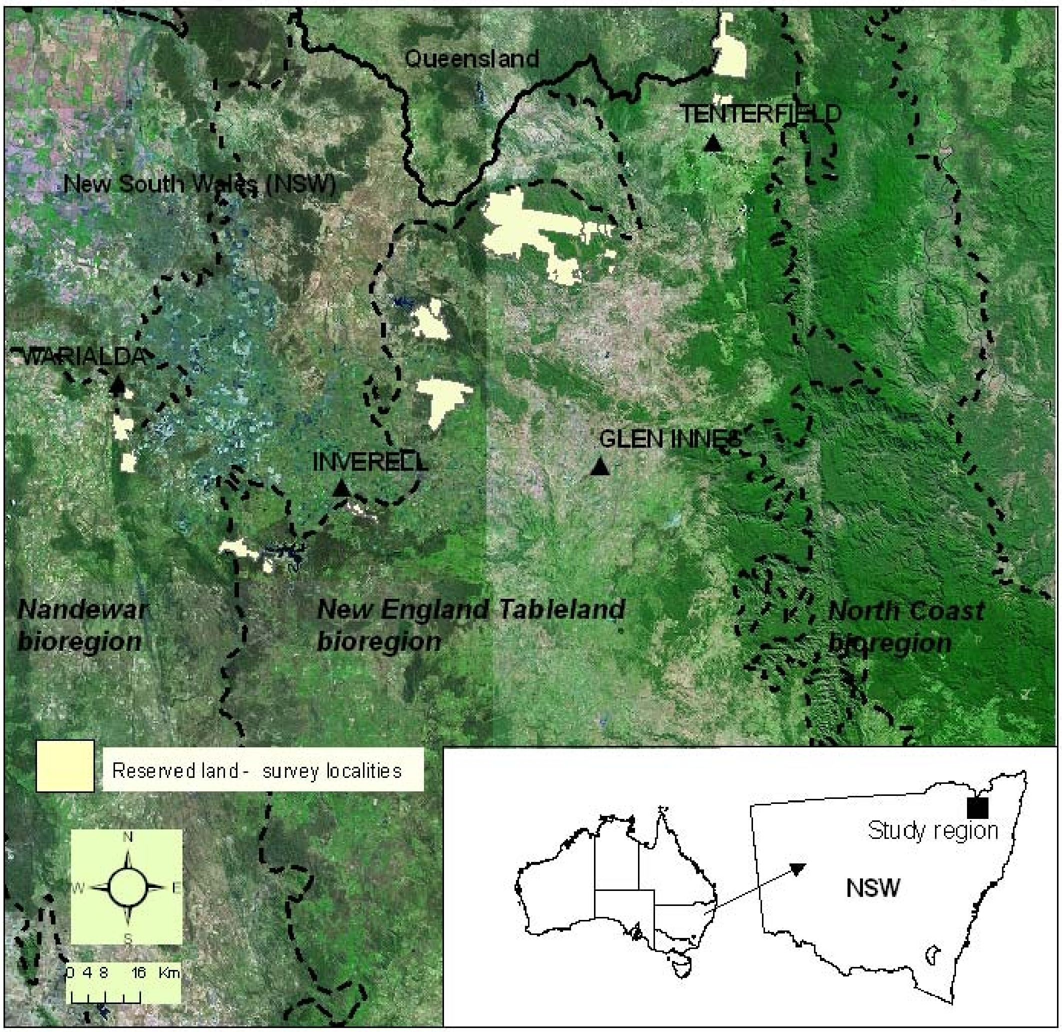


**Fig. 1.3.** General location of the study region and the reserves where surveys and field experiments were conducted.

## 1.4. THESIS AIMS AND OBJECTIVES

The aim of this thesis was to investigate the impact of fire on habitat attributes of open forests and woodlands, to explore the nexus between plant species diversity and fire and other environmental variables at a landscape scale and to study the response of trees and shrubs to the combined effects of fire and drought. A primary objective of this work was to test the current assumptions of basing the fire thresholds of vegetation communities used in fire planning only on plant species' responses to fire. A management goal of the thesis was to apply research findings to the improvement of recommended fire regime guidelines of open forests and woodlands on the Northern Tablelands and North-West Slopes of NSW to enhance the habitat features of these communities. In relation to fire planning more generally the objective was to test the validity of the single attribute approach (i.e. fire) on habitat and fuel modification.

A specific aim of this research was to determine the impact of post-wildfire drought on the survival of trees and shrubs in open forest and woodland by monitoring the survival of post-fire regenerating eucalypts and shrubs that have been subject to prolonged drought and then to develop an extension to a post-fire regeneration model to include drought. The subsequent management goal was to propose an adjustment to fire regimes recommended for open forest and woodland communities to include severe drought. An objective of the thesis was to the test the efficacy of the proposed fire/drought model through the application of repeated fire and drought to the rare wattle *Acacia williamsiana* and monitoring the survival of repsrouts of this endangered plant species.

A second major aim of this study was to determine the impact of fire on fauna habitat quality, concentrating on two critical habitat components, logs and bark. The habitat quality of fallen timber was investigated by recording the use of burnt and unburnt fallen timber by both vertebrate and invertebrate fauna. Similarly, the habitat value of different eucalypt bark types was defined by investigating the use of four eucalypt bark types by invertebrate fauna. This research was extended to determine the impact of fire on the habitat quality of eucalypt bark by investigating the use of different eucalypt bark types by invertebrates after fire.

The crux of this thesis was to explore the complex interrelationships between plant species diversity and fire and other environmental variables at different scales by investigating post-fire species succession in open forests and woodlands and identifying and recording species composition in open forests and woodlands with known fire histories. At the same time species diversity was measured in relation to time since fire at three scales (alpha, pattern, gamma) while considering the impact of landscape variables, other than fire, on the occurrence of species. Concurrently, a further major aim of this survey was to investigate the impacts of fire on the habitat attributes of open forests and woodlands by identifying and recording habitat features in open forests and woodlands with known fire histories.

In relation to fire management and the communities' concern about fuel hazards in the bushland, an aim of the thesis was to measure post-fire fuel dynamics and apply results to overall fuel hazards in open forests and woodlands by assessing fuel loads in this type of vegetation with known fire histories. A fire–habitat–fuel model for open forests and woodlands could then be developed for application in fire management by combining results of research in this thesis including changes in litter, ground and shrub cover, total fuel and habitat features in relation to time elapsed since fire. The objective was then to propose fire management guidelines and refine existing habitat score guidelines to include effects of fire on the quality of habitat attributes of open forests and woodlands.

The overall aim of the thesis was to integrate these specific objectives into a broader understanding of fire management at a landscape scale while being aware of the need to protect life and property. The consequences of managing fire at broader scales are complex and poorly understood. This thesis tests ideas concerning the incorporation of severe drought and landscape attributes into fire planning. Furthermore, flora and fauna conservation in relation to fire planning is extended beyond the use of fire as a single issue management tool where burning is triggered based solely on the response of plant taxa to fire.

## 1.5. THESIS OUTLINE

The impact of fire and drought as environmental extremes on plant species was investigated in open forests and woodlands on the Northern Tablelands and North-West Slopes through field survey in Chapter 2.1. The responses of tree and shrub taxa to the combination of both disturbances were recorded and a new model of regrowth response presented. In Chapter 2.2, the model was tested experimentally for the rare wattle *Acacia williamsiana* by extending the sequence of fire and drought to individuals of an isolated population of the wattle. The implications of the fire and drought plant response survey and subsequent field experiment were considered in relationship to the fire management of the vegetation communities studied in Chapter 2.

An experimental approach and field survey was also adopted in this thesis to increase the understanding of the effect of fire and fire regimes on species composition and habitat attributes in open forest and woodland (Chapters 3, 4, 5 and 6). No studies have investigated the impact of fire on the habitat quality of individual components of fauna habitat in these vegetation communities. In Chapter 3, the habitat value for invertebrates of four eucalypt bark types was measured, as well as experimentally burning the same bark to assess any niche changes within and between bark types due to fire. A similar methodology was applied to partially burnt and unburnt logs located in burnt and unburnt forest in Chapter 4 to ascertain whether fire affected the quality of logs as habitat for vertebrate and invertebrate fauna.

These experiments investigated whether habitat suitability was likely to decrease or increase for fauna species occupying two habitat components (bark, logs) of forest and woodland communities due to simulated fire (one event). However, the habitat structure and complexity of open forests and woodlands has usually been subjected to a variable fire regime over many years. Gill and Catling (2002) and Kershaw *et al.* (2002) pointed out that certain aspects of past fire regimes (e.g. fire intensity or season) are difficult or impossible to discern from records, but fire intervals may be better known for some woodlands and forests in historical time. In Chapters 5 and 6, such records and oral histories were collated to determine the time since fire for selected open forest and woodland sites. This information was used to design a survey to study the effect of time since fire and other environmental variables on plant species composition and diversity (Chapter 5) and habitat attributes (Chapter 6) of these communities, and to consider the implications for current fire management and the conservation of fauna populations.

In Chapter 6, the overall fuel hazard was also measured at sites with a range of times since fire spanning 5 to 120 years. The fire histories included imposed fire management regimes at many sites, making it possible for this study to formulate recommendations concerning fire planning with implications for impacts on plant species richness and habitat attributes. Information gained from long-unburnt sites studied as part of this thesis added to our knowledge of fauna habitat in open forests and woodlands and therefore improved recommendations of maximum fire intervals for habitat protection and enhancement. A model presented in Chapter 7 incorporated results of the survey of species composition and habitat features of open forest and woodlands and detailed fire impact experiments on individual habitat features into a fire management model for the vegetation communities studied.

# Chapter 2

## Plant responses to fire and drought and fire management

Resprouting after fire affected by drought, Kings Plains National Park

# Chapter 3

## Fallen timber and fire

The rare Border thick-tailed gecko lives under fallen timber

# Chapter 4

## Bark habitat and fire

Eastern Long-eared Bat roosts under sheets of bark (photo: Phil Sparke)

# Chapter 5

## Vegetation composition, species richness and turnover in relation to time since fire in eucalypt open-forests and woodlands, with special reference to long-unburnt communities

Species rich understorey, Torrington State Conservation Area

# Chapter 6

## The habitat attributes of long-unburnt open forests and woodlands dictate a rethink of fire management theory and practice

Yellow-tufted Honeyeater nesting in dense, low shrubs (photo: R. Handy)

# Chapter 7

## General discussion and conclusions

Hazard reduction burning using aerial ignition by ridge-top incendiaries (photo: N Holznagel)

# Chapter 7. General discussion and conclusions

## 7.1. INTRODUCTION

The main findings of this study are summarised in a model in this chapter and theoretical advances in fire research are highlighted while consideration is given to further research required to enhance knowledge of the impact of fire on flora and fauna habitat. The results of the research are incorporated into recommendations for significant changes to current fire management guidelines for the vegetation communities surveyed in order to conserve flora and fauna while at the same time protecting life and property. In particular, the thresholds for burning vegetation communities based on plant vital attributes were shown to be inadequate to provide optimum fauna habitat.

## 7.2. SUMMARY OF MAIN FINDINGS

In Chapter 2.1 a stochastic sequence of fire and drought on the Northern Tablelands and North-West Slopes of NSW provided the opportunity to monitor the response of seven trees and two shrubs in a woodland community to these combined disturbances. Mortality in these species affected by drought was similar to that in plants affected by both fire and drought. In cases where plants survived, results suggested that resprouting after drought occurred from buds located on the same morphological parts of tree and shrub species as after fire. The loss of bud resources through the combined affect of successive fire and drought is likely to be more damaging for plant survival and persistence than one or other disturbance on its own. When plants are forced to use bud resources as a result of repeated disturbances, recovery vigour and survival may be diminished. This effect was demonstrated for the rare wattle, *Acacia williamsiana*, in Chapter 2.2. A second sequence of fire and drought, 5 years after the first fire and drought, killed all *A. williamsiana* resprouts. The mechanism by which this may have occurred is that the starch reserves and dormant buds of the previous adult plant's rhizomes were exhausted or destroyed by the second short-interval experimental fire.

Experimental burning was also used in this thesis to investigate changes in the quality and amount of log and bark habitat through fire. Fallen timber is a key habitat feature of forests and woodlands for vertebrate and invertebrate fauna. Similarly, the bark of eucalypt trees is a significant habitat attribute, with different bark types supporting varying populations of fauna. Fallen timber and bark also contribute to fuel loads in wildfires and hazard reduction burning with a concomitant loss of habitat and modification of habitat resources through fire. In most taxa, twice as many animals occurred under unburnt as under burnt artificial timber refuges. Fauna made greater use of experimental refuges in burnt forest. The quality of fallen timber as habitat for fauna is reduced due to changes caused by burning. The same effect was found for some types of burnt bark. Burning bark caused a reduction in total arthropod abundance. Of the four types of eucalypt bark tested (gum, box, stringybark, ironbark), burnt stringybark and gum bark had reduced invertebrate abundance. The relative number of animals caught from the unburnt bark types varied with the least number of animals trapped from box bark, followed by gum bark and stringybark, with the greatest number from ironbarks.

The model in Fig. 7.1 summarises the main findings of the major field survey reported in Chapters 5 and 6 undertaken to determine the impact of fire on plant species diversity and habitat attributes of open forests and woodlands. There was a slight drop in species richness in long-unburnt vegetation but species were found in vegetation communities that had not been burnt for long periods (over 100 years) that were not present in more frequently burnt sites.

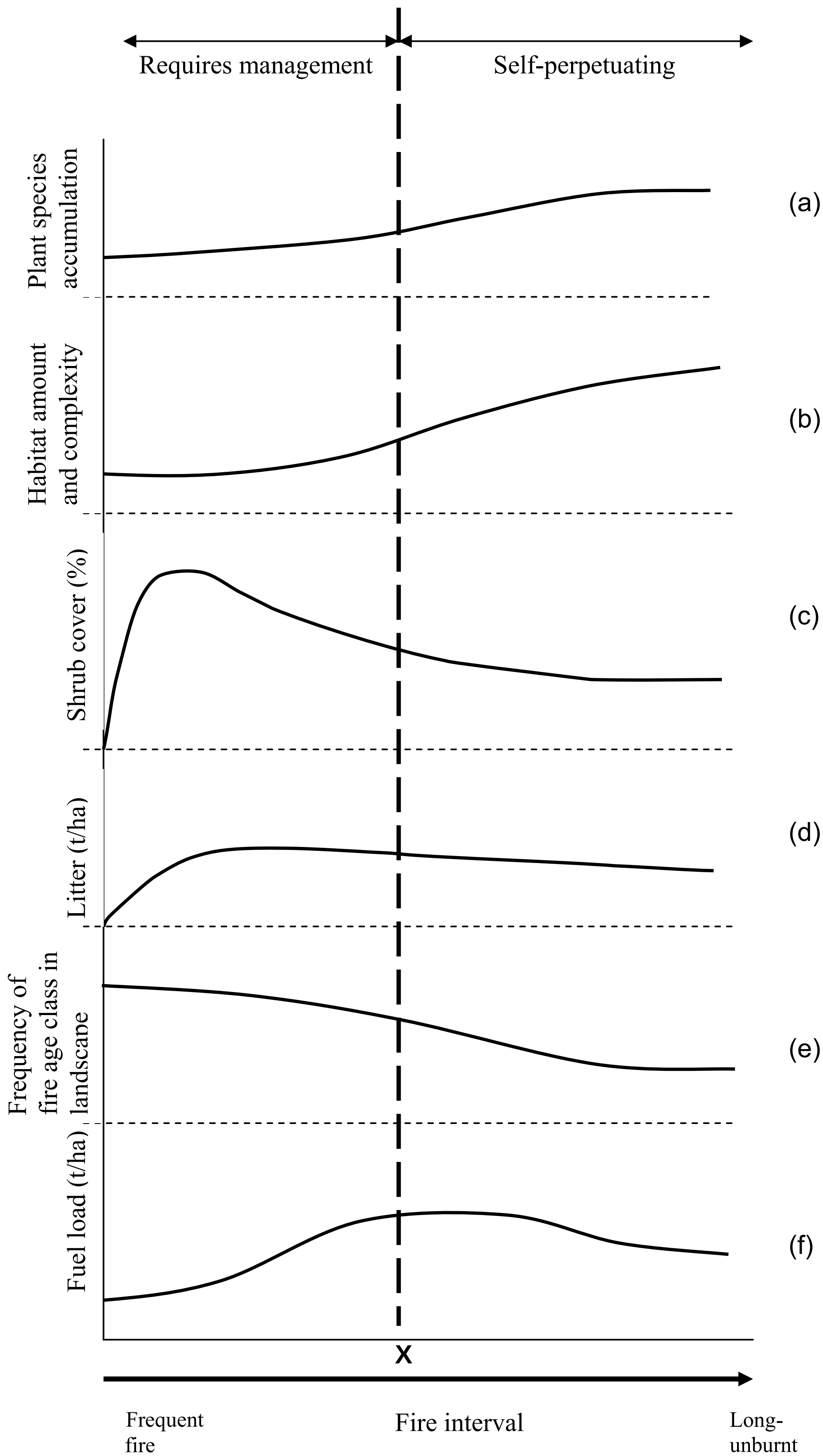
Requires management
Self-perpetuating
Plant species accumulation
(a)
Habitat amount and complexity
(b)
Shrub cover (%)
(c)
Litter (t/ha)
(d)
Frequency of fire age class in landscape
(e)
Fuel load (t/ha)
(f)
X
Frequent fire
Fire interval
Long-unburnt

Figure **7.1.** Model of the relationship between fire interval and management affecting habitat complexity, species abundance and fuel dynamics. To maintain fuel loads at levels to protect life and property and concomitant amounts of habitat attributes modelled to the left of the dividing line (X) requires extensive management input (fire planning, trail construction and maintenance, fuel reduction in asset zones, hazard reduction burning in strategic zones, fire fighting resources) whereas the self perpetuating state (i.e. no imposed hazard reduction burning) to the right of the line results in greater amounts of habitat features in the landscape with moderate fuel loads. (a) Species accumulation in relation to time since fire with long-unburnt sites contributing to landscape scale diversity. (b) Fallen timber, log hollows and tree hollows contribute significantly to habitat complexity in long-unburnt vegetation along with bark, litter and shrubs. (c) Shrub cover increases after fire but eventually decreases in long-unburnt vegetation. (d) Litter load increases immediately after fire but reaches a steady state level approximately 30 years after fire in this study. (e) Long-unburnt vegetation communities were uncommon in the study region. (f) Fuel load increases for up to 30 years after fire but eventually falls in long-unburnt vegetation. The fuel load triggers burning by land managers at time 'X' since fire (usually 10–30 years), however without fire species diversity and habitat complexity continue to increase while fuel loads fall in long-unburnt vegetation communities.

Long-unburnt sites contribute to landscape species diversity (Fig. 7.1a) and play a role in species turnover at a landscape scale. I found that pattern diversity was greatest in long-unburnt sites while turnover between sites was almost four times less immediately after fire than at 31–50 years since fire.

I also showed in Chapter 5 that other landscape variables (especially slope) significantly affected species diversity. Fire was more recent in locations low in the landscape and with deeper soils whereas long-unburnt sites were primarily on steep slopes with shallow soils. In my study long-unburnt sites were not only rare in the landscape generally but also on lowland sites. However, I found that even long-unburnt areas in higher topographic positions, with their concomitant unique flora composition in the study area, are threatened by fire management activities such as aerial ignition of ridge tops during hazard reduction burning.

A further important conservation outcome is summarised in Fig. 7.1b where there is an increase in certain habitat features in open forests and woodlands as time since fire increases. There were significantly more tree hollows, amounts of fallen timber and log hollow habitat in long-unburnt vegetation. In long-unburnt sites I recorded over 100 tree hollows per hectare and found that frequent burning had significantly reduced the density of hollows in open forests and woodlands on the Northern Tablelands and North-West Slopes of NSW. Fallen timber accumulated at a rate of 10m/ha per year with 1400 m/ha of fallen timber, or a volume of 60m$^3$/ha, in long-unburnt vegetation and this amount of fallen timber contained over 400 log hollows/ha compared to less than100 log hollows/ha at frequently burnt sites.

However, patches of long-unburnt vegetation were rare in the landscape (Fig. 7.1e) due to both the extent of hazard reduction burning and the number and frequency of wildfires (possibly exacerbated by climate change). The need to undertake hazard reduction burning on a broad scale was demonstrated to be unnecessary in the vegetation communities studied, as components of the fuel load diminished in longer unburnt vegetation. The shrub layer thinned as the time since fire increased (Fig. 7.1c), litter reached a steady state level relatively soon after fire (Fig. 7.1d) and the total fuel load fell in long unburnt vegetation (Fig. 7.1f). Currently land managers burn prior to time 'X' since fire ( in the vegetation communities studied in this thesis between 10–30 years) in the model in Fig. 7.1 as the fuel loads (litter and shrub cover) build up and there is a perceived need to burn to reduce this fuel. This becomes a continual management cycle requiring the use of extensive fire fighting resources but by allowing the vegetation to remain without fire (notwithstanding unplanned wildfire) beyond time 'X' fuel loads eventually fall while certain habitat features increase. The latter state can be achieved and maintained without management input (Chapter 7.3.2), thus saving limited resources and allowing the reallocation of these resources to be utilised more effectively for conservation, while at the same time reducing the risk to life and property.

## 7.3. MAIN CONTRIBUTIONS OF THIS STUDY

### 7.3.1. **Contribution to scientific theory and practice**

This study has both extended current scientific theory and introduced new theories and models in the disciplines of the ecological impact on plants due to climate change, plant species dynamics in relation to fire and landscape variables and the conservation of habitat in fire-prone landscapes.

In Chapter 2, the results of my study of plant responses to the combined disturbances of fire and drought were used to adapt the tree and shrub fire regrowth response models of Marrinan *et al*. (2005) and Gill and Bradstock (1992) to include the drought responses of these plants (Fig. 2.2). A new dimension to fire planning was highlighted by incorporating fire and drought disturbance into the resilience paradigm of Bauer and Goldney (2000) with an application of their model to demonstrate how plant species extinction can occur as a result of inappropriate fire management of vegetation communities experiencing drought (Fig. 2.4). Bowman and Murphy (2010) predicted that climate change is set to make fire management more complicated due to changes to fire risk, ecosystem function and the habitat template for fauna and flora.

Relatively little work has been conducted on the practical application of strategies for adapting to climate change (Hulme 2005) especially in areas aimed to increase flexibility in managing of vulnerable ecosystems. This thesis elucidated one element of the risk to flora of the combined disturbance of drought and fire and proposed a strategy to adapt management of vegetation communities experiencing stress due to climate change (Chapter 7.3.2.) An understanding of how biodiversity will respond to climate change and the implications for conservation is reported in my thesis. This type of work was considered a priority area of research by Dunlop and Brown (2008) in their assessment of the impact of climate change on Australia's national reserve system.

There are significant gaps in knowledge about the long-term effects and ecological implications of fire on fauna populations (Bradstock *et al*. 1995, Lindenmayer *et al*. 2002, Clarke 2008). McCarthy *et al*. (2001), Clarke (2008) and Whelan (2009) all suggested that the paucity of research on the effects of fire on fauna habitat and habitat quality should be addressed by field experiments, monitoring and adaptive management so as to reassess the fire response of fauna species. No studies had investigated the impact of fire on the habitat quality of individual components of fauna habitat in open forests and woodlands. Experiments described in Chapters 3 and 4 addressed this deficiency and showed that habitat suitability for fauna occupying two habitat components (logs, bark) was detrimentally affected by fire. At the same time, the habitat value of four eucalypt bark types (gum, box, stringybark and ironbark) was compared with different bark types supporting varying populations of invertebrate and vertebrate fauna. Majer *et al*. (2006) considered tree bark to be an important source and substrate for forest biodiversity and suggested that fire management practices have the potential to adversely influence bark-associated invertebrates. This effect was confirmed for two bark types (stringybark, gum) in this thesis by comparing the composition and abundance of invertebrate populations on burnt and unburnt trees of these bark types.

Hobbs (2002) suggested that fire regimes can be expected to impact on fauna populations to the extent that they modify habitat characteristics. In Chapter 6, I found that variation in habitat attributes of open forests and woodlands were determined by many landscape variables (e.g. slope). Time since fire also had a major influence on the amount of fallen timber, tree hollows, log hollows and bark habitat in the vegetation communities surveyed in this thesis, with significantly more of these features in long-unburnt vegetation. Kenny *et al*. (2004) commented that there was no fire response scheme for fauna or fauna habitat and proposed that fire regimes that are acceptable to maintain plant species composition would be appropriate for managing fauna populations. This thesis has cast doubt on the theory that a suitable range of habitats will be maintained by relying solely on plant species requirements. I propose that knowledge of the habitat features of open forests and woodlands should contribute to a fire response scheme for fauna and recommend a new upper fire threshold (50+ years) for the vegetation communities studied.

The link between fauna habitat and fuel was also investigated in Chapter 6 where advances have been documented in empirical research into fire–fauna relationships. This theme has generally been neglected in studies of the association between fire and fuel (Haslem *et al*. 2011). Fuel loads declined in long-unburnt open forests and woodlands with a concomitant increase in habitat attributes (Fig. 6.19). Haslem *et al*. (2011) found a similar result for mallee. This research has enabled the formulation of explicit guidelines for managers attempting to manipulate fuel loads while maintaining fauna habitat.

This study has highlighted the fact that ecological fire management in Australia has not met the needs of fauna in the study region. Despite being built on the assumption that plant requirements are being met (Clarke 2008), burning frameworks have not fully maintained plant community diversity (Chapter 5) except in the rare circumstances where long-unburnt communities (i.e. beyond recommended upper fire thresholds) have remained in the landscape. Manipulation of fire within the landscape is one of the many factors that influence plant composition and richness. Data presented in this thesis links landscape location, along with time since fire, to plant species incidence and abundance in open forests and woodlands. This combination of effects had not been previously investigated in this type of vegetation. Furthermore, the complex interaction of gamma diversity, pattern diversity, environmental variables and fire history with plant species abundance demonstrated in Chapter 5 had not been considered previously in fire research or fire planning in south-eastern Australia.

### 7.3.2. Management recommendations

The impetus for undertaking this research was due to perceived deficiencies in information on the effects of fire on fauna, flora and habitat, and lack of awareness by land managers and researchers of the long term impact of fire on vegetation communities. This situation poses a threat to biodiversity conservation and has been exacerbated by demands for increased areas of hazard reduction burning (House of Representatives Select Committee 2003, Ellis *et al*. 2004, Victorian Parliament 2010, Independent Hazard Reduction Audit Panel 2012). There is an expectation in the public's mind that management agencies should always be capable of managing fire (Clarke 2008) but Gill and Bradstock (2003) recognised the incomplete control people have over fire regimes. They advocated caution when applying prescribed burning as part of land management policy (Gill and Bradstock 2003, Clarke 2008).

Fire management for human protection through suppression and hazard reduction burning is well recognised and necessary in fire planning (Bradstock *et al*. 1995, Bradstock and Kenny 2003, Moritz *et al*. 2004, Spencer and Baxter 2006). However, this burning should be targeted to strategic locations to protect life and property rather than undertaking widespread hazard reduction burning that can threaten biodiversity while providing limited fire protection (Gill 1981, Catling 1991, Spencer and Baxter 2006).

The perception that vegetation has to be actively managed for fire to conserve biodiversity in the future (Penman *et al*. 2008) has been shown to be incorrect in circumstances described in this thesis (Fig. 7.1, long-unburnt vegetation) where passive and protective management (i.e. no hazard reduction burning undertaken and protecting such areas during wildfire suppression) can be justified. Notwithstanding this scenario, widespread prescription burning is now common in Australia and will increase (Victorian Parliament 2010, Independent Hazard Reduction Audit Panel 2012). Climate models project changes in fire weather leading to fire seasons starting earlier and lasting longer. Fire management recommendations, developed from the research findings described in this thesis, are intended to ameliorate the impacts of both natural and prescribed fire and they go beyond the limited response by governments and fire authorities of simply increasing areas of hazard reduction burning and treating fire in isolation to other variables such as drought and landscape position.

This thesis has demonstrated that managing fire for biodiversity conservation is complex. Fire planning needs to consider the diminution of both the amount and quality of habitat and the loss of plant taxa at landscape scales as well as incorporating severe drought into fire planning. I have shown that the combined effect of drought and fire on plants' regenerative resources can cause plant species population declines. Therefore, fire histories should be adjusted to include severe drought in fire planning with such a severe disturbance being treated the same as a fire in the fire chronosequence of a vegetation community.

This study has also highlighted the ecological consequences of fire for habitat quality and amounts of log and bark habitat, whether through wildfire or hazard reduction burning. Fuel was equated to fauna habitat and fuel consumption by hazard reduction should be quantified by the measurement of post-burn habitat variables to assess the impact of burning on the amount of fauna habitat remaining in the landscape. The volume of logs, as well as the degree of charring of log surfaces, should be monitored in hazard-reduction zones to help fine-tune fire management. The prescriptions for undertaking hazard reduction burning (temperature, wind strength, drought index etc.) can be adjusted to ameliorate the effects of the prescribed burn on the amount and quality (degree of charring) of log habitat. Similarly, the deleterious impact of fire on bark habitat resources needs to be considered in developing fire management guidelines (e.g. by excluding or protecting areas of high bark habitat value in the landscape or having smaller patchy burns).

The amount of bark, shrub cover and ground cover was found to be strongly correlated with time since fire while tree and log hollows and fallen timber volume were more abundant in long-unburnt vegetation. Fire-interval guidelines, especially upper thresholds, need to be adjusted to cater for these habitat requirements of fauna. The upper threshold for the communities studied in this thesis should be raised to 50+ years.

A reduction in species richness in long-unburnt vegetation, that exceeds the published fire thresholds for these communities, should not necessarily trigger the need for the hazard reduction burning of these sites or of the community on a broad scale. Investigation of all determinants of species richness, species pools and pattern diversity should be considered before introducing prescribed fire into long-unburnt vegetation simply on the basis of a decline in species richness with time since fire. Long-unburnt vegetation in the study region must be identified as high-conservation–value assets in fire planning due to their contribution to landscape species diversity. A first step in conserving long-unburnt vegetation would be to identify and map such areas and possibly protect them by applying strategic mosaic burning and at the same time encouraging the recruitment of long-unburnt patches.

The approach of mitigating the potential for wildfires by applying broadscale hazard reduction burning, including aerial ignition of large tracts of forest and woodland, must be questioned if plant species diversity and habitat attributes of open forests and woodlands are to be maintained. These techniques should be limited to strategic burning only (e.g. burning zones near urban areas or zones to protect high conservation value areas) or during the suppression of wildfires. This study has highlighted the complexity of the effect of fire and its interaction with other environmental variables such as location in the landscape (topographic position). The importance of topographic position and fire as an influence on vegetation diversity has not been considered in fire planning and this study shows it to be an issue, beyond upper and lower fire interval thresholds, to be incorporated into decisions concerning when and where to burn (e.g. consider excluding more frequently burnt vegetation occurring on lower slopes from hazard reduction burning targets).

## 7.4. FURTHER RESEARCH

The complexities of the impact of fire, along with other environmental variables, on fauna habitat and plant species diversity in open forest and woodland in relation to time since fire are evident from the research presented in this thesis. The significant advances presented in this study provide new information in the neglected area of research concerning upper thresholds applied in fire management addressing fauna habitat requirements. I have mainly concentrated on the value of habitat attributes present in long-unburnt vegetation as well as demonstrating how fire can affect the quality of fauna habitat. This work needs to be extended to further refine thresholds used in the fire management of vegetation communities through some of the areas of study suggested below. The research recommendations extend to addressing the little-known response of fauna and flora to the combined disturbances of drought and fire that may be exacerbated by predicted climate change.

One possible link between climate change (in the form of predicted increased length and frequency of drought) and fire and their combined effect on vegetation communities was investigated in this thesis. This work needs to be extended to determine potential impacts on fauna, especially through the loss of habitat. I have demonstrated in Chapters 3 and 4 that fuel, including logs and bark, equates to the habitat of fauna. It is not known how drought may increase fuel loads through the process of increased drying of potential fuel components (e.g. larger logs) adding to the fuel complex and how this should affect fire management of vegetation communities. However, my observation of hazard reduction burns undertaken after long dry periods indicate that the unintended burning of large logs occurs.

This thesis has demonstrated that fire thresholds used to manage vegetation in natural areas in North-West Slopes and Northern Tablelands of NSW do not adequately cater for the habitat requirements of fauna. Further research is required to refine the upper fire thresholds (that are based on plant vital attributes) employed in fire management to address the needs of fauna inhabiting different vegetation communities that were not surveyed in this thesis, such as tall forests and shrublands and to extend the results to all fire prone vegetation on the east coast of Australia. This thesis found that certain habitat attributes of open forests and woodlands were more abundant in long-unburnt vegetation (amount of fallen timber, log hollows, tree hollows). Whether this leads to greater numbers and species of animals from different groups can be investigated by comprehensive fauna surveys in vegetation communities with different times since fire (e.g. Smith (2013) found the number of late successional reptile species were most common in mallee habitats that had not been burnt for more than 40 years).

Experiments carried out in this study showed that habitat quality was affected by fire. The exact reason for this effect requires further study to determine what microhabitat changes caused a decline in invertebrate and vertebrate fauna occupation of burnt logs and bark. Such work is important as this impact on fauna habitat quality and fauna populations is ubiquitous across increasing areas in NSW, South Australia and Victoria subjected to hazard reduction burning. Future research may identify times and conditions of burning and techniques used to lessen impacts on fauna habitat quality. This study has highlighted the fact that long-unburnt open forest and woodland is disproportionally important for fauna habitat. The same effect was shown for mallee landscapes (Haslem *et al*. 2011). Similar research should now be extended to tall forests on the tablelands, escarpment and coastal regions of NSW that may be liable to burn more readily due to the effects of climate change or that are being increasingly targeted to enhance the area of hazard reduction burning.

I determined the effect of one component of the fire regime, time since fire, on species composition and richness in open forests and woodlands at three different scales (alpha, pattern and gamma diversity). Beta diversity (the compositional turnover of species along gradients) was not able to be measured in this thesis as not enough sites were found with differing fire histories in the same locations. Expansion of the study region may reveal enough sites to investigate correlations between compositional turnover of species according to fire history and other significant environmental variables.

## 7.5. CONCLUSIONS

The aim of this thesis was to investigate the impact of fire on the habitat attributes of open forests and woodlands and to broaden our understanding of fire management at a landscape scale while being aware of the need to protect life and property. The consequences of managing fire at broader scales are poorly understood and this thesis tested ideas concerning the incorporation of severe drought, landscape attributes, the impact of fire on habitat quality and species composition into fire planning and biodiversity conservation beyond the use of fire as a single issue management tool.

The theory that fire thresholds based on plant responses to fire adequately cater for fauna habitat requirements was shown to be inadequate in the open forests and woodlands studied, do not factor in multifactorial issues such as drought and slope and therefore cannot, in itself, protect threatened species and does not reduce fuel loads in the long term. Also, the theory does not take into account how to protect landscape diversity. Instead, I recommend based on evidence in this thesis, that the upper fire threshold for these communities be raised to 50+ years to ensure that fauna vital habitat attributes remain in the landscape. This recommendation would eventually lead to larger areas of long-unburnt vegetation, with concomitant enhanced fauna habitat and increased plant species diversity, in the landscape. In such a scenario fire authorities and the public need not be concerned about excessive fuel build up or threats to life or property, as fuel loads in open forests and woodlands unburnt for 100 or more years were low to moderate and similar to the hazard in recently burnt sites.

Hazard reduction policy in the eastern states of Australia has not adequately considered these complexities with consequent threats to fauna and flora populations. Theories presented in this thesis have elucidated issues related to the impact of fire frequency and scale of burning on fauna and flora in fire planning. The incorporation of the recommendations from the results of this research into fire planning, are intended to ameliorate the impacts of frequent broad scale burning on biodiversity conservation.

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