Threatened Species Recovery Hub

National Environmental Science Programme

Better managing fires and their impacts for koala conservation

Pablo Jose Negret, Daniel Lunney, Jonathan Rhodes

July 2021

The University Of Queensland AUSTRALIA

THE UNIVERSITY OF SYDNEY

Queensland Government

NSW GOVERNMENT Planning, Industry & Environment

Cite this publication as: Negret P. J., Lunney, D., Rhodes, J., 2021. Better managing fires and their impacts for koala conservation. NESP Threatened Species Recovery Hub Project 8.4.5 report, Brisbane.

Cover image: Koala. Image: Craig Garrett, Unsplash

Contents

1. Executive summary 4
2. Introduction 5
   - 2.1 Fire association with koalas 5
   - 2.2 Impact of prescribed burning on koalas 10
   - 2.3 Other factors associated with koala conservation in fire prone landscapes 10
   - 2.4 Approach used for the framework 10
   - 2.5 Purpose of the framework 10
3. How to use the framework 11
4. Maintenance of koala population status 13
   - 4.1 Fire and koala population status 13
   - 4.2 Management actions related to koala population status and fire 13
     - 4.2.1 Fire and the mitigation of other threats 13
     - 4.2.2 Koala population monitoring 13
5. Maintenance of Koala habitat status 15
   - 5.1 Fire and habitat characteristics 15
   - 5.2 Management actions related to koala habitat status and fire 15
     - 5.2.1 Restoration, connectivity and protection of koala habitat 15
     - 5.2.2 Koala habitat monitoring 15
     - 5.2.3 Assessment of habitat status and fire history 16
6. Maintenance of appropriate fire regimes 17
   - 6.1 Fire regimes and koala conservation 17
   - 6.2 Management actions related to fire regimes and koala conservation 17
     - 6.2.1 Prescribed burning management strategies 17
     - 6.2.2 Other fire management alternatives to burning 17
     - 6.2.3 Koala protection actions before and during human induced fires 18
7. Consistency with cultural values 19
   - 7.1 Importance of cultural values for fire management and koala conservation 19
   - 7.2 Recommendations to integrate traditional fire management knowledge with other management practices 19
   - 7.2 External sources related to the association between fire management and cultural values 19
8. Consistency with land use and land management objectives 20
   - 8.1 Fire regimes, koala conservation and land tenure 20
   - 8.2 Fire management actions for koala conservation related to land use and land management objectives 20
     - 8.2.1 Strategies that can be implemented when other management purposes determine fire management protocols 20
     - 8.2.2 Mosaic burning and koala conservation 21
9. Appropriate post fire management 22
   - 9.1 Post fire scenarios and koala conservation 22
   - 9.2 Management actions for koala conservation immediately after fire 22
     - 9.2.1 Koala habitat and population management after fire 22
   - 9.3 Long term management actions for koala conservation after fire 22
     - 9.3.1 Koala rehabilitation and release 22
     - 9.3.2 Koala habitat management after fire 23
10. Future framework development and opportunities 24
    - 10.1 Knowledge gaps 24
    - 10.2 Conclusions 25
11. Acknowledgments 25
12. References 26

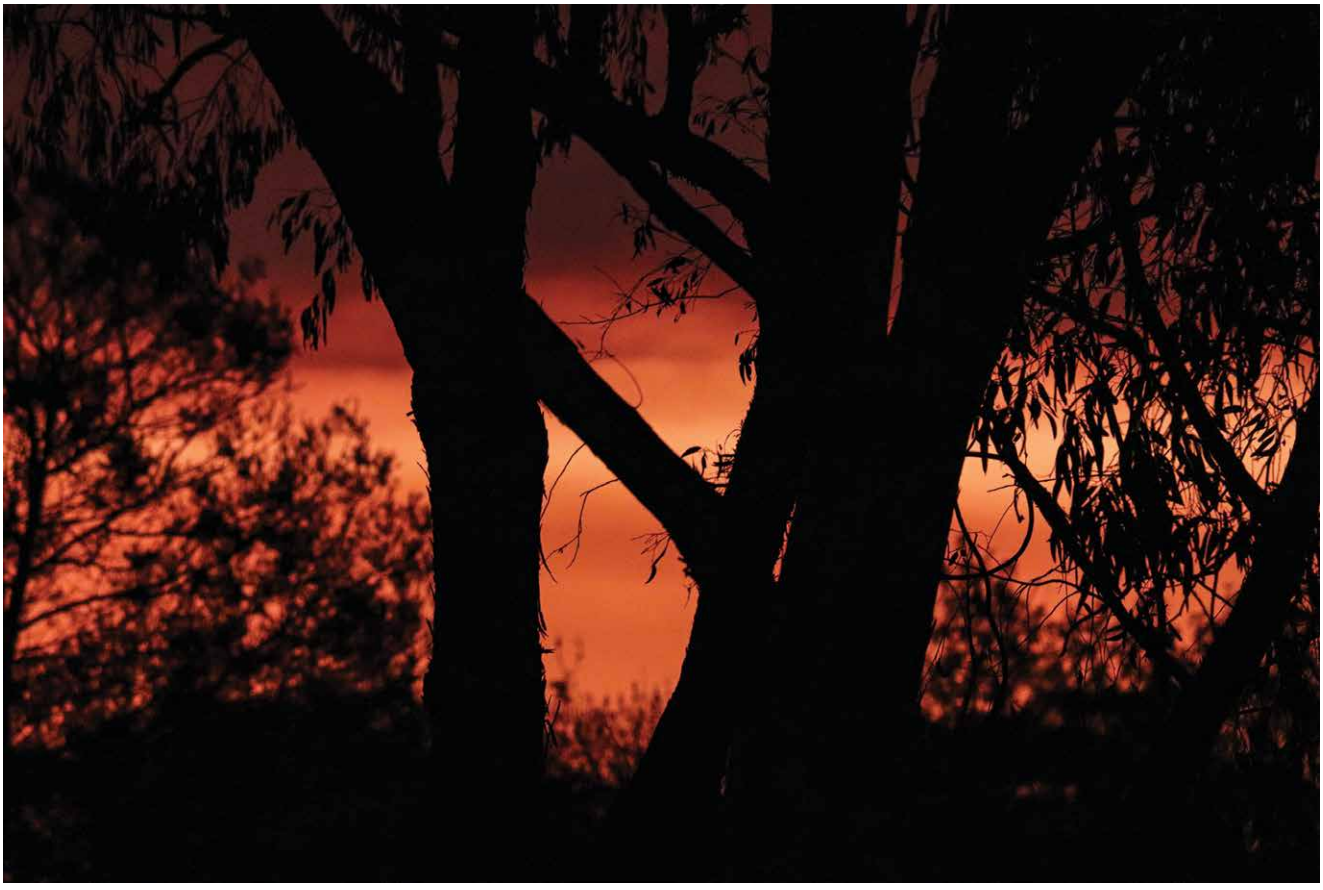
1. Executive summary

The NESP Threatened Species Recovery Hub Project 8.4.5, Better managing fires and their impacts for koala (*Phascolarctos cinereus*) conservation, was a 6-month collaboration to develop a **framework** for fire management for koalas to ensure koala persistence and recovery in the fire prone landscape in which they occur. The project aimed to assist with identifying appropriate fire management and response strategies in priority areas to inform the National Koala Recovery Plan and Queensland and New South Wales koala conservation strategies.

NESP TSR Hub Project 8.4.5 has developed a **Conceptual model** on the effect of the different fire management strategies and alternative post fire actions (including rehabilitation, release and habitat restoration) on koala habitat quality and population dynamics. In order to achieve national koala population recovery and long term persistence in fire prone ecosystems there is the need for guidelines to inform fire management. To support this, the framework includes recommendations and priority actions to inform fire management strategies that support koala persistence and recovery. This includes recommendations and actions to maintain appropriate fire regimes and habitat characteristics that are important for koalas.

Fire is an inherent property of Australian landscapes, which has influenced the country's ecosystems. Understanding what controls the occurrence and severity of wildfire and how to manage fire for maintenance of biodiversity is then crucial for conservation and for human wellbeing. Particularly, in the case of koalas, fire can affect the species habitat quality, as well as directly impact the population numbers through individual mortalities.

This research takes a multiscale approach to conservation that includes a **decision support diagram** that aims to help identify the management actions that can be taken before during and after fire to support koalas long term persistence in fire prone landscapes. This framework takes into account key principles grouped in six components (Maintenance of koala habitat status, maintenance of koala population status, maintenance of appropriate fire regimes, consistency with cultural values, consistency with land use and management objectives and post fire management), that interact with fire management in order to identify management options that could be taken in a fire management context in order to achieve koala habitat and population persistence in the long term.



Bushfires can severely affect some koala populations and habitats. Image: Daniel Morton, Unsplash

2. Introduction

Fire is an inherent property of Australian landscapes, which has dramatically shaped the country's ecosystems. Fire regimes, defined as the patterns, frequency, and intensity of the fires that prevail in an area over long periods of time, have changed along Australia history due to the effect of climate change and Indigenous and European fire management (Bradstock et al., 2012). Changes in burning practices and the effects of climate change, resulting in a warmer and drier environment over much of Australia, have affected fire regimes (intensity, scale, frequency and seasonality) and increased the incidence of extreme fire-danger events in some parts of Australia (Australian Bureau of Meteorology & CSIRO, 2020; Dowdy, 2020; Sharples et al., 2016). Additionally, climate change has complex effects on vegetation, through interactions with elevated CO2 production, biomass growth, vegetation flammability, fire weather, and ignitions, which collectively will also influence future fire regimes (Williams et al., 2009). Understanding what influences the occurrence and severity of wildfire and how to manage fire for maintenance of biodiversity is then crucial for conservation and for human wellbeing (Australasian Fire and Emergency Service Authorities Council, 2015).

Koala populations and their habitat have been repeatedly impacted by bushfires (Lunney et al., 2007, 2004; Matthews et al., 2016; Phillips et al., 2021). The most significant changes in the next 50 to 100 years due to altered fire regimes are predicted for sclerophyll dominated vegetation such as forests of eastern Australia (Hilbert et al., 2001; Williams et al., 2009), in which the koalas occur. As arboreal animals (Grand and Barboza, 2001) koalas are highly susceptible to high intensity wildfires, and particularly hot crown fires affecting the forest canopy which cause a high number of koalas deaths and injuries and reduce habitat availability (Melzer et al., 2000).

Koalas also have potential to be highly mobile across landscapes, making them vulnerable to low intensity ground fires. This is due to the risk of koalas sustaining burn injuries to hands and feet as they travel on-the-ground to move between food and habitat trees (Grand and Barboza, 2001). More frequent or extended movements to find food in post-fire environments can also exacerbate koalas vulnerability to other threats such as road collision, predation from dogs and may even facilitate the spread of disease such as Chlamydia (Lunney et al., 2007; Matthews et al., 2016).

Despite these susceptibilities, mobility is also a critical factor in assisting koala populations to recover after fire. For example, mobility allows koalas to rapidly recolonise burnt forest and establish sufficiently large home ranges in regenerating sites (Matthews et al., 2016), and importantly facilitates breeding. Factors which are positively associated with increased mobility in koala populations include habitat quality attributes such as extent, suitability and connectivity; as well as social factors such as high population density and the increase in social interactions leading up to and during the breeding season (Ellis et al., 2015; Watchorn and Whisson, 2019).

The 2019-2020 mega fires are estimated to have killed more than 60,000 koalas (van Eeden et al., 2020) and affected more than 10% of the species distribution (Legge et al., 2020). The identification and implementation of fire management strategies and post fire actions that support koalas in different scenarios and contexts would help reduce the direct impact of wildfire on koala populations and their habitat. Yet, these fire management strategies and post fire actions should also take into account other potential management objectives, like human safety and property protection, as well as constraints in relation to the strategies and actions that could be implemented under different land tenures and cultural values that are present in landscapes.

2.1 Fire association with koalas

The koala (combined populations of Queensland, New South Wales and the Australian Capital Territory) was listed as Vulnerable in 2012 (TSSC, 2012a) under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act). This listing is currently being reassessed following the 2019/2020 bushfires and a determination is due October 2021. Populations in Victoria and South Australia are not currently listed as threatened. The species has suffered population declines in many areas of its distribution. The main threats to the species are land-use change resulting in habitat loss, fragmentation and degradation; disease, vehicle collisions, dog attacks and climate change, which is increasing heatwaves, drought and reducing habitat quality (TSSC, 2012b).

Fire is also considered a threatening process to koalas (Commonwealth of Australia, 2021). Both wildfire and inappropriate prescribed burns can affect koala habitat quality or reduce it to remnant patches, as well as directly impact population numbers through mortalities (Bradshaw et al., 2018; Phillips et al., 2021; van Eeden et al., 2020). Especially concerning are planned or unplanned fires that raise temperature in the canopy and produce burning and scorching of the canopy that destroy koala habitat and result in koala mortalities (Bentley and Penman, 2017; Parkins et al., 2019). An important consideration for fire management is the presence of unburnt refuge areas in the landscape, which can improve the probability of local population survival and recolonization of habitat as the vegetation recovers (TSSC, 2012b). Despite this, fire can also have long term benefits on koala habitat, including recruitment of new feed trees, and regulation of soil nutrients, soil pH, ectomycorrhizal communities around feed tree roots, and reducing mid-storey competition for nutrients and water (Ashton, 2000; Close et al., 2009; Crisp et al., 2011; Turton and Duff, 1992).

The main factors associated with koala persistence in fire prone habitats, their interactions and the potential actions that can influence the effect of those factors on koala conservation are illustrated in the conceptual model depicted in Figure 1. **Conceptual models** are considered an external representation created by researchers that facilitates the comprehension of natural systems based on scientifically accepted knowledge (Greca and Moreira, 2000). The purpose of our conceptual model is to assist with the identification of research assumptions related to the interactions between factors associated with fire management and koala conservation as part of the process to identify fire management strategies and actions for koala conservation.

In the conceptual model each arrow represents an association between two components of the system. Dashed arrows represent associations which have large knowledge gaps so additional research is needed. Green arrows represent positive associations and purple ones negative associations. The components are divided in four different types. Management objective, demographic factors, social and ecological context and actions. All four components directly or indirectly influence the probability of persistence of koala populations in fire prone habitats. The actions outlined are the ways in which persistence can be improved through human interventions. An overview and justification of the key associations is given in Table 1.

Table 1. *Overview and justification of the main factors associated with koala persistence in fire prone habitats, their interactions and the potential actions that can influence the effect of those factors on koala conservation.*

Association	Mechanism	References
Severe weather events and koala deaths and births	Severe weather events increase koala mortality and reduce births due to high temperatures and reduction of water and food availability creating adverse condition for breeding and higher risk of death due to starvation and dehydration.	(Lunney et al., 2012)
Severe weather events and wildfires (extent, frequency and severity)	An increase in severe weather events leads to an increase in extent, frequency and severity of wildfires due to an increase in fire weather and in the length of fire season.	(Australian Bureau of Meteorology & CSIRO, 2020)
Severe weather events and koala population status (body condition, threat mitigation, density and distribution)	An increase in severe weather events leads to a decrease in koala population status due to a reduction of water and food availability which impacts the body condition of individuals and the density and distribution of the koalas in the landscape.	(Adams-Hosking et al., 2011; Crowther et al., 2014; Lunney et al., 2014, 2012)
Severe weather events and rainfall post fire	An increase in severe weather events can leads to a decrease in rainfall post fire, through extended drought periods and fire season.	(Australian Bureau of Meteorology & CSIRO, 2020)
Rainfall post fire and habitat recovery post fire	Rainfall post fire increases the rate of habitat recovery post fire as water availability increases the potential for the generation of new leaves and increases the leaf moisture on the remanent ones.	(Davies et al., 2013; Mella et al., 2019; Williams et al., 2009)
Wildfires (extent, frequency and severity) and koala mortality	An increase in the extent, frequency and severity of wildfire directly increases koala mortality from burns and low post-fire resource availability.	(Adams-Hosking et al., 2011; Lunney et al., 2007, 2004; Matthews et al., 2016)
Wildfires (extent, frequency and severity) and postfire habitat recovery	An increase in the extent, frequency and severity of wildfire decreases post-fire habitat recovery due to the increased chance of scorching and tree death.	(Lunney et al., 2004; Sharples et al., 2016)
Habitat status (connectivity, quality and extent) and habitat recovery post-fire	An habitat in good status (connectivity, quality and extent) increases habitat recovery post-fire due to lower risk of canopy scorching due to taller trees and lower edge flammability.	(Driscoll et al., 2021; Lindenmayer et al., 2020)
Koala rehabilitation and release and deaths	Koala rehabilitation and release decreases deaths immediately post-fire by rescuing and rehabilitating individuals that would have otherwise succumbed to burns or lack of food and water.	(Lunney et al., 2004)
Probability of koala persistence and births and immigrations	Probability of koala persistence increases with births and immigration to the site and decreases with deaths and emigration from the site.	(Lunney et al., 2007, 2004; Matthews et al., 2016)

Association	Mechanism	References
Habitat recovery post-fire, births, deaths, immigration and emigration	As the landscape recovers from fire, habitat recovery post-fire increases food availability which increases births and decreases deaths. Immigration may increase as koalas from surrounding areas seek out food and shelter. A shorter recovery time also reduces emigration from the area. **There is a need for a better understanding of the movement patterns of koalas during and after fires.**	(Lunney et al., 2007; Lunney and Matthews, 2004; Matthews et al., 2016, 2007)
Maintaining or restoring habitat condition and habitat status (connectivity, quality and extent)	Habitat status (connectivity, quality and extent) can be increased by maintaining or restoring habitat condition (for example through burning, weeding or revegetation)	(Ashton, 2000; Close et al., 2009; Crisp et al., 2011; Isaac et al., 2008; Turton and Duff, 1992)
Fire management and habitat status (connectivity, quality and extent)	Fire management that is conservation-based can improve habitat status by facilitating recruitment of new feed trees, regulating soil nutrients, soil pH, ectomycorrhizal communities around feed tree roots, and reducing mid-storey competition for nutrients and water. **There is a need for a better understanding of the impact of prescribed burning on habitat status (connectivity, quality and extent) but that is outside the scope of this framework.**	(Ashton, 2000; Close et al., 2009; Crisp et al., 2011; Isaac et al., 2008; Turton and Duff, 1992)
Fire management and wildfires (extent, frequency and severity)	Fire management that is conservation-based may decrease the extent, frequency and severity of wildfires, by reducing the fuel hazard in the ecosystems (for example through burning and weeding). **There is a need for a better understanding of the impact of prescribed burning on posterior wildfires but that is outside the scope of this framework.**	(Altangerel and Kull, 2013; Australasian Fire and Emergency Service Authorities Council, 2015; Dixon et al., 2018; Isaac et al., 2008; Price et al., 2015)
Land-management objectives and fire management for ecosystem maintenance	The capacity to do fire management for ecosystem maintenance may be decreased if there are land-management objectives different from conservation. This includes, for example, human safety and property protection.	(Altangerel and Kull, 2013; Bentley and Penman, 2017)
Fire regulations and prescribed burning	The capacity to carry out prescribed burning for ecosystem maintenance may be decreased if there are fire regulations for other management objectives. This can include, for example, fire bans due to proximity to human settlements or increased frequency of prescribed burning which does not align with the optimal fire frequency for a particular ecosystem.	(Altangerel and Kull, 2013; Bentley and Penman, 2017)
Prescribed burning and koala mortality	prescribed burning can increase the mortality of koalas in the landscape by increasing the frequency and in some instances intensity of posterior fires. **There is a need for a better understanding of the impact of prescribed burning on koala mortality.**	(Lunney et al., 2007; Zylstra, 2019)
Habitat connectivity and extent of fire	Connected habitat can increase the extent of fire events by increasing fire spread and decreasing suppression capability. **There is a need for a better understanding of the association between habitat connectivity, fire spread and koala movement.**	(Driscoll et al., 2021; Leach and Givnish, 1996; Yates and Broadhurst, 2002)
Habitat status (connectivity, quality and extent) and koala population status (body condition of individuals and population density and distribution)	An increase on the status of the habitat (connectivity, quality and extent) increases the koala population status (body condition of individuals and population density and distribution) by providing the appropriate conditions for koalas to thrive in the landscape.	(Matthews et al., 2007; McAlpine et al., 2015, 2006)

Association	Mechanism	References
Koala population status (body condition, threat mitigation, density and distribution) and the probability of persistence of koala populations	An increase on the status of the koala populations (body condition, threat mitigation, density and distribution) increases the probability of persistence of koala populations.	(Beyer et al., 2018; Lunney et al., 2007; McAlpine et al., 2015)
Management of other factors impacting koala conservation and koala's population status	We identified disease, vehicle collision and dog attacks as additional factors impacting koala conservation. If these factors are present, an increase in their management will increase the koala's population status. We are aware that there are other threats and factors that affect koala conservation apart from the ones outlined here, however, for this project we included these as the more relevant factors in relation to koala conservation and fire management. These factors can have multiple influences in koala conservation and in some circumstances can represent more important threats than fire. Additionally, these factors can interact in multiple ways with fire management. Underneath we outline some of the more relevant links of these factors with fire and fire management.	(Beyer et al., 2018; Lunney et al., 2007; Matthews et al., 2016; McAlpine et al., 2015)
Dog attacks, vehicle collision and koala population status (body condition, threat mitigation, density and distribution)	Nutritionally and socially stressed koalas due to fire events move more, increasing the probability of dog attacks, vehicle collision and transmission of disease.	(Beyer et al., 2018; Lunney et al., 2007; Matthews et al., 2016; McAlpine et al., 2015)
Transmission of disease and koala population status (body condition, threat mitigation, density and distribution)	Koala populations with disease are less capable of recovering after a high intensity, widespread fire event.	Beyer et al., 2018; Matthews et al., 2016; McAlpine et al., 2015)

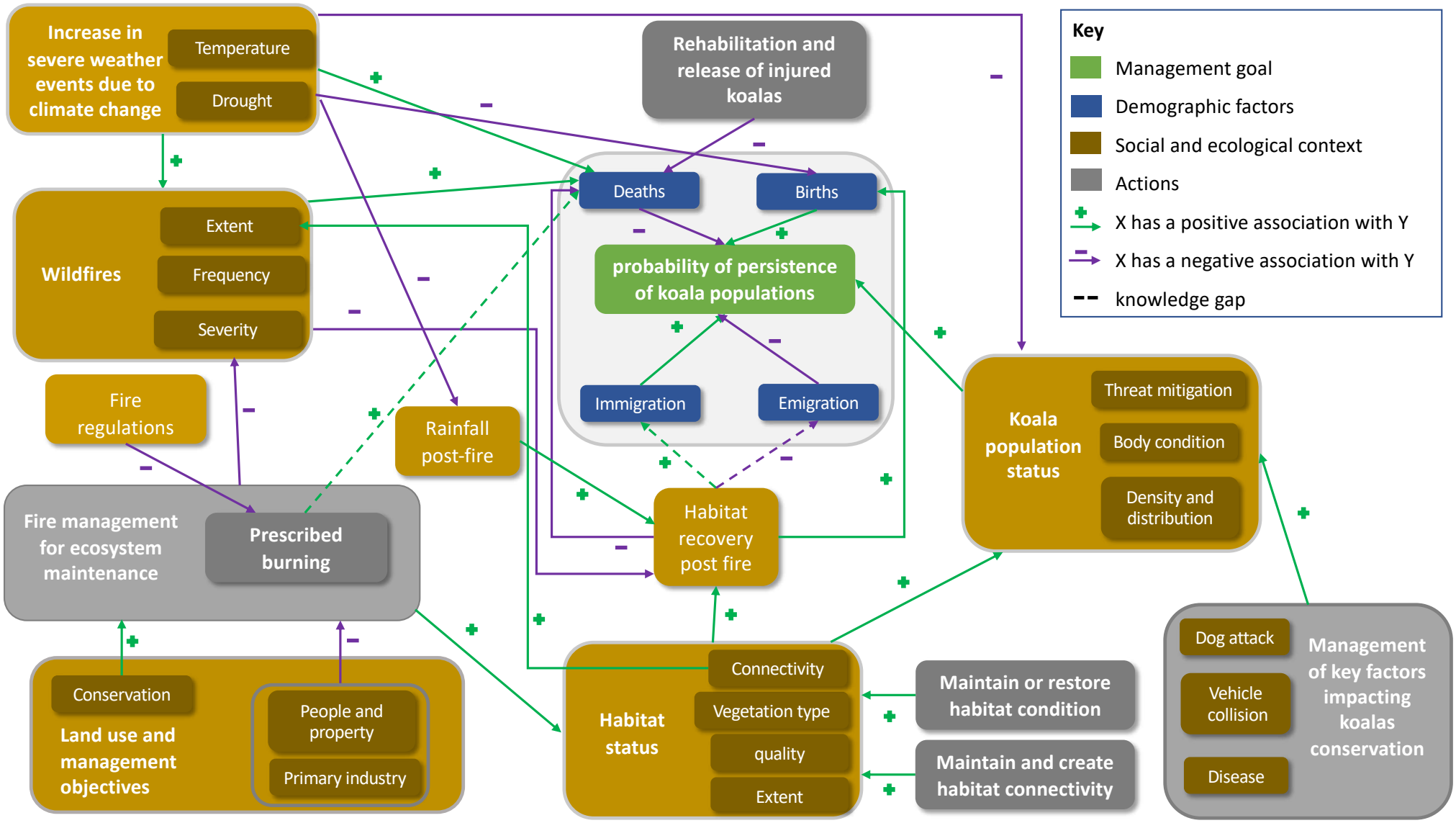


Figure 1. *Conceptual model of the factors associated to koala persistence in a fire prone habitat. This conceptual model was adapted from Cunningham, 2020.*

2.2 Impact of prescribed burning on koalas

Prescribed burning is a fire management tool often used to mitigate threats from bushfire and to maintain and conserve biodiversity affected by changed fire regimes (Australasian Fire and Emergency Service Authorities Council, 2015). A key goal of this approach is to reduce the fuel hazard in landscapes to avoid high intensity fires that can be difficult to supress, threaten human property and safety and affect wildlife and ecosystems (Australasian Fire and Emergency Service Authorities Council, 2015).

Prescribed burning can have both advantages and disadvantages for koalas. Koalas may benefit from prescribed burning if it subsequently reduces the intensity of wildfires leading to increased survival of koalas in the landscape after wildfire events. Also, prescribed burning can have long term benefits on koala habitat, through recruitment of new feed trees, and regulation of soil nutrients, soil pH, ectomycorrhizal communities around feed tree roots, and reducing mid-storey competition for nutrients and water (Ashton, 2000; Close et al., 2009; Crisp et al., 2011; Turton and Duff, 1992). There is a need for a better understanding of the impact of prescribed burning on fuel hazard and ecosystems characteristics (Altangerel and Kull, 2013; Bradshaw et al., 2018; Dixon et al., 2018; Isaac et al., 2008; Price et al., 2015; Zylstra, 2019) but that is outside the scope of this framework.

Prescribed burning can also increase overall fire frequency (prescribed + wildfire, Price et al., 2015) and in some cases increase landscape flammability (Price et al., 2015; Zylstra, 2021, 2019), potentially reducing survival of koalas after wildfire events. NSW forests burned in the Black Summer bushfires did so with higher likelihood of canopy damage if they had been burned in the previous 25 years, whether by planned or unplanned fires (Bowman et al., 2021). Prescribed burns also frequently have direct effects on koalas, ranging from direct mortality through to post-fire injuries such as burns from smouldering bark and hot ash on the ground (Zylstra, 2019, Pers Comm. D. Lunney). Despite the potential benefits for the habitat and koala populations in the long term, koalas are likely still at risk of injury and death to some extent through prescribed burning during the fire management activities. More research is needed in relation to mortality effects and movement patterns of koala during and after prescribed burning events to be able to identify better management actions that can reduce its impact to koalas.

2.3 Other factors associated with koala conservation in fire prone landscapes

There are a range of fire related factors that influence the probability of koala persistence in fire prone landscapes. These include appropriate management of injured koalas after fire events, including rehabilitation, and release (Lunney et al., 2004; Matthews et al., 2016). Management actions to restore koala habitat and increase its resilience before and after fire events (Driscoll et al., 2021; Lindenmayer et al., 2020; McAlpine et al., 2006). And other fire management considerations, such as cultural values (Maclean et al., 2018; Robinson et al., 2016; Weir et al., 2011) and land tenure characteristics and management objectives (Bentley and Penman, 2017), that may take precedence over koala management priorities.

2.4 Approach used for the framework

The information and ideas presented in this framework were gathered through a review of the literature related to fire ecology and management, and koala ecology and conservation. Expert advice was also used to gather additional information in two ways: through individual discussions with fire and koala expert and through two, one-day workshops.

One of the workshops was conducted in Brisbane, Queensland, using the D'Aguilar range as a reference area for the discussions. The other workshop was conducted in Tweed Heads, New South Wales, using the tweed coast as a reference area. In both workshops local stake holders, state representatives, and koala and fire experts, were invited. The workshops included a morning session focusing on the development of the structure of the framework and the conceptual model and an afternoon session focused on identifying management actions. These workshops were undertaken under University of Queensland Human Ethics Approval number HE000727.

2.5 Purpose of the framework

The objective of this framework is to assist land managers, stakeholders, scientists and the general public to identify the potential fire management strategies and post fire actions in areas identified as priorities for koala conservation. The framework was also prepared to complement the Commonwealth and State koala recovery and management plans with strategies and actions to reduce the direct impact of wildfire and prescribed burning on koala populations and their habitats.

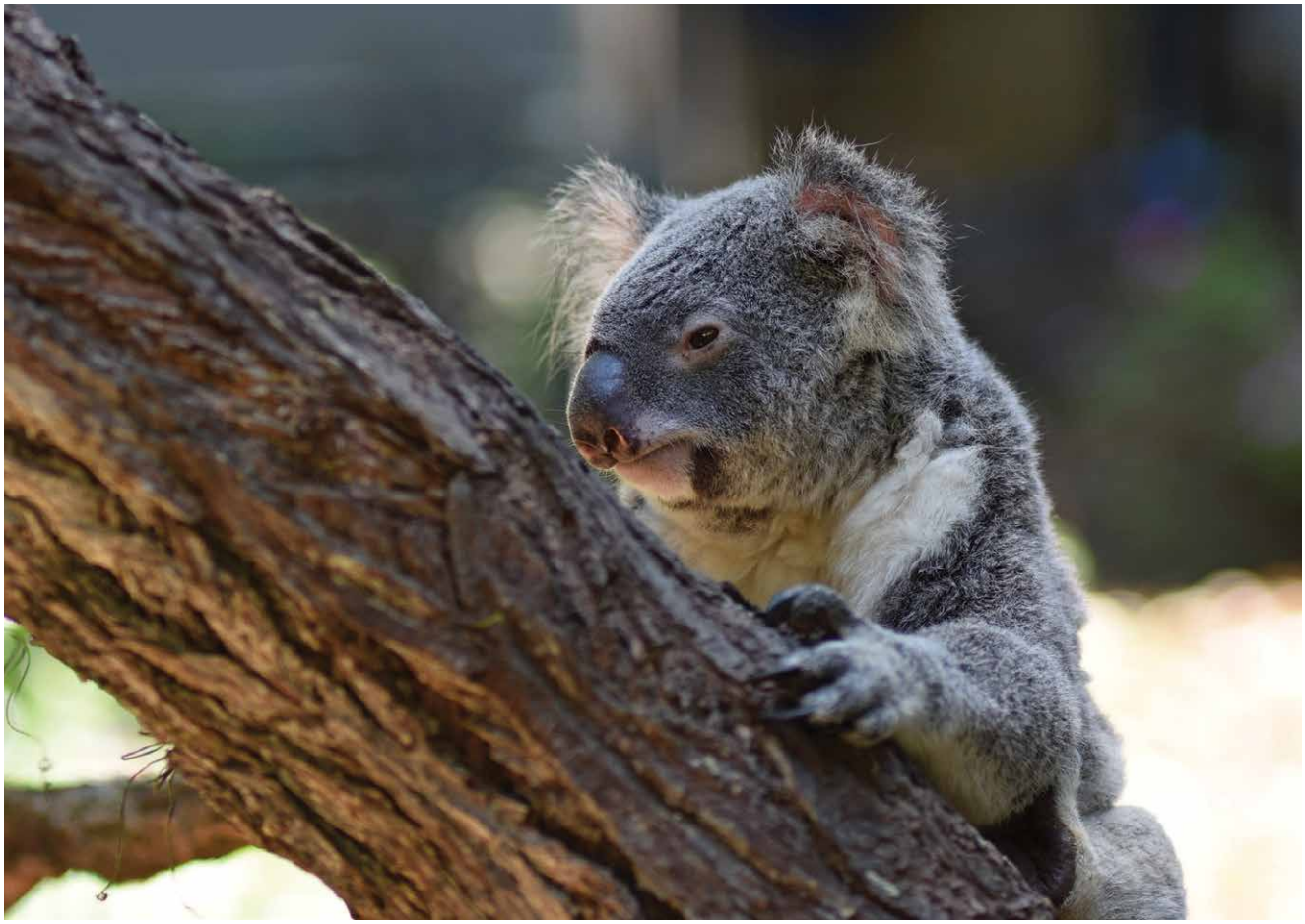
This framework is intended to be applied to koala habitat within Queensland (QLD), New South Wales (NSW) and the Australian Capital Territory (ACT), although it could also be broadly applicable to all koala habitat in Australia.

3. How to use the framework

This framework is intended to be used as a support tool to identify potential fire management strategies and post fire actions in areas identified as priorities for koalas in order to promote koala persistence and recovery in those landscapes. However, the framework should not be considered a standalone document. We recommend the use of additional supporting documents and expert advice when applicable. Complementary documents that may be useful for this purpose include:

- Draft National Recovery Plan for the Koala Phascolarctos cinereus (combined populations of Queensland, New South Wales and the Australian Capital Territory) (Commonwealth of Australia, 2021)
- Commonwealth Conservation Advice on Phascolarctos cinereus (Threatened Species Scientific Committee, 2012b)
- Overview of Prescribed Burning in Australasia (Australasian Fire and Emergency Service Authorities Council, 2015)
- Protocols for Indigenous fire management partnerships (Robinson et al., 2016)

The range of management actions outlined in this framework are based on six key intermediate objectives that if achieved will contribute towards maintaining koala populations in fire prone landscapes. These are: **Maintenance of koala habitat status, maintenance of koala population status, maintenance of appropriate fire regimes, consistency with cultural values, consistency with land use and management objectives and appropriate post fire management**. In order to achieve the six intermediate objectives, we identified a series of principles associated with each intermediate objective and a set of potential management strategies and actions related to those principles. This approach is summarized in a **decision support diagram** in Figure 2. In the diagram we present the six key intermediate objectives at the top, and underneath each are six boxes with the related principles. The pages in the framework related to the principles related to each intermediate objective and the particular management action and strategies related to them are shown underneath each box displaying the principles. Users of the framework should identify the particular intermediate objective they are interested on and refer to the principles related to the objective in order to identify the section of the framework that would be most useful for them. Then each sections has a detailed description of the principles and management action related to that intermediate objective. Each section of the framework has a table that summarizes the specific management actions identified for each intermediate objective.



Koala. Image: Martin Pelikann, Unsplash

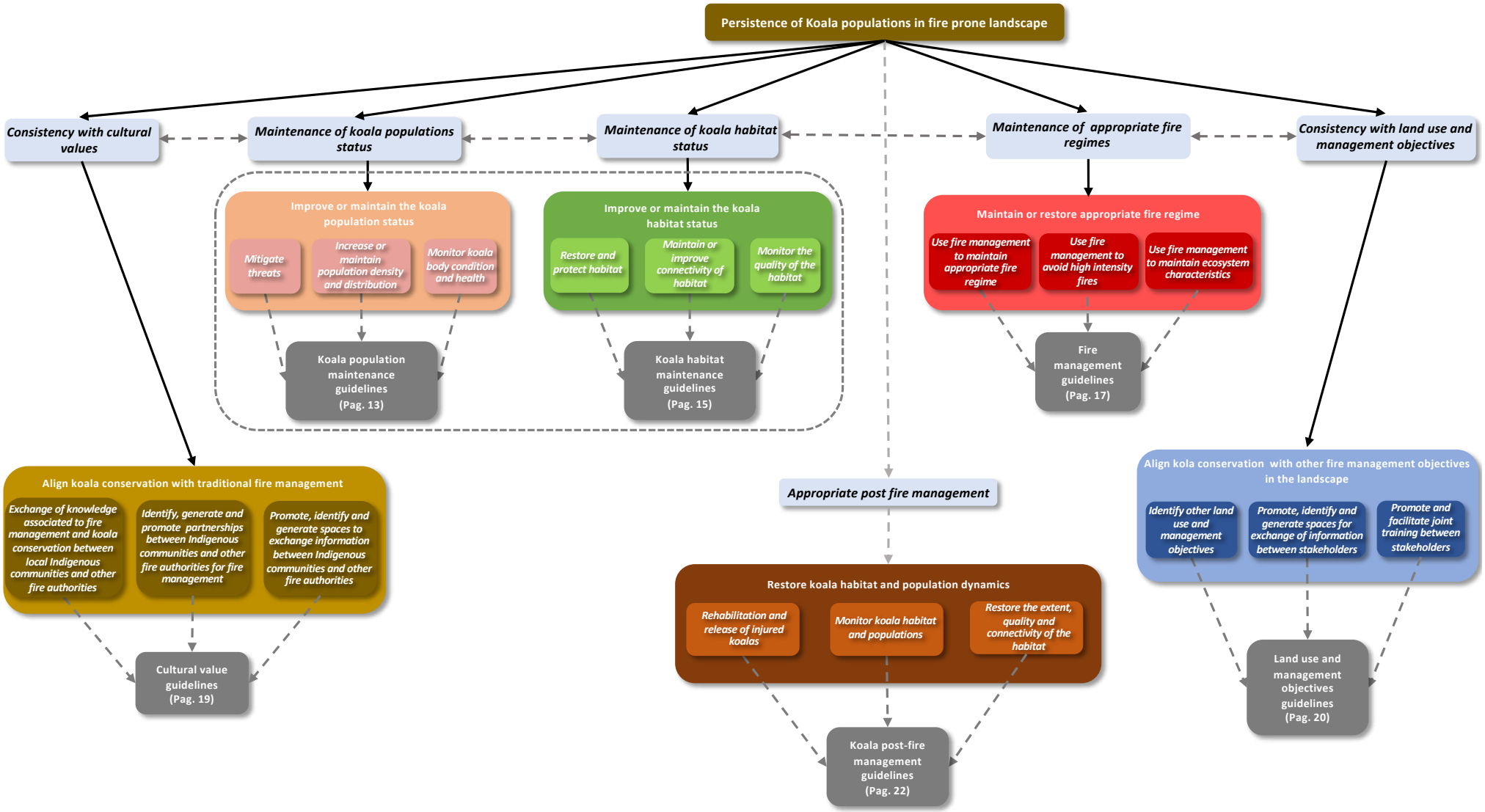


Figure 2. Decision support diagram showing the six intermediate objectives, that if achieved will increase the probability of persistence of koala populations in fire prone landscapes, at the top and underneath each of them the principles related to them. Then the pages in the framework related to the principles and particular management action and strategies are shown underneath.

4. Maintenance of koala population status

4.1 Fire and koala population status

The long term survival of koala populations in fire prone landscapes is strongly associated with the status of the populations. We define population status as the characteristics of a particular koala population in relation to overall body condition, disease, distribution and abundance. Koala populations which are affected by other threats including disease, road kills and dog attacks are more strongly affected by fire events and have a lower probability of survival. For example, koalas with chlamydiosis can present conjunctivitis, cystitis, infertility and rhinitis (Griffith and Higgins, 2012; Quigley and Timms, 2020). These diseases affect the koala's capacity to move, their sight and their body condition, reducing their survival capacity during and after fire events and in this way impacting the population density and distribution. Additionally, the impact on fertility reduces the reproductive capacity of the populations, impacting the potential recovery of the populations through lower birth rates after fire events. Finally, threats such as vehicle collisions and dog attacks can play an important role in increasing deaths and reducing the movement capacity of individuals during and after fire events (Lunney et al., 2007, 2004).

4.2 Management actions related to koala population status and fire

Here we present a suite of potential management strategies to maintain or improve the koala population status and its resilience to fire. The management actions outlined in this section are summarized in Table 2.

4.2.1 Fire and the mitigation of other threats

Koalas face multiple threats apart from fire. In some circumstances those other threat can represent more imminent risk to koala population persistence. Particularly relevant are habitat degradation, climate change, disease, dog attacks and vehicle collisions (Beyer et al., 2018; Lunney et al., 2007, 2004; McAlpine et al., 2015, 2006; Quigley and Timms, 2020). If these threats are not mitigated, koala populations will likely be more strongly affected by fire events and also will have a lower probability of survival after them. Mitigating these threats, if present, should be a task as important as reducing and monitoring the potential effects of fire in the landscape. The ways in which these other threats can be mitigated is outside the scope of this framework. However, there are other sources that can provide guidance in this matter. See the Draft national Recovery Plan for the Koala (Commonwealth of Australia, 2021) and the NSW and QLD koala conservation strategies (NSW Office of Environment and Heritage, 2018; QLD Department of Environment and Science, 2020) for more detailed information.

4.2.2 Koala population monitoring

Understanding koala population characteristics, and the changes they undergo due to fire events is essential to understand and predict the impact of future fire events on koala populations. Long term monitoring of koala populations is fundamental to achieving this goal and to improve the effectiveness and adaptability of the management actions for koala conservation. Particularly relevant is to monitor the characteristics of populations, the additional threats they face, the health of individuals and their recovery after fire in relation to the severity and extent of the events. A good understanding of these characteristics will allow stakeholders to undertake more effective management actions for koalas in relation to fire.

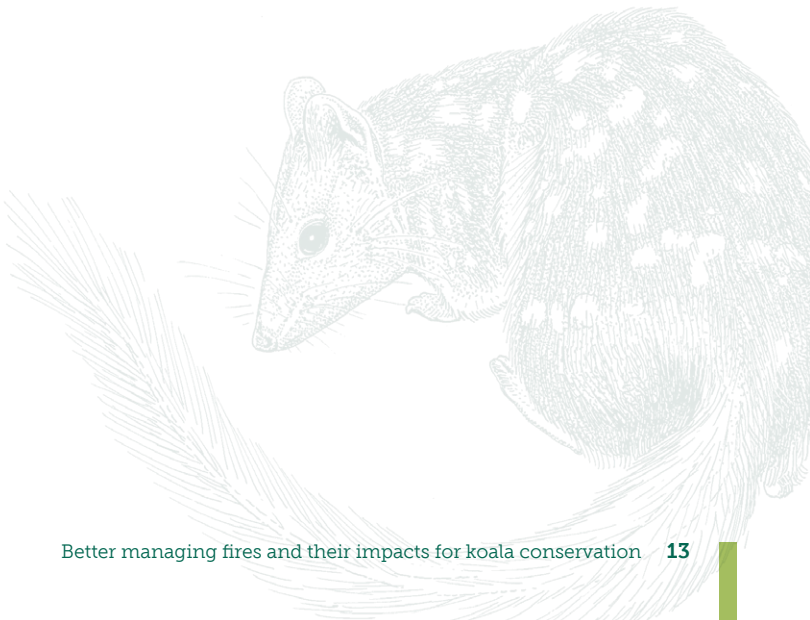


Table 2. *Summary of management actions identified to maintain koala population status in fire prone landscapes.*

Objective	Action	Scale
Maintenance of koala population status	Mitigation of other threats (vehicle collisions, dog attacks, disease, habitat loss, climate change, others).	Local, landscape and national level
	Long term monitoring of koala population status to understand population characteristics and their interaction with fire. Particularly in areas where koalas have been identified to be affected by other threats (dog attacks, disease, car collisions, others). Sharing this information with the local conservation and fire management authorities is important. A good understanding of these characteristics will allow stakeholders to undertake more effective management actions for koalas in relation to fire.	Local and landscape level
	Identify important koala populations (including source and sink and connected and isolated populations) and share this information with the local conservation and fire management authorities. Sharing this information with the local conservation and fire management authorities is important. A good understanding of these characteristics will allow stakeholders to undertake more effective management actions for koalas in relation to fire.	Local, landscape and national level

The persistence of koala populations depends on quality habitat. Image: Alex Eckermann, Unsplash

5. Maintenance of Koala habitat status

5.1 Fire and habitat characteristics

The long term survival of koala populations in fire prone landscapes is strongly associated with the characteristics and configuration of habitat. Characteristics such as the extent, level of fragmentation and quality of the habitat directly influence the persistence of koala populations in the landscape (McAlpine et al., 2006; Rus et al., 2021). Fire can interact with these habitat characteristics and impact koala population persistence in several ways. For example, fire can destroy, fragment or reduce the koala habitat on the landscape (Legge et al., 2020). Fragmentation can also increase fire frequency and intensity, by increasing edge flammability and the possibility of people igniting fires (Driscoll et al., 2021), increasing the risk of koala mortality due to fire events (Phillips et al., 2021). The combination of altered fire regimes and fragmentation can also affect habitat quality, vegetation characteristics, its structure and composition (Driscoll et al., 2021; Russell-smith et al., 2018), impacting the suitability of the habitat and food availability for koalas persistence. On the other hand, fragmentation can also reduce fire extent by impeding fire spread and increasing suppression capability (Driscoll et al., 2021; Leach and Givnish, 1996; Yates and Broadhurst, 2002).

5.2 Management actions related to koala habitat status and fire

Here we present a suite of potential management strategies to maintain or improve the koala habitat status and resilience to fire as well as actions related to habitat characteristics that may reduce high intensity fires and their impact on koala habitat. The management actions outlined in this section are summarized in Table 3.

5.2.1 Restoration, connectivity and protection of koala habitat

Restoration of ecosystems in areas with koala populations will increase the amount of available habitat which will directly benefit koalas by increasing the food availability and the mobility of individuals through the land use matrix (McAlpine et al., 2006). Making sure these restoration actions increase habitat connectivity is a key aspect that will enhance koala movement and space use (Rus et al., 2021).

In addition to the benefits mentioned above, promoting connectivity in the landscape through restoration can (i) increase koala mobility through the landscape (Rus et al., 2021) and in this way their capacity to escape fire events, (ii) increase koala probability of survival after a fire event by a reduction in the hostility of the land use matrix and an increased probability of finding unburnt food trees (McAlpine et al., 2006), (iii) reduce the proportion of habitat edges and in this way decrease edge flammability (Driscoll et al., 2021), and (iv) avoid ecosystem transformation through the combined effect of fragmentation and altered fire regimes (Driscoll et al., 2021).

Despite the benefits mentioned above, increased connectivity in the landscape can also increase fire extent by allowing fire spread and by decreasing suppression capability (Driscoll et al., 2021; Leach and Givnish, 1996; Yates and Broadhurst, 2002). It is important then to identify ways to increase koala population connectivity but at the same time try to avoid an increase in the potential for fire spread. Promoting the protection of koala habitat, particularly habitat that acts as refugia from fire, is also important to improve habitat resilience to fire (McAlpine et al., 2015).

5.2.2 Koala habitat monitoring

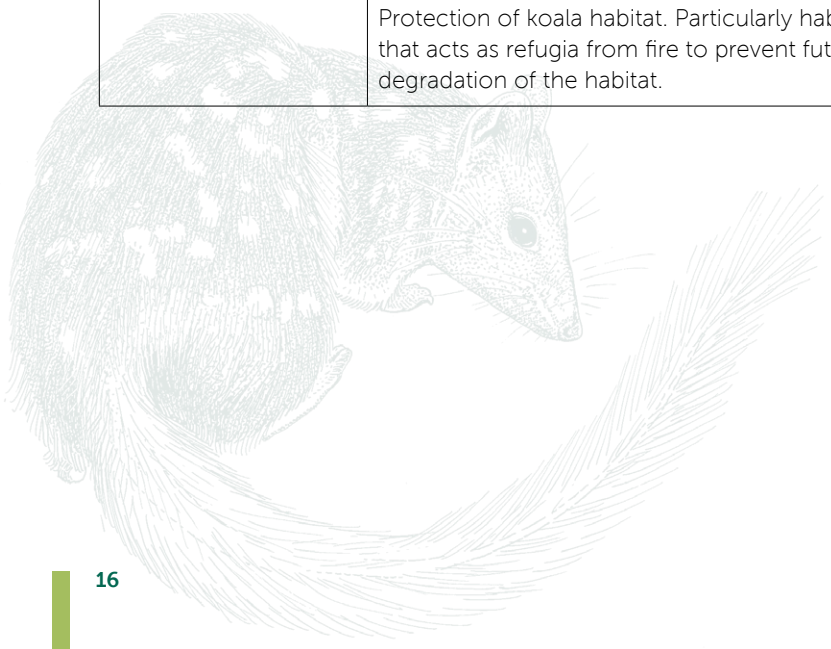
Understanding habitat characteristics, its interaction with fire and its fire regime is essential to be able to understand and predict the impact and characteristics of future fire events (Bradstock et al., 2012). Long term monitoring of koala habitat is thus fundamental to achieve this goal and to improve the effectiveness and adaptability of the management actions for koala conservation. Particularly relevant is to monitor the characteristics of the habitat and its recovery after fire in relation to the intensity and extent of the events. A good understanding of these characteristics will allow stakeholders to undertake more effective management actions for koalas in relation to fire. This monitoring can be done through on the ground assessments of the habitat and remote sensing (Australasian Fire and Emergency Service Authorities Council, 2015; Bradstock et al., 2012).

5.2.3 Assessment of habitat status and fire history

Evaluation of the quality of the habitat in landscapes where koalas are present can help identify areas of koala habitat with high and low ecosystem integrity. Areas with high ecosystem integrity are likely to have a higher resilience to fire events (Lindenmayer et al., 2020) as well as older trees with higher diameter and height which koalas have been found to prefer (Matthews et al., 2007). Fire history could also be used to evaluate areas of importance for koalas. Identification of areas with low and high historical incidence of fire can help identify fire refugia for koalas and areas of high fire risk. This information can be used for koala habitat prioritization strategies in relation to fire risk. For example by: 1) protecting areas with high ecosystem integrity and low historical fire frequency to increase the resilience of koala habitat to fire and the survival of koalas after fires; and 2) identifying areas of low ecosystem integrity and high historical fire frequency within koala habitat and implementing conservation actions in those areas to minimise the risk of fires to koalas.

Table 3. *Summary of management actions identified to maintain koala habitat status in fire prone landscapes.*

Objective	Action	Scale
Maintenance of koala habitat status	Identification of critical koala conservation areas (including high value areas for connectivity, feeding and resting) and share this information with the local fire management authorities. A good understanding of these characteristics will allow stakeholders to undertake more effective management actions for koalas in relation to fire.	Landscape level
	Restoration of koala habitat (replanting, weed management, reforestation, pest control).	Local level
	Restoration of koala habitat connectivity in the landscape but accounting for potential increased fire spread.	Landscape level
	Long term monitoring of koala habitat and habitat connectivity to understand habitat characteristics, its interaction with fire and its fire regime. Particularly relevant is to monitor the characteristics of the habitat and its recovery after fire in relation to the intensity and extent of the event. Sharing this information with the local conservation and fire management authorities is important. A good understanding of these characteristics will allow stakeholders to undertake more effective management actions for koalas in relation to fire.	Local, landscape and national level
	Assessment of koala habitat quality and fire history to identify areas of importance for koala. Sharing this information with the local conservation and fire management authorities is important. A good understanding of these characteristics will allow stakeholders to undertake more effective management actions for koalas in relation to fire.	Local, landscape and national level
	Protection of koala habitat. Particularly habitat that acts as refugia from fire to prevent future degradation of the habitat.	Local, landscape and national level



6. Maintenance of appropriate fire regimes

6.1 Fire regimes and koala conservation

Altered fire regimes have the potential to undermine efforts to recover koala populations. Fire has influenced Australian landscapes, but climate change and altered fire frequency is rapidly shifting the severity, frequency and extent of fires in some parts of Australia (Australian Bureau of Meteorology & CSIRO, 2020). Inappropriate fire regimes can cause structural changes to ecosystems, resulting in altered fire hazards, changes to woodland structure, and changes in the flora and fauna present in the landscape (Driscoll et al., 2021). Fire management, defined as the process of planning, preventing and fighting fires, can be a useful tool to maintain appropriate fire regimes within ecosystems, maintain koala food tree recruitment, prevent vegetation composition change and reduce the likelihood and extent of catastrophic high severity fires (Ashton, 2000; Close et al., 2009; Crisp et al., 2011; Turton and Duff, 1992).

Fire management actions used for maintaining appropriate ecosystem fire regimes, as well as for other purposes, such as for human safety and property protection, can also affect koalas through direct mortality of individuals or through the reduction of habitat (Matthews et al., 2016). If management involves the introduction of fire, then actions to prevent or minimise impacts of prescribed burns are needed to protect koala populations.

6.2 Management actions related to fire regimes and koala conservation

Here we present a suite of potential management strategies to maintain appropriate fire regimes and manage fire and fuel hazard in koala habitat. Also, actions to protect koalas and their habitat during human induced fires are discussed. All the management actions outlined in this section are summarized in Table 4.

6.2.1 Prescribed burning management strategies

Prescribed burning may be used to manage ecosystem flammability or to maintain the habitat characteristics in situations where fire frequency is declining. Identifying adequate fire intervals for the ecosystems in the area is essential to determine if prescribed burning in the landscape is needed. These intervals should be based on on-ground assessment of vegetation health, fuel accumulation and wildlife risk. If it is established that prescribed burns are required in areas of koala habitat, mosaics burning with areas of varying age since fire are recommended. This will reduce the risk of simultaneously burning areas that represent a risk to koalas when burned (areas with canopy burning risk or areas with low connectivity for example) and provide individuals with the possibility to move to adjacent unburnt forest patches (Matthews et al., 2007; McAlpine et al., 2006). Additionally, mosaic burning promotes more heterogenous habitat, higher biodiversity and the recruitment of trees used by koalas and other mammals (Isaac et al., 2008).

6.2.2 Other fire management alternatives to burning

Burning can represent a high threat to koalas. Koalas are highly susceptible to high intensity wildfires, and particularly hot crown fires affecting the forest canopy which can cause a high number of koalas deaths and injuries and reduce habitat availability (Melzer et al., 2000). Koalas can be highly mobile across landscapes, making them also vulnerable to low intensity ground fires. This is due to the risk of koalas sustaining burn injuries to hands and feet as they travel on-the-ground to move between food and habitat trees (Grand and Barboza, 2001). More frequent or extended movements to find food in post-fire environments can also exacerbate koalas vulnerability to other threats such road collision, predation from dogs and may even facilitate the spread of disease such as Chlamydia (Lunney et al., 2007; Matthews et al., 2016).

Due to this, alternative fire management practices should be considered, if possible, to prevent koala mortality. One optional fire management strategy when prescribed burning has a high potential of generating koala mortality or injury is manual fuel reduction, including weed control, raking surface fuels, trimming of elevated fuels away from the base of trees and manual extraction of fuel sources including fallen branches, dry weeds and bushes. Where forest understorey naturally self-thins and reduces fire risk (Dixon et al., 2018; Zylstra, 2018), strategies may be implemented to protect disturbed areas so that they can age and become more fire resilient.

Table 4. Summary of management actions identified to maintain koala habitat status in fire prone landscapes.

Objective	Action	Scale
Maintenance of appropriate fire regimes	Prescribed burning can be used to manage ecosystem flammability.	Local and landscape level
	Prescribed burning can be used to maintain habitat status.	Local and landscape level
	Applying mosaics burning, with areas of varying age since fire.	Local and landscape level
	Other fire management actions different from prescribed burning can be used to manage ecosystem flammability and to maintain the habitat characteristics including weed management, raking surface fuels, trimming of elevated fuels away from the base of trees and manual extraction of fuel sources including fallen branches, dry weeds and bushes.	Local level

6.2.3 Koala protection actions before and during human induced fires

If prescribed burning is adopted in koala habitat there are actions that can be taken that could reduce the risk of koala mortality during the process. In Table 5 we include some general recommendations and actions that can be applied prior to and during prescribed burns to reduce the risk of koala mortality and habitat loss. This are modified from Baker (2016);

Table 5. General recommendations and actions for koala habitat and populations protection prior to and during prescribed burnings.

Stage	Action
Pre-Fire	Check areas that will be burned for koalas prior to burning, for example by using koala sniffing dogs. If present, assess the risk of the prescribed burning to koala population.
	Assess vegetation flammability in the area if it is koala habitat or koala populations are present to ensure the risk of high intensity fire is low.
	Test burn the site to assess if there is risk of the canopy being burned. If there is, assess the risk to koala populations in the area and inform the conservation authorities of the prescribed burning risk to koalas in order for them to take further actions.
	Manual fuel reduction prior to burning, including raking surface fuels and trimming of elevated fuels away from the bases of trees with koalas or that are known to be used by them, to reduce the risk of burning to individuals and/or canopy scorching.
	Wetting down around the bases of trees know to be used by koalas prior to the burn.
	Retain koala food and habitat trees if possible.
	Exclusion of koala risk areas from burning can be done by for example using containment lines or sprinkler lines.
	Assess soil moisture before burning, particularly in areas where koalas are present or areas of high value to local koala populations, in order to reduce scorch height, risk of koalas injuries and limit leaf drop post fire.
	Consider the timing of burning in relation to koala sensitive timeframes when possible. For example by avoiding prescribed burning in seasons when koalas are breeding or males or young koalas are dispersing.
During Fire	Avoid a running-fire towards areas with risk of koala mortality if possible.
	In sloping areas, and when the logistics allow it, utilise the surrounding topography to create low-intensity backing fire that travels down the slope away from areas where there is risk of koala mortalities.
	Particular lighting patterns can be used along the margin of areas where there is risk of koala mortality to promote a low-intensity fire that burns away from those areas.
	Use methods to control the expansion of fire like sprinkler lines or mechanical containment lines to prevent fire to spread to areas of high value for koalas.
	Generating prescribed burning of moderate intensity in unoccupied habitat can increase fuel reduction and stimulate regeneration of koala feeding trees.

7. Consistency with cultural values

7.1 Importance of cultural values for fire management and koala conservation

Indigenous cultural values and knowledge and cultural burning practices are critical considerations when managing fire-prone landscapes for koalas. This includes Indigenous knowledge on fire regimes and fire management. For example, Indigenous people communities commonly exercise their own fire management actions as part of their broader activities referred to as 'Caring for Country'. These activities are often intricately linked to maintaining cultural life, identity, autonomy and health (Weir et al., 2011). In addition, many places and landscapes of importance to Traditional Owners in areas with koala populations are themselves artefacts of cultural burning (Robinson et al., 2016).

In this section, we outline a set of recommendations that can be used to integrate traditional fire management knowledge with other practices for koala conservation and fire management. We also outline different sources of information related to fire management and the cultural values that are linked to the management of fire-prone landscapes where koalas occur. We recommend that future iteration of this framework should be co-designed with Indigenous communities as this was outside of the scope of this project.

7.2 Recommendations to integrate traditional fire management knowledge with other management practices

Exchange of knowledge between Traditional Owners, Indigenous Communities of the area and other fire management authorities is fundamental for the identification of effective and feasible fire management strategies and actions (Commonwealth of Australia, 2020). In order to do so, the identification, and promotion of partnerships between local Indigenous communities and other fire management authorities is needed to build trust and engagement (Commonwealth of Australia, 2020; Robinson et al., 2016) and in order for this to happen it is fundamental to generate spaces to exchange information between Indigenous communities and other authorities in charge of fire management. These spaces can be generated for example through joint training and workshops related to fire management and koala conservation. The recommendations outlined in this section are summarized in Table 6.

Table 6. *Summary of recommendations to integrate traditional fire management knowledge with other practices for koala conservation and fire management.*

Objective	Action	Scale
Consistency with cultural values	Promote, identify and generate spaces to exchange information between Indigenous communities and other fire management authorities.	Local level
	Identify, generate and promote partnerships between Indigenous communities and other fire management authorities.	Local level
	Exchange knowledge associated to fire management and koala conservation between Indigenous communities and other fire management authorities.	Local level

7.2 External sources related to the association between fire management and cultural values

- The Benefits Associated with Caring for Country (Weir et al., 2011)
- Protocols for Indigenous fire management partnerships (Robinson et al., 2016)
- AIATSIS Submission : Independent review of the EPBC Act 1999 (Strelein et al., 2020)
- Indigenous land and fire management (Commonwealth of Australia, 2020)
- A national framework to report on the benefits of Indigenous cultural fire management (Maclean et al., 2018)

8. Consistency with land use and land management objectives

8.1 Fire regimes, koala conservation and land tenure

Land use and associated management objectives may limit the actions that can be done to ensure koala population persistence as well as the potential fire management actions that can be implemented. Fire management actions that have as one of their main objectives to protect and preserve biodiversity, such as many of the actions for fire management inside protected areas (Goverment of South Australia, 2002), may have more flexibility and capability to include specific guidelines for koala protection and fire management. Moreover, many protected areas already have guidelines in place for the purposes of maintaining ecosystem status and protecting biodiversity. On the other hand, fire management actions for other objectives, like for protection of human lives and property may impact koalas (Bentley and Penman, 2017), even though there are multiple cases where fire management actions can benefit both people and biodiversity (Bentley and Penman, 2017). Fire management for objectives related to protection of human lives and property normally take place near private lands or urban areas, where there may be objectives that take precedence over koala management priorities (Commonwealth of Australia, 2020; CSIRO, 2009; NSW Rural Fire Service, 2015; Robinson et al., 2016). In these cases, proposed koala conservation actions that are considered need to take into account those other objectives (Bentley and Penman, 2017). The recommendation outlined in this section are summarized in Table 7.

8.2 Fire management actions for koala conservation related to land use and land management objectives

In this section, we outline a suite of recommendations that could benefit koala population recovery and that can be done when there are other objectives, such as protection of property or human safety, which dictate fire management. Also, fire management actions that could benefit land use and management objectives related to both human safety and property protection and koala conservation are outlined.

8.2.1 Strategies that can be implemented when other management purposes determine fire management protocols

As is the case of cultural values, an exchange of knowledge between the entities in charge of fire management for the different objectives in the area is fundamental to identify effective and feasible fire management strategies and actions that at least do not affect other fire management objectives or that benefit multiple objectives at the same time (Altangerel and Kull, 2013; Bentley and Penman, 2017). To do so, the identification of other land use and management objectives in the area is essential and to do so the generation of spaces for exchange of information between stakeholders is needed.

These spaces should promote and facilitate the exchange of information between the different parties involved but also can be used to do join training between the local stakeholders, fire management authorities and the community. Joint training exercises could also include the description of specialized terminology used by fire management, conservation authorities and other parties involved to identify a common language.

8.2.2 Mosaic burning and koala conservation

Mosaic burning is a method where the main objective is to burn different patches of habitat at different time-frames (Bradstock et al., 2012). This allows it to be applied when other management objectives are in place in the area without a high impact on them. Prescribed burning using a mosaic pattern, has been suggested as a useful tool to maintain biodiversity as it promotes more heterogenous habitat, higher biodiversity and the recruitment of trees used by koalas and other mammals (Bradstock et al., 2012; Isaac et al., 2008). Additionally, as was mentioned previously in section 6.2.1, mosaic burning reduces the risk of simultaneously burning areas that represent a risk to koalas when burned (areas with canopy burning risk or areas with low connectivity for example) and provides individuals with the possibility to move to adjacent unburnt habitat patches (Matthews et al., 2007; McAlpine et al., 2006).

Table 7. *Summary of recommendations to integrate management actions for koala conservation with other land use and land management objectives.*

Objective	Recommendations	Scale
Consistency with land use and land management objectives	Promote, identify and generate spaces to exchange information between the entities influencing fire management actions in the area and the entities in charge of koala conservation.	Local level
	Promote and facilitate joint training between different stakeholders in relation to fire and koala management objectives and actions.	Local level
	Undertake mosaic burning, with areas of varying age since fires.	Local and landscape level

Mosaic burning can help promote recruitment of trees used by koalas. Image: Matt Palmer, Unsplash

9. Appropriate post fire management

9.1 Post fire scenarios and koala conservation

The recurrence of hot, dry weather conditions as well as increased frequency and intensity of fire events in recent years due to the effect of climate change has had negative consequences for koala habitat and the species populations in some parts of Australia (Adams-Hosking et al., 2011; McAlpine et al., 2015; Phillips et al., 2021). Management actions to reduce the severity and extent of fires as well as to prevent the proliferation of widespread high intensity fires will help national koala population recovery and long term persistence in fire prone habitat (Lunney et al., 2007). However, since the likelihood of dangerous fire days has increased over historical levels in large parts of eastern Australia (Australian Bureau of Meteorology & CSIRO, 2020), the development and implementation of koala management plans for effective and appropriate actions after fire events are needed. These plans should include management actions immediately after fire to minimise mortality of individual koalas in addition to actions to support recovery of koala habitat and population post fire (e.g., habitat restoration and koala rehabilitation and release). These actions could be relevant both after wildfire events and prescribed burns. All the management actions outlined in this section are summarized in Table 8.

9.2 Management actions for koala conservation immediately after fire

Here we present a suite of koala management actions that could be applied immediately after fire events to minimise mortality of injured individuals.

9.2.1 Koala habitat and population management after fire

Burnt area should be patrolled during and after a fire event to ensure that no animals have been injured. If the koala habitat is affected or if injured or dead koalas are found, systematically collecting this information, and reporting it to the local conservation authorities and National Koala Monitoring Program is important in order to increase the understanding of the impacts of fires on koala conservation.

The use of free drinking water has been observed by koalas, especially after periods of low rainfall (Mella et al., 2020, 2019). Provision of food and water in areas with koala populations that are affected by fire may help individuals overcome this period of scare water and food availability (Mella et al., 2019). These tasks should be carried out by qualified and equipped personnel, prioritizing the safety of personnel. If injured koalas are found it is important to make sure that they are promptly treated by trained personnel. Koalas that are properly treated after fire injuries and then reintroduced to their habitat have a survival rate similar to uninjured koalas (Lunney et al., 2004).

9.3 Long term management actions for koala conservation after fire

Here we present a set of long term koala management actions that can be applied in areas of koala habitat that had fire events, to improve the recovery potential of koala populations and habitat.

9.3.1 Koala rehabilitation and release

Rehabilitation and release of injured koalas can help the recovery of koala populations following fire, especially if the population number in the area is low making it difficult to repopulate the area (Matthews et al., 2016). The release of koalas to the same habitat where they were found is strongly recommended as the release of animals into a novel environment is known to have a greater effect on stress than the release of animals back into their home area (Dickens et al., 2009) and may have genetic consequences.

When releasing rehabilitated koalas, it is important to make sure post fire regeneration of the habitat is sufficient to sustain rehabilitated and unburnt koalas in the landscape. Koalas have been found to use areas previously affected by fire with epicormic growth (Lunney et al., 2004).

Translocation of burnt koalas might be needed if the original habitat has been lost (Matthews et al., 2016). If this is the case finding suitable habitat in close proximity to the original habitat is recommended (Dickens et al., 2009). Commonwealth and jurisdiction approval prior to undertaking translocation actions is needed. Refer to the EPBC translocation policy for more information on this topic (Department of Sustainability, Environment, Water, 2013).

9.3.2 Koala habitat management after fire

Koalas are often restricted to fragmented patches of habitat in many areas of their distribution. These fragmented koala populations may be at higher risk of mortality during and after fire events due to decreased koala mobility through the landscape (Rus et al., 2021) and in this way their capacity to escape fire events (Matthews et al., 2016). Fragmentation also is increases after fire events as well as the proportion of habitat edges which increase edge flammability (Driscoll et al., 2021). Restoration actions that increase connectivity after fire events may stimulate koala population recovery, especially in heavily fragmented landscapes. However, Despite the benefits mentioned above, increased connectivity in the landscape can increase fire extent by allowing fire spread and by decreasing suppression capability (Driscoll et al., 2021; Leach and Givnish, 1996; Yates and Broadhurst, 2002), so it is important to account for the effect of increased connectivity on potential increased fire spread. Refer to section 5.2 for more management actions related to koala habitat status and fires.

Table 8. *Summary of short term and long term post-fire management actions identified to maintain koala population and habitat in the landscape.*

Objective		Recommendations	Scale
Appropriate post fire management	Short term	Provision of food and water devices in areas with koala populations that were affected by fire.	Local and landscape level
		Report koala mortality and koala health after fire events with the local conservation and fire management authorities to have a better understanding of fire impacts on koala populations.	Local and landscape level
		Report koala habitat status after fire events with the local conservation and fire management authorities to have a better understanding of fire impacts on koala habitat.	Local level
		Patrolling of areas after fire to identify injured koalas. Human safety has to prevail over koala conservation.	Local and landscape level
		Rehabilitation of koalas injured during fire events. the longest it takes to rehabilitate the koalas after fire the lower the probability of survival.	Local level
	Long term	Rehabilitation and release of koalas in the landscape.	Local level
		Restoration of koala habitat (replanting, weed management, reforestation, pest control, others).	Local and landscape level
		Re-establish connectivity in the landscape if fire impacted the connectivity of the habitat but accounting for potential increased fire spread.	Local and landscape level
		Monitor the status of koalas through time after a fire event to have a better understanding of fire impacts on koalas. Sharing this information with the local conservation and fire management authorities is important. A good understanding of these characteristics will allow stakeholders to undertake more effective management actions for koalas in relation to fire.	Local level
		Monitor the status of koala habitat through time after a fire event to have a better understanding of fire impacts on koala habitat. Sharing this information with the local conservation and fire management authorities is important. A good understanding of these characteristics will allow stakeholders to undertake more effective management actions for koalas in relation to fire.	Local level

10. Future framework development and opportunities

The objective of this framework was to identify the factors related to fire management that influence koala conservation, determine their associations and interactions and identify which actions and strategies would be beneficial in different contexts. This framework is one of the first of its kind and is an initial step for the identification of effective conservation actions for the conservation of koalas and other types of wildlife in fire prone landscapes. It integrates aspects from the interaction of koala habitat and populations with fire and fire management to the relation of fire management with cultural values and human and property management objectives.

Koala populations and their habitat have been repeatedly impacted by fire through time (Lunney et al., 2007, 2004; Matthews et al., 2016; Phillips et al., 2021). Changes in burning practices and the effects of climate change, resulting in a warmer and drier environment over much of Australia, have affected fire regimes (intensity, scale, frequency and seasonality) and increased the incidence of extreme fire-danger days (Australian Bureau of Meteorology & CSIRO, 2020; Dowdy, 2020; Sharples et al., 2016). This increase in the severity and extent of fires, including the recent Australia megafires in 2019-2020, has shown the importance of having a good understanding of the impact of fire on biodiversity and the value of identifying the most effective management strategies to mitigate its threats (Ward et al., 2020).

10.1 knowledge gaps

The understanding of fire ecology and particularly fire regimes remains embryonic for most ecosystems in Australia (Murphy et al., 2013). Similarly, the understanding of the effect of fire management and prescribed burning on biodiversity continues to evolve (Australasian Fire and Emergency Service Authorities Council, 2015).

We have identified a series of key knowledge gaps that need more research in order to be able to advance on the understanding of the interaction between fire management and koala conservation. Particularly we identified three major knowledge gaps: (1) A need for a better understanding of koala movement and activity patterns during and after fire events. (2) Improve the understanding of the impact of prescribed burning on koala population dynamics at short and long term, and (3) a need for more knowledge related to the associations between habitat connectivity, fire characteristics and koala population dynamics.

The understanding of the movement patterns of koalas during and after wildfires and prescribed burning is limited, which impacts the understanding of the severity of fires on koala population due to a lack of information of its actual impact on population numbers. Additionally, the changes in movement in relation to the severity, extent and other characteristics of fire events is important to be able to identify which are the best suit of management actions to do during fire events. Injuries after wildfires and prescribed burns such as from smouldering bark when koalas move between trees have been reported (Zylstra, 2019, pers comm. D. Lunney). However, how this impacts koala movement and dispersal patterns is less well understood. Long term monitoring of the movement of koalas in fire prone landscapes particularly after fire, for example through GPS tracking, is needed in order to have a better understanding of these movement patterns.

The impact of prescribed burning to koala populations is another aspect that is not well understood. Koalas may benefit from prescribed burning if it subsequently reduces the severity of wildfires leading to increased survival of koalas in the landscape after wildfire. Also, well-executed prescribed burning can have long term benefits on koala habitat, including recruitment of new feed trees, regulation of soil nutrients, soil pH, ectomycorrhizal communities around feed tree roots, and reduction of mid-storey competition for nutrients and water (Ashton, 2000; Close et al., 2009; Crisp et al., 2011; Turton and Duff, 1992). On the other hand, prescribed burning can have a direct negative impact on koalas through injury or death (Lunney et al., 2007, 2004; Matthews et al., 2016).

These direct and indirect impacts as well as the trade-offs between the negative and positive impacts are not well understood. Long term studies that assess these impacts and their trade-offs are needed to understand the net impact of prescribed burning on koalas. This can be done for example, through long term GPS tracking of individuals and monitoring of koalas population densities through time. Also, systematically collecting and compiling information related to injured or dead koalas during or after prescribed burns and reporting it to the local conservation authority is needed in order to increase the understanding of the impacts of prescribed burnings on koala conservation.

Habitat connectivity has different interactions with fire which can impact in different ways koala populations. Fire can have a negative impact on koalas by increasing fragmentation and reducing or destroying koala habitat (Legge et al., 2020). Additionally, fragmentation can increase fire frequency and intensity, by increasing edge flammability and the possibility of people igniting fires (Driscoll et al., 2021), increasing the risk of koala mortality due to fire events (Phillips et al., 2021). The combination of altered fire regimes and fragmentation can also affect habitat quality and vegetation structure and composition (Driscoll et al., 2021), impacting the suitability of the habitat and food availability for koalas persistence.

Despite the negative impact on koalas of increased fragmentation and fire, there is also positive effect, as fragmentation in the landscape can decrease fire extent by limiting fire spread and increasing suppression capability (Driscoll et al., 2021; Leach and Givnish, 1996; Yates and Broadhurst, 2002). Due to this contrasting effects of fragmentation on koala conservation in fire prone landscapes it is important to generate more studies to understand the trade-offs between changes in connectivity, fire characteristics and its impacts on koala habitat and populations.

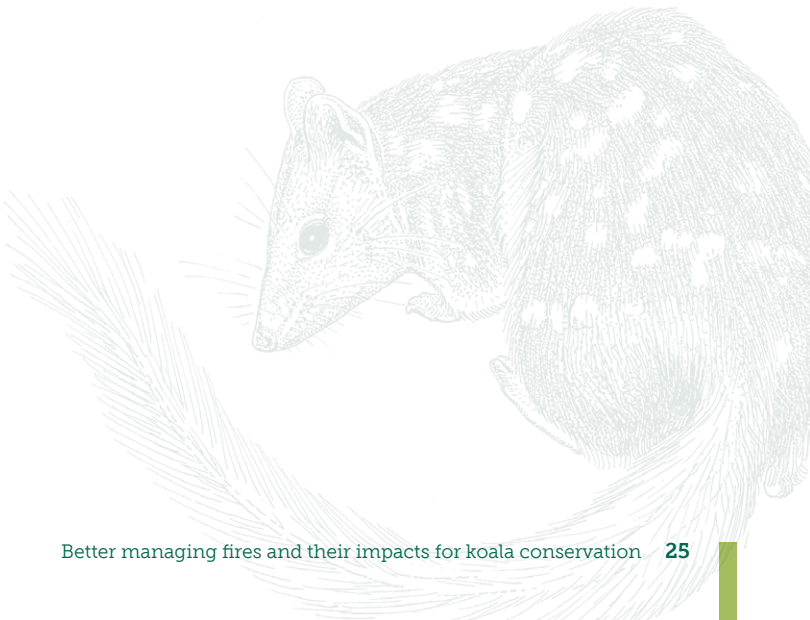
10.2 Conclusions

The main objective of this framework is to assist with identifying appropriate fire management and response strategies in priority areas for the National koala Recovery Plan and the Queensland and New South Wales koala conservation strategies. However, it is also broadly applicable to any koala population in Australia.

More knowledge is needed in relation to fire ecology, the impact of fire management on biodiversity and on koala conservation and to properly identify the best suite of management actions and strategies in relation to fire management for conservation purposes in different contexts and scenarios. This framework is an initial step to integrate that knowledge, previously scattered in different sources and branches of knowledge, but will require further development over the coming years.

11. Acknowledgments

We are grateful to all the researchers, stakeholders, governmental agencies, and others who contributed to the material and ideas discussed here. Special thanks go to the steering committee of the project, which comprised Mike Roache, Jacqui Dunlop, Philip Zylstra, Claire Runge, Catherine George, Peter Latch, Harriet Preece and Steven Howell. Thanks also go to the participants of the workshops in Queensland and New South Wales for their critical input and discussion around the framework. The names of the participants in the workshops are not listed because their anonymity was a condition in the Human Ethics approval from The University of Queensland for this project, Ethics Approval number HE000727. The interpretations placed on their work and thoughts around the framework are ours, but the stimuli belong to them. We thank Helen Mayfield and Courtney Melton for invaluable reviews of the manuscript and support in the workshop conceptualisation, organisation and development and the NESP Threatened Species Recovery Hub for funding.



12. References

Adams-Hosking, C., Grantham, H.S., Rhodes, J.R., McAlpine, C., Moss, P.T., 2011. Modelling climate-change-induced shifts in the distribution of the koala. *Wildl. Res.* 38, 122–130. https://doi.org/10.1071/WR10156

Altangerel, K., Kull, C.A., 2013. The prescribed burning debate in Australia: Conflicts and compatibilities. *J. Environ. Plan. Manag.* 56, 103–120. https://doi.org/10.1080/09640568.2011.652831

Ashton, D.H., 2000. The Big Ash forest, Wallaby Creek, Victoria - Changes during one lifetime. *Aust. J. Bot.* 48, 1–26. https://doi.org/10.1071/BT98045

Australasian Fire and Emergency Service Authorities Council, 2015. Overview of Prescribed Burning in Australasia.

Australian Bureau of Meteorology & CSIRO, 2020. State of the Climate 2020. Commonwealth of Australia.

Baker, A., 2016. Hazard Reduction Burning Guidelines For Koala Habitat on the Tweed Coast. Mullumbimby.

Bentley, P.D., Penman, T.D., 2017. Is there an inherent conflict in managing fire for people and conservation? *Int. J. Wildl. Fire* 26, 455–468.

Beyer, H.L., de Villiers, D., Loader, J., Robbins, A., Stigner, M., Forbes, N., Hanger, J., 2018. Management of multiple threats achieves meaningful koala conservation outcomes. *J. Appl. Ecol.* 55, 1966–1975. https://doi.org/10.1111/1365-2664.13127

Bowman, D.M.J.S., Williamson, G.J., Gibson, R.K., Bradstock, R.A., Keenan, R.J., 2021. The severity and extent of the Australia 2019–20 Eucalyptus forest fires are not the legacy of forest management. *Nat. Ecol. Evol.* https://doi.org/10.1038/s41559-021-01464-6

Bradshaw, S.D., DIxon, K.W., Lambers, H., Cross, A.T., Bailey, J., Hopper, S.D., 2018. Understanding the long-term impact of prescribed burning in mediterranean-climate biodiversity hotspots, with a focus on south-Western *Australia. Int. J. Wildl. Fire* 27, 643–657. https://doi.org/10.1071/WF18067

Bradstock, R., Gill, M., Williams, R., 2012. Flammable Australia: Fire Regimes, Biodiversity and Ecosystems in a Changing World.

Close, D.C., Davidson, N.J., Johnson, D.W., Abrams, M.D., Hart, S.C., Lunt, I.D., Archibald, R.D., Horton, B., Adams, M.A., 2009. Premature decline of eucalyptus and altered ecosystem processes in the absence of fire in some Australian forests. *Bot. Rev.* 75, 191–202. https://doi.org/10.1007/s12229-009-9027-y

Commonwealth of Australia, 2021. National Recovery Plan for the Koala Phascolarctos cinereus (combined populations of Queensland, New South Wales and the Australian Capital Territory). Commonwealth of Australia, Canberra.

Commonwealth of Australia, 2020. Chapter 18: Indigenous land and fire management, in: Royal Commission into National Nutrual Disaster Arrangements. p. 387.

Crisp, M.D., Burrows, G.E., Cook, L.G., Thornhill, A.H., Bowman, D.M.J.S., 2011. Flammable biomes dominated by eucalypts originated at the Cretaceous-Palaeogene boundary. *Nat. Commun. 2.* https://doi.org/10.1038/ncomms1191

Crowther, M.S., Lunney, D., Lemon, J., Stalenberg, E., Wheeler, R., Madani, G., Ross, K.A., Ellis, M., 2014. Climate-mediated habitat selection in an arboreal folivore. Ecography (Cop.). 37, 336–343. https://doi.org/10.1111/j.1600-0587.2013.00413.x

CSIRO, 2009. Bushfires in Australia. Canberra.

Cunningham, I., 2020. A Bayesian Belief Network to map species recovery from fire. University of Queensland.

Davies, N.A., Gramotnev, G., McAlpine, C., Seabrook, L., Baxter, G., Lunney, D., Rhodes, J.R., Bradley, A., 2013. Physiological stress in koala populations near the arid edge of their distribution. *PLoS One 8.* https://doi.org/10.1371/journal.pone.0079136

Department of Sustainability, Environment, Water, P. and C., 2013. Environment Protection and Biodiversity Conservation ACT 1999 (CTH) policy statement: Translocation of listed threatened species - assessment under chapter 4 of the EPBC Act.

Dickens, M.J., Delehanty, D.J., Romero, L.M., 2009. Stress and translocation: Alterations in the stress physiology of translocated birds. *Proc. R. Soc. B Biol. Sci.* 276, 2051–2056. https://doi.org/10.1098/rspb.2008.1778

Dixon, K.M., Cary, G.J., Worboys, G.L., Seddon, J., Gibbons, P., 2018. A comparison of fuel hazard in recently burned and long-unburned forests and woodlands. *Int. J. Wildl. Fire* 27, 609–622. https://doi.org/10.1071/WF18037

Dowdy, A.J., 2020. Seamless climate change projections and seasonal predictions for bushfires in Australia. *J. South. Hemisph. Earth Syst. Sci.* 70, 120–138. https://doi.org/10.1071/ES20001

Driscoll, D.A., Armenteras, D., Bennett, A.F., Brotons, L., Clarke, M.F., Doherty, T.S., Haslem, A., Kelly, L.T., Sato, C.F., Sitters, H., Aquilué, N., Bell, K., Chadid, M., Duane, A., Meza-Elizalde, M.C., Giljohann, K.M., González, T.M., Jambhekar, R., Lazzari, J., Morán-Ordóñez, A., Wevill, T., 2021. How fire interacts with habitat loss and fragmentation. *Biol. Rev.* https://doi.org/10.1111/brv.12687

Ellis, W., FitzGibbon, S., Pye, G., Whipple, B., Barth, B., Johnston, S., Seddon, J., Melzer, A., Higgins, D., Bercovitch, F., 2015. The role of bioacoustic signals in koala sexual selection: Insights from seasonal patterns of associations revealed with GPSProximity units. *PLoS One* 10, 1–12. https://doi.org/10.1371/journal.pone.0130657

Goverment of South Australia, 2002. Use of fire for ecological purposes in protected area management.

Grand, T.I., Barboza, P.S., 2001. Anatomy and development of the koala, *Phascolarctos cinereus*: An evolutionary perspective on the superfamily *Vombatoidea*. *Anat. Embryol. (Berl).* 203, 211–223. https://doi.org/10.1007/s004290000153

Greca, I.M., Moreira, M.A., 2000. Mental models, conceptual models, and modelling. *Int. J. Sci. Educ.* 22, 11. https://doi.org/10.1080/095006900289976

Griffith, J.E., Higgins, D.P., 2012. Diagnosis, treatment and outcomes for koala chlamydiosis at a rehabilitation facility (1995-2005). *Aust. Vet. J.* 90, 457–463. https://doi.org/10.1111/j.1751-0813.2012.00963.x

Hilbert, D.W., Ostendorf, B., Hopkins, M.S., 2001. Sensitivity of tropical forests to climate change in the humid tropics of north Queensland. *Austral Ecol.* 26, 590–603. https://doi.org/10.1046/j.1442-9993.2001.01137.x

Isaac, J.L., Valentine, L.E., Goodman, B.A., 2008. Demographic responses of an arboreal marsupial, the common brushtail possum (*Trichosurus vulpecula*), to a prescribed fire. *Popul. Ecol.* 50, 101–109. https://doi.org/10.1007/s10144-007-0057-1

Leach, M.K., Givnish, T.J., 1996. Ecological Determinants of Species Loss in Remnant Prairies. Science (80-.). 273, 1555–1558.

Legge, S., Woinarski, J., Garnett, S., Nimmo, D., Scheele, B., Lintermans, M., Mitchell, N., Ferris, J., 2020. Rapid analysis of impacts of the 2019-20 fires on animal species, and prioritisation of species for management response – preliminary report. Dep. Agric. Water Environ. 31.

Lindenmayer, D.B., Kooyman, R.M., Taylor, C., Ward, M., Watson, J.E.M., 2020. Recent Australian wildfires made worse by logging and associated forest management. *Nat. Ecol. Evol.* 4, 898–900. https://doi.org/10.1038/s41559-020-1195-5

Lunney, D.;, Gresser, S.;, O'neill, L.E.;, Matthews, A.;, Rhodes, J., 2007. The impact of fire and dogs on Koalas at Port Stephens, New South. *Pacific Conserv. Biol.* 13, 189.

Lunney, D., Crowther, M.S., Wallis, I., Foley, W.J., Lemon, J., Wheeler, R., Madani, G., Orscheg, C., Griffith, J.E., Krockenberger, M., Retamales, M., Stalenberg, E., 2012. Koalas and climate change: a case study on the Liverpool Plains, north-west New South Wales. *Wildl. Clim. Chang.* 150–168. https://doi.org/10.7882/fs.2012.022

Lunney, D., Gresser, S.M., Mahon, P.S., Matthews, A., 2004. Post-fire survival and reproduction of rehabilitated and unburnt koalas. *Biol. Conserv.* 120, 567–575. https://doi.org/10.1016/j.biocon.2004.03.029

Lunney, D., Matthews, A., 2004. Conserving the forest mammals of New South Wales. *Conserv. Aust. For. Fauna* 988–1021. https://doi.org/10.7882/fs.2004.988

Lunney, D., Stalenberg, E., Santika, T., Rhodes, J.R., 2014. Extinction in Eden: Identifying the role of climate change in the decline of the koala in south-eastern NSW. *Wildl. Res.* 41, 22–34. https://doi.org/10.1071/WR13054

Maclean, K., Robinson, C., Costello, O., 2018. A national framework to report on the benefits of Indigenous cultural fire management - Final report. Csiro.

Matthews, A., Lunney, D., Gresser, S., Maitz, W., 2016. Movement patterns of koalas in remnant forest after fire. *Aust. Mammal.* 91–104.

Matthews, A., Lunney, D., Gresser, S., Maitz, W., 2007. Tree use by koalas (*Phascolarctos cinereus*) after fire in remnant coastal forest. *Wildl. Res.* 34, 84–93. https://doi.org/10.1071/WR06075

McAlpine, C., Lunney, D., Melzer, A., Menkhorst, P., Phillips, S., Phalen, D., Ellis, W., Foley, W., Baxter, G., de Villiers, D., Kavanagh, R., Adams-Hosking, C., Todd, C., Whisson, D., Molsher, R., Walter, M., Lawler, I., Close, R., 2015. Conserving koalas: A review of the contrasting regional trends, outlooks and policy challenges. *Biol. Conserv.* 192, 226–236. https://doi.org/10.1016/j.biocon.2015.09.020

McAlpine, C.A., Rhodes, J.R., Callaghan, J.G., Bowen, M.E., Lunney, D., Mitchell, D.L., Pullar, D. V., Possingham, H.P., 2006. The importance of forest area and configuration relative to local habitat factors for conserving forest mammals: A case study of koalas in Queensland, Australia. *Biol. Conserv.* 132, 153–165. https://doi.org/10.1016/j.biocon.2006.03.021

Mella, V.S.A., McArthur, C., Krockenberger, M.B., Frend, R., Crowther, M.S., 2019. Needing a drink: Rainfall and temperature drive the use of free water by a threatened arboreal folivore. *PLoS One* 14, 1–15. https://doi.org/10.1371/journal.pone.0216964

Mella, V.S.A., Orr, C., Hall, L., Velasco, S., Madani, G., 2020. An insight into natural koala drinking behaviour. *Ethology* 126, 858–863. https://doi.org/10.1111/eth.13032

Melzer, A., Carrick, F., Menkhorst, P., Lunney, D., John, S., 2000. Overview , critical assessment , and conservation implications of koala distribution and abundance. *Conserv. Biol.* 14, 619–628.

Murphy, B.P., Bradstock, R.A., Boer, M.M., Carter, J., Cary, G.J., Cochrane, M.A., Fensham, R.J., Russell-Smith, J., Williamson, G.J., Bowman, D.M.J.S., 2013. Fire regimes of Australia: A pyrogeographic model system. *J. Biogeogr.* 40, 1048–1058. https://doi.org/10.1111/jbi.12065

NSW Office of Environment and Heritage, 2018. NSW Koala Strategy. Sydney, Australia.

NSW Rural Fire Service, 2015. Guide for Bush Fire Prone Land Mapping Version 5b.

Parkins, K., Cirulis, B.A., Penman, T.D., 2019. Fire risk management of populations of the koala *Phascolarctos cinereus* in the NSW southern tablelands: A simulation study 1–22.

Phillips, S., Wallis, K., Lane, A., 2021. Quantifying the impacts of bushfire on populations of wild koalas (*Phascolarctos cinereus*): Insights from the 2019/20 fire season. *Ecol. Manag. Restor.* 22, 80–88. https://doi.org/10.1111/emr.12458

Price, O.F., Penman, T.D., Bradstock, R.A., Boer, M.M., Clarke, H., 2015. Biogeographical variation in the potential effectiveness of prescribed fire in south-eastern Australia. *J. Biogeogr.* 42, 2234–2245. https://doi.org/10.1111/jbi.12579

QLD Department of Environment and Science, 2020. South East Queensland Koala Conservation Strategy 2020–2025. Brisbane, Australia.

Quigley, B.L., Timms, P., 2020. Helping koalas battle disease - Recent advances in Chlamydia and koala retrovirus (KoRV) disease understanding and treatment in koalas. *FEMS Microbiol. Rev.* 44, 583–605. https://doi.org/10.1093/femsre/fuaa024

Robinson, C., Barber, M., Hill, R., Gerrard, E., James, G., 2016. Protocols for Indigenous fire management partnerships.

Rus, A.I., McArthur, C., Mella, V.S.A., Crowther, M.S., 2021. Habitat fragmentation affects movement and space use of a specialist folivore, the koala. *Anim. Conserv.* 24, 26–37. https://doi.org/10.1111/acv.12596

Russell-smith, A.J., Stanton, P.J., Edwards, A.C., Peter, J., Russell-smith, J., Stanton, P.J., Edwards, A.C., Whitehead, P.J., 2018. Rain Forest Invasion of Eucalypt-Dominated Woodland Savanna , Iron Range , North-Eastern Australia : II . Rates of Landscape Change Published by : Wiley Stable URL : http://www.jstor.org/stable/3554830 _ Rain forest invasion of eucalypt- Wa ~ g l dominate 31, 1305–1316.

Sharples, J.J., Cary, G.J., Fox-Hughes, P., Mooney, S., Evans, J.P., Fletcher, M.S., Fromm, M., Grierson, P.F., McRae, R., Baker, P., 2016. Natural hazards in Australia: extreme bushfire. *Clim. Change* 139, 85–99. https://doi.org/10.1007/s10584-016-1811-1

Strelein, B.L., Tran, T., Wang, T., 2020. AIATSIS Submission : Independent review of the EPBC Act 1999.

TSSC, 2012a. Listing advice for *Phascolarctos cinereus* (combined population in Queensland, New South Wales and the Australian Capital Territory). Camberra.

TSSC, 2012b. Commonwealth Conservation Advice on *Phascolarctos cinereus* (combined population in Queensland, New South Wales and the Australian Capital Territory). Camberra.

Turton, S.M., Duff, G.A., 1992. Light environments and floristic composition across an open forest-rainforest boundary in northeastern Queensland. *Aust. J. Ecol.* 17, 415–423. https://doi.org/10.1111/j.1442-9993.1992.tb00824.x

van Eeden, L.M., Nimmo, D., Mahony, M., Herman, K., Ehmke, G., Driessen, J., O'Connor, J., Bino, G., Taylor, M., Dickman, C.R., 2020. Impacts of the unprecedented 2019-2020 bushfires on Australian animals. Report prepared for WWF-Australia, Ultimo, NSW.

Ward, M., Tulloch, A.I.T., Radford, J.Q., Williams, B.A., Reside, A.E., Macdonald, S.L., Mayfield, H.J., Maron, M., Possingham, H.P., Vine, S.J., O'Connor, J.L., Massingham, E.J., Greenville, A.C., Woinarski, J.C.Z., Garnett, S.T., Lintermans, M., Scheele, B.C., Carwardine, J., Nimmo, D.G., Lindenmayer, D.B., Kooyman, R.M., Simmonds, J.S., Sonter, L.J., Watson, J.E.M., 2020. Impact of 2019–2020 mega-fires on Australian fauna habitat. *Nat. Ecol. Evol.* 4, 1321–1326. https://doi.org/10.1038/s41559-020-1251-1

Watchorn, D.J., Whisson, D.A., 2019. Quantifying the interactions between koalas in a high-density population during the breeding period. *Aust. Mammal.* 42, 28–37. https://doi.org/10.1071/AM18027

Weir, J.K., Stacey, C., Youngetob, K., 2011. The Benefits Associated with Caring for Country 1–29.

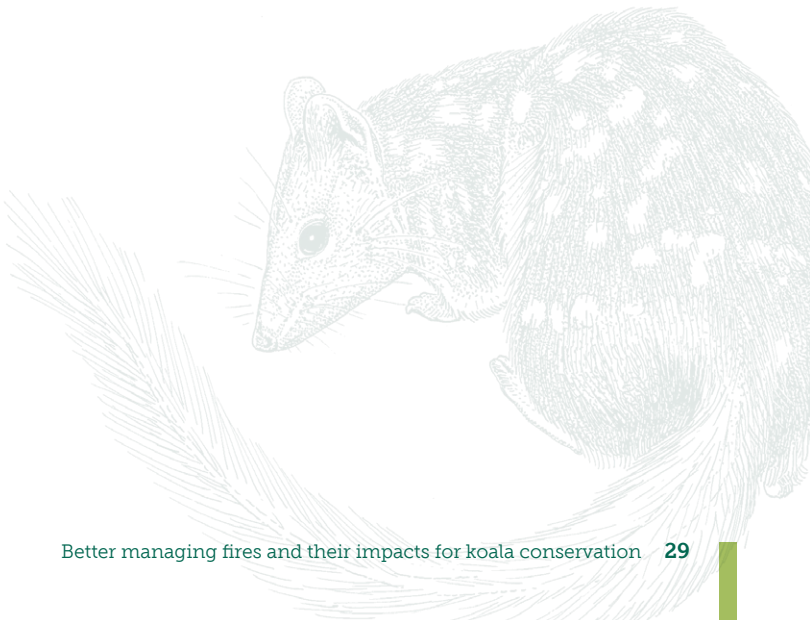
Williams, R.J., Bradstock, R.A., Cary, G.J., Enright, N.J., Gilll M., A., Leidloff, A.C., Lucas, C., Whelan, R., Andersen, A.N., Bowman, D.M.J.S., Clarke, P.J., Cook, G.D., Hennessy, K., York, A., 2009. Interactions between climate change, fire regimes and biodiversity in Australia - a preliminary assessment. Rep. to Dep. Clim. Chang. Dep. Environ. Herit. Arts, Canberra, Aust. 17, 196.

Yates, C.J., Broadhurst, L.M., 2002. Assessing limitations on population growth in two critically endangered *Acacia* taxa. *Biol. Conserv.* 108, 13–26. https://doi.org/10.1016/S0006-3207(02)00084-8

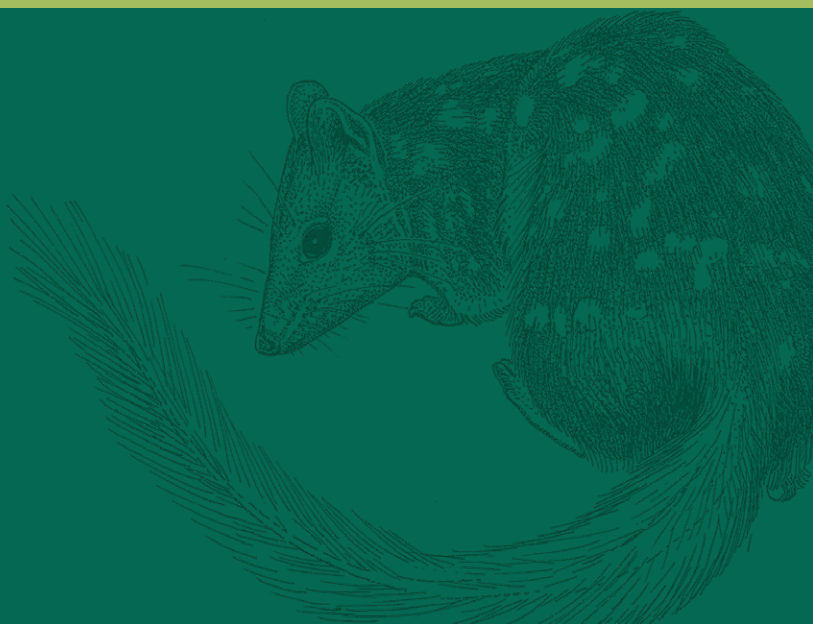
Zylstra, P.J., 2021. Linking fire behaviour and its ecological effects to plant traits, using FRaME in R. *Methods Ecol. Evol.* 12, In Press. https://doi.org/10.1111/2041-210X.13615

Zylstra, P.J., 2019. Fire regimes for risk management of koalas on the NSW Southern Tablelands. Report to the NSW Office of Environment and Heritage 21.

Zylstra, P.J., 2018. Flammability dynamics in the Australian Alps. *Austral Ecol.* 43, 578–591. https://doi.org/10.1111/aec.12594



Further information:
http://www.nespthreatenedspecies.edu.au



This project is supported through funding from the
Australian Government's National Environmental Science Program.

Threatened Species Recovery Hub

National Environmental Science Programme