Australian Government
Department of Agriculture, Water and the Environment

National Recovery Plan for the Koala

Phascolarctos cinereus

(combined populations of Queensland, New South Wales and the Australian Capital Territory)

Draft June 2021

The Species Profile and Threats Database page linked to this recovery plan can be found at: http://www.environment.gov.au/cgi-bin/sprat/public/sprat.pl

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Due to the vast number of individual contributors who have provided inputs to this plan representing the interests of a diverse range of stakeholder groups including traditional owners, land managers, landowners, conservation organisations, and government agencies, to list them would be impractical and risk missing someone unintentionally.

We extend our sincerest thanks to each and every individual and organisation that has contributed and invested effort to support the recovery of this iconic and culturally significant species to remain in the Australian landscape for future generations.

Glossary

Barrier/s. Impediments to the genetic dispersal of Koalas such that fewer than 1 individual capable of breeding can naturally move between populations over 3 generations. Barriers include geographic features such as escarpments or inhospitable landscapes but do not include structures such as roads where movement is possible even if irregular or results in an increased rate of mortality.

Drivers. Drivers are the demands from the society or human systems from which threats arise. Drivers can be direct or indirect. Indirect drivers are factors that influence the level of production and consumption of ecosystem services and the sustainable use of resources (*sensu* MA 2003), and can include biophysical, economic, social, cultural, or other factors.

Ecological threatening processes. The biophysical processes that may affect the survival, abundance or evolutionary potential of a native species or ecological community. Examples include habitat fragmentation, increased mortality and changes in habitat quality. Processes need not be outside the natural bounds of variability to be ecologically threatening. These can be grouped into landscape processes – those processes acting on Koala habitat and landscapes, and metapopulation processes – those processes acting on Koala populations and structure.

Indices (singular, index). Parameters or numerical metrics used to characterise a system of interest. An index is a single number compiled from one or more metrics and may be a direct or indirect metric. Direct metrics may be measures of abundance, density, and presence/absence (population parameters), or; homozygosity, allelic richness (genetic parameters). Indirect metrics may include measures of population change of the Koala inferred from changes in habitat area or a categorical measure such as an overall condition score for Koala health.

Landscape effects. The consequences of ecologically threatening processes acting on Koala habitat and landscapes. Examples include habitat loss and fragmentation, changes in habitat quality.

Metapopulation (synonyms: composite population, assemblage of populations). The set of biological populations within a larger area, where movement or gene flow from one biological population to at least some other patches is possible, even if irregular.

Metapopulation processes. The processes acting on populations that influence spatial structure of populations. Processes that cause extinction and recolonisation and affect metapopulation structure may be caused by disruption to dispersal patterns and exchange of genes between populations, changes in the carrying capacity of habitat and therefore the size of populations and their viability, changes to sex ratios, mortality rates.

Patch. Location or area of habitat with all the necessary resources for the persistence of a population and that is separated from other patches by inhospitable habitat that does not contain all the resources necessary for persistence. At any given time, a patch may be occupied or empty. Isolated patches are those patches separated from other patches by habitat or a distance that is unlikely to be traversed by Koalas.

Population. Population as defined in this Recovery Plan draws on the EPBC Act definition s528 and is an occurrence of the species in a particular area. Within this document population can refer to the

total number of individuals across all occurrences of listed Koalas, or unlisted Koalas; or all occurrences of Koalas or collections of Koala populations within a particular region or bioregion. That is, the area has a clearly defined boundary and may not necessarily concur with a biological population.

Population (biological definition). A biological population as defined in this Recovery Plan is a set of individuals that live in the same habitat patch and interact with one another, commonly forming a breeding unit within which the exchange of genetic material is more or less unrestricted (synonyms: local population, subpopulation, deme).

Population effects. The consequences of ecologically threatening processes acting on Koala populations and individuals to influence the demographic structure and status of populations. Examples include stress, changes to mortality rates and recruitment.

Populations. The biological populations identified to be declining or at risk to decline within the lifetime of the plan. A national agreement on populations will be identified in collaboration with the states and territories, and input through public consultation.

Species. Following the EPBC Act (s528) a species is a group of biological entities that (a) interbreed to produce fertile offspring; or (b) possess common characteristics derived from a common gene pool; and includes (c) a sub-species.

Threats. Activities, events and processes, whether anthropogenic or natural, that directly or indirectly influence the biophysical environment or natural demographic or ecological processes and may interfere with the conservation of the Koala. Examples include residential development, livestock farming, climate change, abstraction of water and increased fire frequency.

Direct threats. The proximate human activities or processes that directly cause changes to Koala's survival or their habitat. These may also result in cascading effects through landscape and population processes on the status of the Koala. Examples include housing developments, road building, and harvesting using silvicultural systems that directly remove habitat trees and patches. The occurrence of dogs and vehicles may cause direct mortality of Koalas.

Acronyms

CSIRO	Commonwealth Scientific and Industrial Research Organisation (Commonwealth)
ABARES	Australian Bureau of Agricultural and Resource Economics and Sciences
DAWE	Department of Agriculture, Water and the Environment (formerly DoEE and DotE)
DotE	Department of the Environment (Commonwealth)(former)
DoEE	Department of Energy and the Environment (Commonwealth) (former)
DECC	Department of Environment and Climate Change (NSW) (former)
DES	Department of Environment and Science (Queensland)(formerly DERM)
DERM	Department of Environment and Resource Management (Queensland)(former)
DELWP	Department of Environment, Land, Water and Planning (Victoria)(formerly DSE)
DPIE	Department of Planning, Industry and Environment (NSW)
DSE	Department of Sustainability and Environment (Victoria)(former)
EPBC Act	*Environment Protection and Biodiversity Conservation Act 1999* (Commonwealth)
IBRA/IBRA7	Interim Biogeographic Regionalisation for Australia. Version 7
IUCN	International Union for Conservation of Nature
KoRV	Koala retrovirus
Minister	The Australian Government Minister for Agriculture, Water and the Environment.
NGO	Non-government organisation
NRM	Natural Resource Management
OEH	NSW Office of Environment and Heritage
SPRAT	Species Profile and Threats Database
TSSC	Threatened Species Scientific Committee
WIRES	Wildlife Rescue

Summary

The Koala *Phascolarctos cinereus* (Goldfuss 1817) is recognised globally as an iconic Australian marsupial and is of cultural and emotional significance to both Indigenous and non-Indigenous Australians. Human-induced land-use change continues to impact the habitat of the Koala, resulting in population declines which will only be exacerbated by climate change. Consequently, the combined populations of Koalas in Queensland, New South Wales and the Australian Capital Territory (the listed Koala) are listed as threatened under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act).

The National Recovery Plan for the Koala *Phascolarctos cinereus* (combined populations of Queensland, New South Wales and the Australian Capital Territory) (the recovery plan) is made under the EPBC Act. The purpose of this plan is to stop the decline of, and support the recovery of, the listed Koala, so that the chances of its long-term survival in nature are maximised. It is the road map to recovery.

This recovery plan outlines national actions for the listed Koala at the metapopulation and population level. The national-level approach will identify areas for priority investment and action that will maximise long-term population-level recovery efforts and improve the coordination of state and local-level actions.

This recovery plan provides principles for state-level and local governments to support the recovery of listed Koala populations and, although it aims as a priority to complement and augment state-level strategies and actions, it does not preclude locally driven activities.

The Australian Government acknowledges that, to appropriately manage the listed Koala, a national approach is required that considers the listed Koala in the context of its relationship with unlisted Koala populations in Victoria and South Australia. The implementation of the recovery plan will consider the management and populations status of Koalas across Victoria and South Australia though cooperation and collaboration, national governance, and monitoring. It is envisioned that all respective Koala plans, strategies and plans will mutually inform conservation effort at a national scale.

The goal of the recovery plan is ***to reverse the trend of decline in population size of the listed Koala, by having resilient, connected, and genetically healthy metapopulations across its range, and to increase the extent, quality and connectivity of habitat occupied.***

Three objectives for the listed Koala are that by 2031:

Objective 1: The area of occupancy and size of populations that are declining, suspected to be declining and predicted to decline are increased.

Objective 2: Metapopulation processes are maintained or improved

Objective 3: Communities and individuals have a greater role and capability in Koala conservation and management.

The human-induced threats of land-use change and climate change, and their social and economic, cultural and biophysical drivers, underlie the impacts on listed Koala populations that this recovery plan aims to address. With a large distribution, Koalas are impacted by a wide range of interacting direct threats: land-use threats such as urbanisation, grazing, agriculture, transport infrastructure, mining and energy extraction; vegetation change through forest harvesting; the modification of natural processes of fire, hydrology and soil erosion; disease; and from droughts, heatwaves and bushfires, exacerbated by climate change.

These threats interact to impact Koala populations through the ecologically threatening processes of habitat loss, fragmentation and degradation, disease, barriers to safe movement and loss of genetic diversity.

Addressing any individual driver, threat or ecological threatening processes alone is unlikely to recover listed Koala populations. Recovering the listed Koala will require a holistic and integrated approach to action (Figure 3 and diagram below). The three objectives of this recovery plan are underpinned by four supporting strategies and two on-ground (direct) strategies, or action areas, as a way of organising and implementing coordinated action:

Strategy 1: Build and share knowledge

Strategy 2: Strong community engagement and partnerships

Strategy 3: Increase habitat protection

Strategy 4: Koala conservation is integrated into policy, and statutory and land-use plans

Strategy 5: Active metapopulation management

Strategy 6: Strategic habitat restoration.

The supporting strategies (Strategies 1-4) provide for governance to coordinate actions. They provide for research to improve effectiveness of actions, mapping, monitoring and survey methods, data collation, curation and analysis, dissemination of information, community support and capacity building, and to provide principles for state-level conservation planning for the listed Koala. They also provide to increase the area of protected priority Koala habitat to prevent further habitat loss and fragmentation, and to maintain population viability.

The on-ground (direct) strategies (Strategies 5-6) relate to improving habitat quality and restoration, and the collective actions required to ensure metapopulation processes are maintained.

Implementation of this plan will require commitment and collaboration between partners, with the Commonwealth Government leading national coordination. A detailed Implementation Plan is to be developed, subject to negotiation with major partners. Regional plans will provide the basis for planning and implementation prioritisation to reflect local land-use patterns, threats, and social and economic influences.

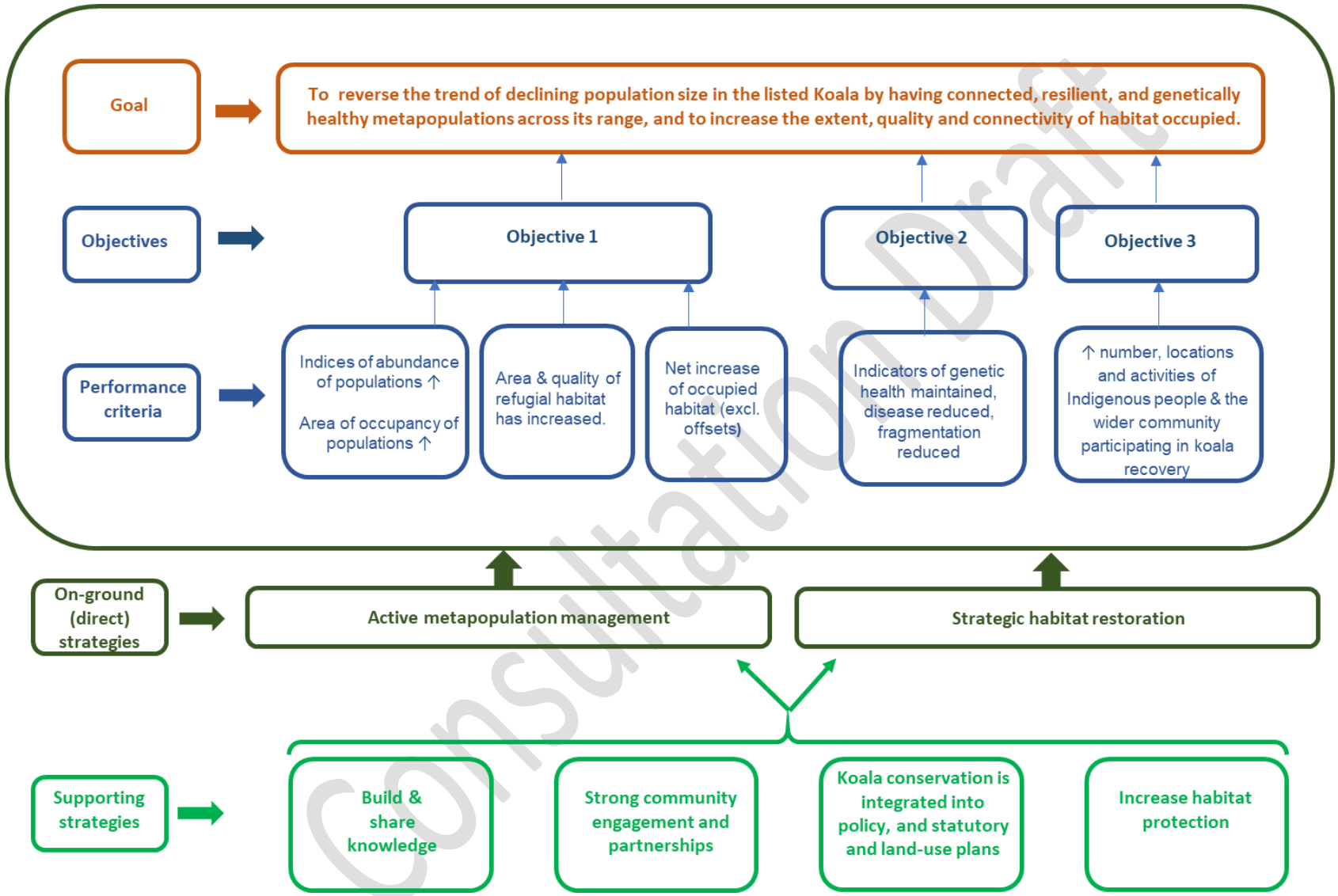

Diagram showing the goal, objectives, performance criteria, and strategies. No single strategy meets a single objective, they are cross-cutting and integrated.

A national Recovery Team, representative of the diversity of those engaged with Koala conservation, will be the nucleus to recovery efforts. It will monitor progress in implementation, share and review information, and identify funding opportunities. The Recovery Team will be supported by an Expert Technical Advisory Committee and community sub-committees, and Commonwealth and state and territory governments.

Indigenous and non-Indigenous groups will play a central role in the recovery of the listed Koala through co-designing, direct land management, habitat restoration, citizen science, welfare and care of injured Koalas, and in many other ways.

A National Koala Monitoring Program will be established in partnership with states and territories, and other interest groups to establish baselines, monitor population trends, increase predictive capacity, and understand the drivers and local threats affecting decline or recovery. It will also allow the evaluation of the effectiveness of management actions through an adaptive management framework.

Habitat across the geographic distribution of the listed Koala supports more than 150 other threatened species and ecological communities listed under the EPBC Act. Consequently, actions in this recovery plan to manage and protect the habitat of the listed Koala may well provide direct benefits to many species and communities.

The implementation of this recovery plan is expected to have social and economic benefits and costs. Measures to assist recovery of this species that involve restrictions on the use or management of land may result in economic impacts to some affected industries. Conversely, engaging positively with sectors may provide benefits in terms of achieving sustainability certification or other indirect benefits such as the increasing the amenity of urban landscapes.

Australians greatly value the Koala. As an iconic Australian species, enabling the recovery of the listed Koala is likely to provide a positive image of Australia to the world and to Australians, and encourage visitors in regions where Koalas are recovering, in addition to areas where they currently exist. The recovery of the listed Koala will be an exemplary representation of broader efforts to manage Australia's environment sustainably into the future.

Preface

The Koala *Phascolarctos cinereus* (Goldfuss 1817), is recognised globally as an iconic Australian marsupial and is of cultural and emotional significance to both Indigenous and non-Indigenous Australians. To see a Koala is a highlight for most international and Australian tourists and, as a drawcard, it provides a significant contribution to Australia's tourism economy (Hundloe & Hamilton 1997). It is also a very significant species to global biodiversity because it is the only surviving member of the ancient line of the marsupial family Phascolarctidae (Black 1999).

The Koala is associated with the distribution of the genera *Eucalyptus, Corymbia, Angophora* on which it predominantly feeds (Moore & Foley 2000) and is widely, but patchily, distributed across eastern and southern mainland Australia (Figure 4, section 21, DAWE 2021a). Much of the Koala's habitat is directly impacted by urban and infrastructure development, and by grazing, agricultural and natural resource use. These pressures have resulted in habitat loss, fragmentation and degradation, disrupting metapopulation processes and severely reducing Koala populations in some localities, especially those of south eastern Queensland and coastal areas of NSW. Urbanisation of Koala habitat also contributes to population declines through direct mortality from domestic dog attacks and vehicle strikes. Stress from urban interactions exacerbates disease and reduces breeding success in populations (Melzer et al. 2000; TSSC 2012a).

In addition, climate change is a growing threat to Koala persistence in many areas, increasing the frequency and intensity of extreme weather events such as heatwaves and droughts, and associated high-intensity bushfires. These can reduce habitat quality, cause rapid population declines and reduce the potential for Koala population recovery.

In 2012, the combined populations of Queensland, New South Wales and the Australian Capital Territory was listed as a Vulnerable 'species' under s517 of the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act)(TSSC 2012a).

Hereafter, the Koala will be referred to as either '*Koala*' or '*Koalas*' when referring to individuals or populations, '*the Koala'* or '*the species'* when referring to the total populations of the species, or the '*listed Koala*' when referring explicitly to the EPBC Act-listed Koala (combined populations of Queensland, New South Wales and the Australian Capital Territory). The populations of Victoria and South Australia may be referred to by their state origin or collectively as either the '*unlisted Koala'* or '*southern populations*'; the latter is consistent with the term used in research publications.

The reader is directed to the glossary at the front of this document for definitions specific to terms used in this plan that may otherwise have a slightly different/wider interpretation.

An initial national recovery plan for the listed Koala was drafted in consultation with the states and territories to replace the National Koala Strategy (NRM Ministerial Council 2014). However, the subsequent development of state and territory Koala strategies and plans (ACT Scientific Committee 2019; DES 2020; OEH 2018a), new research, and the impact of the 2019/2020 bushfires warranted significant redrafting to ensure the recovery plan was up-to-date, responsive to new information and aligned with state and territory Koala plans.

This recovery plan is a nationally led, landscape-scale conservation framework for recovery of the listed Koala, therefore requiring cross-jurisdictional and multi-tenure considerations. Direct threats, both natural in origin (e.g. some diseases) and human-induced (e.g., land-use change and climate change), cause cascading ecological threatening processes to landscapes and metapopulation processes, largely resulting in population declines (Figure 2, section 5).

The recovery plan encompasses objectives and actions (Part II) that are multi-faceted and linked at the population level, while recognising the need to manage populations locally because of the heterogeneity of threats across landscapes (Part IV). A National Koala Monitoring Program will measure progress on recovery and evaluate effectiveness of actions in an adaptive management framework (section 9).

This recovery plan is informed by the 2012 EPBC Act listing assessment (TSSC 2012b) and Conservation Advice (TSSC 2012a), new research, state and territory koala plans and strategies, and extensive consultations with partners and interest groups. Although the recovery plan focuses on the ten years to 2031, it is also a plan for the listed Koala conservation beyond this time, when climate change impacts are predicted to increase.

The recovery plan has been split into the following parts:

- **Part I** provides background and policy context for the listed Koala
- **Part II** presents the national goal, objectives and six strategies of actions to recover the listed Koala
- **Part III** outlines the nationally led implementation approach
- **Part IV** details the relationships between drivers, direct threats and ecological threatening processes impacting the listed Koala
- **Part V** presents background information on the distribution, population trends, habitat and habitat critical to the survival of the listed Koala
- **Part VI** presents an overview of biology and ecology of the Koala important for recovery planning and actions
- **Appendices 1 – 3** provide further technical information and resource material.

PART I Background and policy context

1 Cultural significance

1.1 Indigenous cultural and spiritual significance

The Koala is a totemic animal for many indigenous people and has a prominent place in creation stories as well as having a utilitarian role. This importance is indicated by the depiction of the Koala in rock art. The place of the Koala in creation stories, beliefs and lore demonstrates a strong understanding of the ecology of the species and connection by Indigenous people in the past, which continues to today (Phillips 1990).

There are many Koala creation stories and variations: for example, stories connecting the Koala with water and therefore salvation from danger; mystical powers of invisibility; a land bridge constructed from the Koala's intestines; why young Koalas cling to their mothers back; and the Koala's transformation to significant places and topographical formations (Cahir, Schlagloth & Clark 2020; Phillip 1990; Schlagloth, Cahir & Clark 2018).

Likewise, there were also many local variants for the Indigenous name for the Koala which include kulu, gulamany, yarri and barrandhang (NSW) (Cahir, Schlagloth & Clark 2020) and wirngbuul, ngarm-bal-mum and kullah (Victoria) (Schlagloth, Cahir & Clark 2018). The modern name of 'Koala' is thought to be derived from the Dharuk language of the Sydney region and is possibly a result of a scribal error of 'coola' and 'koolah' (Schlagloth, Cahir & Clark 2018).

Subject to local Indigenous lore, the Koala was used in ritual rites or hunted for meat. Skins were used in cultural ceremonies and rug making, although this use varies by locality (Cahir, Schlagloth & Clark 2020; Schlagloth, Cahir & Clark 2018). One contemporary account is that the Koala is special to women as a symbol of great motherhood and therefore women are not allowed to eat the Koala (Cahir, Schlagloth & Clark 2020).

Indigenous people today retain a strong connection to country and maintain healthy country on which the Koala and many other species of conservation concern occur.

1.2 Non-Indigenous significance

Australians have an emotional connection to the Koala. This is reflected in the attention it receives in media stories, in the number of community groups dedicated to Koala conservation and exemplified by its use as a symbol of the impacts of the disastrous bushfires during 2019/2020. The Koala is also an icon of Australian wildlife and is important in shaping Australia's global image. As one of the major attractions for tourists, its appeal is widely used in campaigns to attract overseas travellers to the country, and local and international visitors to zoos and sanctuaries (Markwell 2020).

2 Conservation status

The Koala (combined populations in Queensland, New South Wales and the Australian Capital Territory) was listed as Vulnerable in 2012 under the EPBC Act (TSSC 2012a). A reassessment of the listing status under the EPBC Act and an updated Conservation Advice is in progress, due for completion in October 2021. These documents and this recovery plan are being developed in parallel and will inform one another. Any change to the status and new information will be incorporated into the final version of the recovery plan.

The listed Koala is also considered Vulnerable under state and territory legislation in Queensland, NSW and the ACT. The Koala also occurs in Victoria and South Australia, where it is not considered threatened. In contrast to other states, populations of the Koala in Victoria and South Australia are largely stable, although in places such as the Otway Ranges (Vic.) and Kangaroo Island (SA) it is intensively managed due to over-abundance (at least, prior to the 2019/2020 bushfires). The total population of the Koala is listed as Vulnerable under the IUCN Red List of Threatened Species. Table 1 provides a summary of the conservation status of the Koala.

Table 1: International, national, state and territory conservation status of the Koala

Legislation	Conservation Status
Environment Protection and Biodiversity Conservation Act 1999 *Phascolarctos cinereus* (combined populations in Queensland, New South Wales and the Australian Capital Territory)	Vulnerable
Nature Conservation Act 1992 (Qld) Koala (*Phascolarctos cinereus*)	Vulnerable
Biodiversity Conservation ACT 2016 (NSW) Koala (*Phascolarctos cinereus*)	Vulnerable
Nature Conservation Act 2014 (ACT) Koala *(Phascolarctos cinereus)*	Vulnerable
Flora and Fauna Guarantee Act 1988 (Vic.) Koala *(Phascolarctos cinereus)*	Not listed
National Parks and Wildlife Act 1972 (SA) Koala *(Phascolarctos cinereus)*	Not listed
IUCN Red List of Threatened Species Koala *(Phascolarctos cinereus)*	Vulnerable

3 Planning and policy context

Within the Commonwealth of Australia, biodiversity conservation and protection are delivered by the combined efforts of local, state, territory and Australian governments, along with the actions of landholders, communities, traditional owners, the private sector and non-government organisations. Koala conservation is therefore influenced by a variety of cross-jurisdictional, Australian Government, and state, territory and local government policies, legislation, regulations and programs. This recovery plan is informed by, and interacts with, these policies and frameworks at

multiple levels (Figure 1). It is the key national planning document guiding national and collaborative recovery effort for the listed Koala.

3.1 Australian Government

Australia is Party to the international Convention on Biological Diversity, and *Australia's Strategy for Nature 2019-2030* is a national plan to implement the Convention's Strategic Plan and meet the Aichi Targets. Together with A*ustralia's Native Vegetation Framework*, these polices provide broad frameworks for conservation planning. They recognise the essential role that vegetation plays in conserving and promoting a biodiverse and thriving natural landscape and the shared responsibility at all levels of government to manage and protect Australia's environment for all Australians.

The EPBC Act is the Australian Government's key piece of environmental legislation. The EPBC Act provides a legal framework to protect and manage nationally and internationally important flora, fauna, ecological communities and heritage places—defined in the EPBC Act as Matters of National Environmental Significance (MNES). As an MNES, the listed Koala is subject to regulatory decision making under the EPBC Act. The EPBC Act is triggered when an action has, will have, or is likely to have, a significant impact on one or more MNES. Such an action would require referral to the Australian Government for assessment and approval under the EPBC Act to be carried out lawfully.

The EPBC Act provides a framework to plan for the long-term recovery of listed threatened species and ecological communities through the development of recovery plans and conservation advices. As national plans, these guide collaborative investment and participation by all levels of government and the broader community in recovery effort. The EPBC Act provides a significant foundation upon which longer term conservation planning and action is directed and is a major step in reporting on Australia's international responsibilities in protecting biodiversity.

The EPBC Act is part of a broader framework that aligns legal protection with Australian Government program investment and biodiversity policy to direct focus on priority national-level matters. The Commonwealth directly invests in the protection and recovery of Australia's biodiversity through the Natural Heritage Trust funding package. Environmental programs are delivered through the national Regional Landcare Program with benefits for listed threatened species and ecological communities.

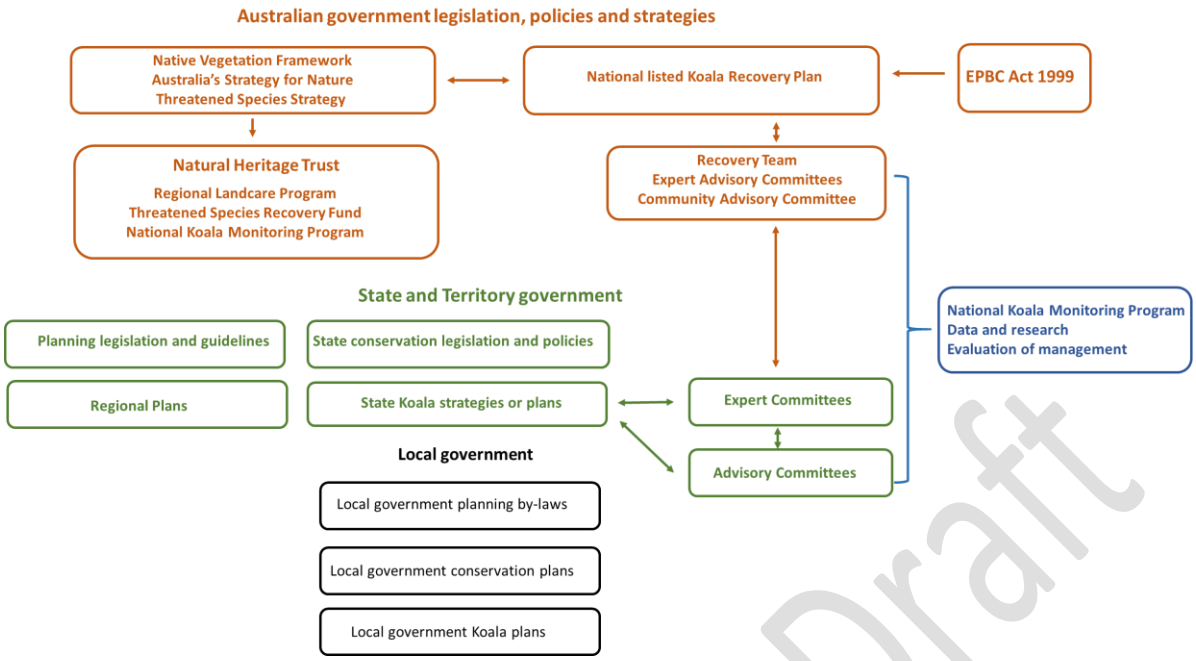

Figure 1. The geographical distribution of the listed Koala covers multiple land tenures across Queensland, NSW and the ACT, which are subject to a range of policies, programs, strategies and regulations at all levels of local, state, territory and Australian governments.

3.2 State and Territory Governments

States and territories are responsible for regulating environmental matters in their respective jurisdictions and are the primary regulators for Australia's native plants and animals. All state and territory governments have legislation to conserve biodiversity and to retain and manage habitats, including through a conservation reserve system. State and territory governments operate native vegetation conservation programs, while also providing for sustainable development of lands and waters within their jurisdictions.

NSW Government

The NSW Government has in place a range of laws and policies to help secure the future of the listed Koala in the wild.

In May 2018, the NSW Koala Strategy was released. The strategy sets out initial actions to achieve the NSW Government's goal of stabilising and then increasing Koala numbers over the longer-term, ensuring genetically diverse and viable populations across NSW. The NSW Government has committed $44.7 million to meet this goal (section 13). The Strategy delivers actions under four pillars: Koala habitat conservation, conservation through community action, safety and health of Koala populations and building our knowledge and education.

The NSW Government has committed to releasing its next whole-of-government strategy in early 2021 to help achieve the goal of doubling the number of Koalas in NSW by 2050.

The *Biodiversity Conservation Act 2016* (BC Act) contains provisions for identifying and protecting threatened species. The Koala is listed as a Vulnerable species under Schedule 1 of the BC Act. The BC Act also establishes a framework for assessing and offsetting biodiversity impacts from proposed development. The listing of Koalas as Vulnerable means they must be considered under the Environmental Planning and Assessment Act 1979 when preparing environmental planning instruments and when undertaking development assessments. The BC Act also requires a Biodiversity Conservation Program be established to maximise the long-term security of threatened species and threatened ecological communities in nature. The NSW Koala Strategy fulfils this requirement.

The State Environmental Planning Policy (Koala Habitat Protection) 2020 (Koala SEPP), aims to protect Koala habitat through the planning system. The Koala SEPP requires consideration of Koala habitat before certain development can be approved. It also provides a framework for councils to prepare a strategic Koala plan of management that would apply to the whole or part of a local government area. The NSW Government plans to develop an updated Koala SEPP in 2021.

ACT Government

The ACT lies within more marginal habitat for the listed Koala, and although currently there are no known extant populations, populations existed in the past (section 21.6). In 2019, the Koala was listed as Vulnerable, under the ACT Government's *Nature Conservation Act 2014* and a Conservation Advice issued (ACT Scientific Committee 2019).

The ACT Government plans to work in collaboration with the NSW Government on surveys in relation to populations along the NSW and ACT borders.

Queensland Government

Despite protection measures to date in Queensland, an independent review determined that the decline in peri-urban Koala populations in the Koala Coast and Pine Rivers areas of South East Queensland showed no evidence of slowing, and may even be increasing. These declines were linked to ongoing habitat loss in South East Queensland resulting from increasing urbanisation as well as other threats, such as dog attacks, road mortality associated with development, and disease. These causes for decline have been the driver for an increase in the extent and level of protection of Koala habitat, and other management actions for Koala conservation in South East Queensland.

The introduction of amendments to the Koala conservation planning framework in 2020 has resulted in the strongest Koala habitat protections Queensland has ever seen. This framework provides increased protection for Koala habitat in South East Queensland by increasing both the size and level of protections for Koala habitat areas compared with the State's previous regulatory framework. Koala habitat areas (including both core Koala habitat areas (KHA) and locally refined Koala habitat areas (LRKHA)) now cover 716,266 ha of land across South East Queensland. Of this, 330,660 ha, including 9,938 ha within the South East Queensland Urban Footprint, falls within Koala priority areas in which the clearing of Koala habitat areas is prohibited by the Queensland Government, subject to certain exemptions. These exemptions balance protecting Koala habitat with the need to allow clearing for limited development such as essential services.

The new planning protections introduced by the Queensland Government are supported by state-of-the-art Koala habitat mapping using advanced modelling techniques. The new methodology was endorsed by the Koala Expert Panel and independently reviewed by the CSIRO. The mapped Koala habitat represents the best habitat for Koalas, based on the combination of biophysical measures (including climate), suitable vegetation and Koala occurrence records. This approach will allow the new Koala habitat modelling and mapping to be updated and refined periodically, and enable the government to continue to accurately identify the best quality Koala habitat and track changes over time.

Outside South East Queensland, Koala populations are protected by a range of measures under the *Nature Conservation Act 1992* and subordinate Nature Conservation (Koala) Conservation Plan, including requirements in relation to clearing habitat in areas containing Koalas. Koala habitat outside South East Queensland is also regulated through the *Vegetation Management Act 1999* as Essential Habitat.

4 Purpose of the recovery plan

A recovery plan under the EPBC Act must provide for the research and management actions to stop the decline of, and support the recovery of, a listed threatened species so that its chances of long-term survival in nature are maximised. It is the road map to recovery.

This recovery plan for the listed Koala replaces the *National Koala Conservation and Management Strategy (2009-2014)* (NRM Ministerial Council 2009). It has been developed with relevant state and territory governments to provide an overarching national conservation framework for the listed Koala that aligns with local, state and territory government plans, programs and strategies. It does not replace them. It is the first recovery plan for the nationally listed Koala.

The Australian Government acknowledges that to appropriately manage the listed Koala a national approach is required that considers the listed Koala in the context of its relationship with unlisted Koala populations in Victoria and South Australia. The implementation of the recovery plan will consider the management and populations status of Koalas across Victoria and South Australia though cooperation and collaboration, national governance, and monitoring. It is envisioned that all respective Koala plans, and strategies will mutually inform conservation effort at a national scale.

The Victorian and South Australian populations are considered overall to be stable or increasing, although in some places there are local declines (Menkhorst 2008). Nevertheless, these populations are still susceptible to the direct threats and threatening ecological processes outlined in this recovery plan. For example, some of the unlisted Koala populations have low genetic diversity and display evidence of inbreeding (section 22), while populations of East Gippsland and Kangaroo Island (introduced) were significantly impacted by the bushfires in 2019/2020.

These populations may also become of greater significance as a stronghold in the future as climate change impacts progress, or some unpredicted widescale catastrophe befalls the listed Koala populations. And the remnant South Gippsland population in Victoria, possibly a genetic representative of an original Victorian population (Wedrowicz et al. 2018), may take on national significance and should be considered in the context of long-term recovery effort for the listed Koala, while other populations that are derived from a small number of founders and are

overabundant may provide clues to the physiological or genetic basis of adaptation. Thus, although this recovery plan does not legally inform management of the populations of the Koala in Victoria and South Australia, the principles and actions outlined here are also largely applicable, and engagement of Victoria and South Australian Koala management agencies will be sought as part of a broader national, coordinated Koala conservation effort.

PART II Goal, objectives & strategies

5 Overview of threats

The human-induced threats of land-use change and climate change, and their social and economic, and cultural drivers, underpin the impacts on listed Koala populations that this recovery plan aims to address. With a wide distribution, Koalas are impacted by a broad range of interacting direct threats: land use threats such as urbanisation, grazing, agriculture, transport infrastructure, and energy extraction; vegetation change through forest harvesting; the modification of natural processes of fire, hydrology and soil erosion; disease; and droughts, heatwaves and bushfires exacerbated by climate change.

These threats interact to impact Koala populations through the ecologically threatening processes of habitat loss, fragmentation and degradation, disease, barriers to safe movement and genetic effects (Figure 2, see Part IV for further details on threats).

In responding to those direct threats, addressing individual drivers, threats, and resultant ecological threatening processes in isolation from each other is unlikely to recover listed Koala populations (Beyer et al. 2018; Rhodes et al. 2011). Therefore, a holistic strategy that simultaneously manages multiple threats, and is appropriate to local conditions and is undertaken at an appropriate scale, is the most effective and efficient response to address declines.

Recovering populations will require an integrated package of coordinated actions, recognising the high profile but complex conservation context for this species including: the integration and harmonisation of Koala recovery actions into existing and future planning, policy and land-use plans; improved governance structures; increasing the area of protected habitat; building and maintaining strong community engagement and partnerships; building knowledge to inform priority settings, strategies and planning; and adaptive metapopulation management (section 8).

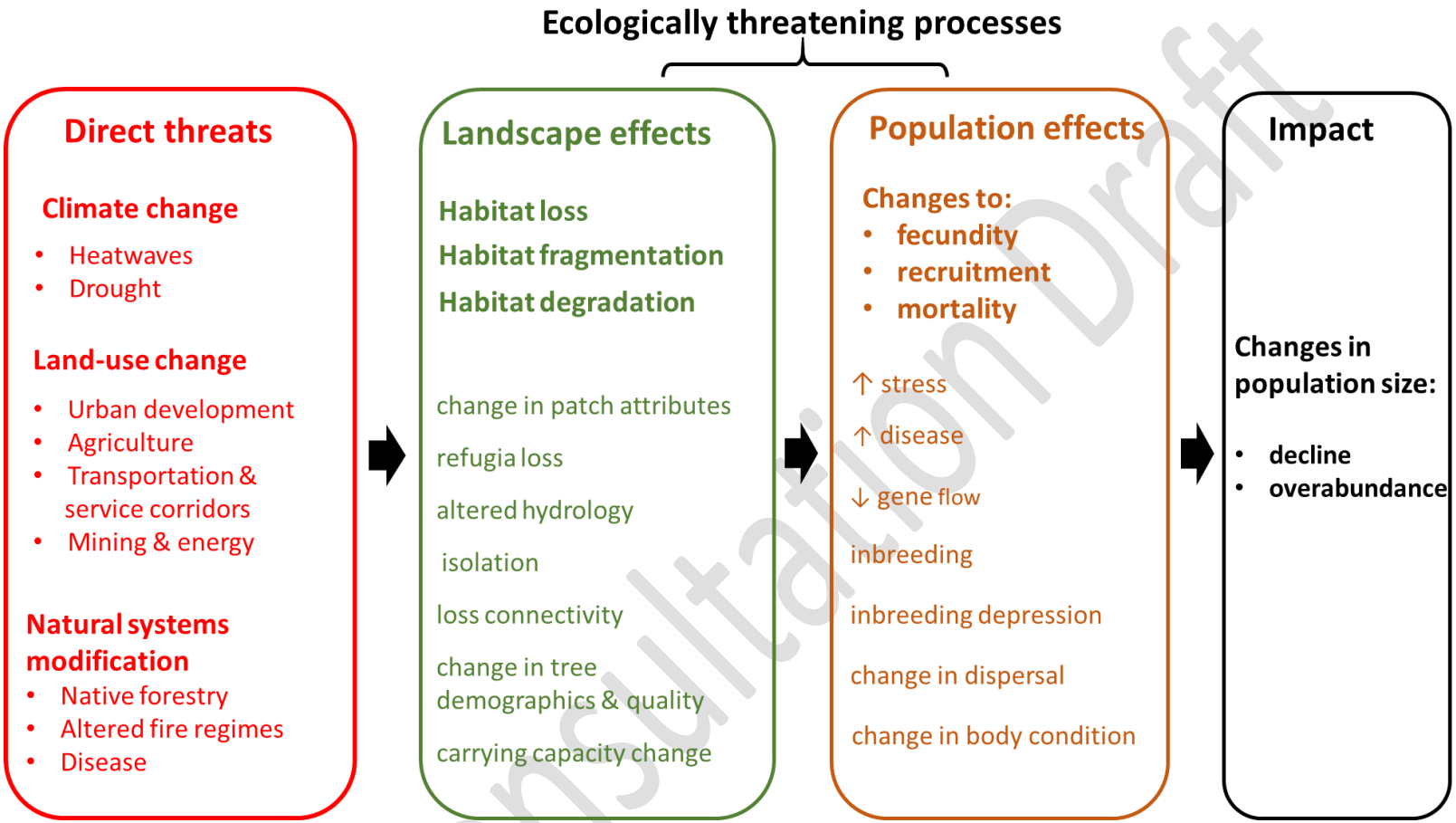

Figure 2. Stylistic representation of the relationships between land-use change on the landscape and Koala habitat, and Koala populations, exacerbated by climate change and natural systems change. Changes in landscape configuration and habitat quality mediate the disruption of population processes of both Koala trees and Koala populations through many interrelated and synergistic processes culminating with changes to population sizes, dominated by declines for the listed Koala. Disease is both a direct threat and ecologically threatening process due to increased stress from anthropogenic threats, resulting in increased mortality and reduced fecundity. Red = direct threats; Green = landscape processes and effects; Brown = population processes; and Black is the impact on Koala populations.

6 Goal

To reverse the trend of decline in population size of the listed Koala, by having resilient, connected, and genetically healthy metapopulations across its range, and to increase the extent, quality and connectivity of habitat occupied.

7 Objectives

To progress the long-term recovery goal, three objectives are set for the 10-year life of this plan. These complement and build upon state and territory Koala plans and strategies, and the 2012 Conservation Advice (TSSC 2012a).

Attainment of the first two objectives will ensure that national and regional trends of populations improve in terms of distribution, abundance, the quality of habitat, and the health of populations. The third objective is an enabling objective to determine the effectiveness of national coordination and engagement in Koala conservation. Effective engagement, whereby on-ground efforts are realised, will result in positive outcomes for the first three objectives. For example, strategic habitat restoration, supported by research, planning and engagement by community groups to plant trees or improve habitat quality, will likely improve the status of the Koala, however the measure of the impact may take several years to show.

The indices (or indicators) used to numerically measure and chart progress against each objective will be determined individually or under the National Koala Monitoring Program in collaboration with the states and territory. The National Koala Monitoring Program (section 9) will address gaps in existing programs, establish baseline information on population trends and also evaluate the effectiveness of management in an adaptive framework. It will develop indices to represent measures of genetic health (homozygosity or genetic diversity), population trends (abundance or density), habitat quality (vegetation composites) or Koala health (infection incidence, symptoms or condition score) (see Glossary for explanation of indices and metrics).

1. **The area of occupancy and size of populations that are declining, suspected to be declining, and predicted to decline are increased**

   Performance Criteria: By 2031,

   Indices of abundance of a representative sample of populations show that population size has increased.

   The area of occupancy of a representative sample of populations has increased.

   The area and quality of refugial habitat of populations whose primary threat is climate change, and indirectly drought and heatwaves, has increased.

   For *all* populations, there is a total net increase of occupied habitat (excluding offset areas) five-yearly.

2. **Metapopulation processes are maintained or improved**

   Performance Criteria: By 2031,

   Indicators of genetic health have been maintained.

   Indicators of disease impacts have been reduced.

   The level of population fragmentation has been reduced.

3. **Communities and individuals have a greater role and capability in Koala conservation and management**

   Performance Criteria: By 2031,

   There is an increase in the number, locations and activities of Indigenous peoples and the wider community participating in Koala recovery, including leadership, agenda setting, citizen science and on-ground works.

Populations are to be defined under Action 1a, in consultation with the states and territory, Recovery Team and supporting committees (Action 1k, establish a governance structure), and informed by new research and analysis (Action 1j).

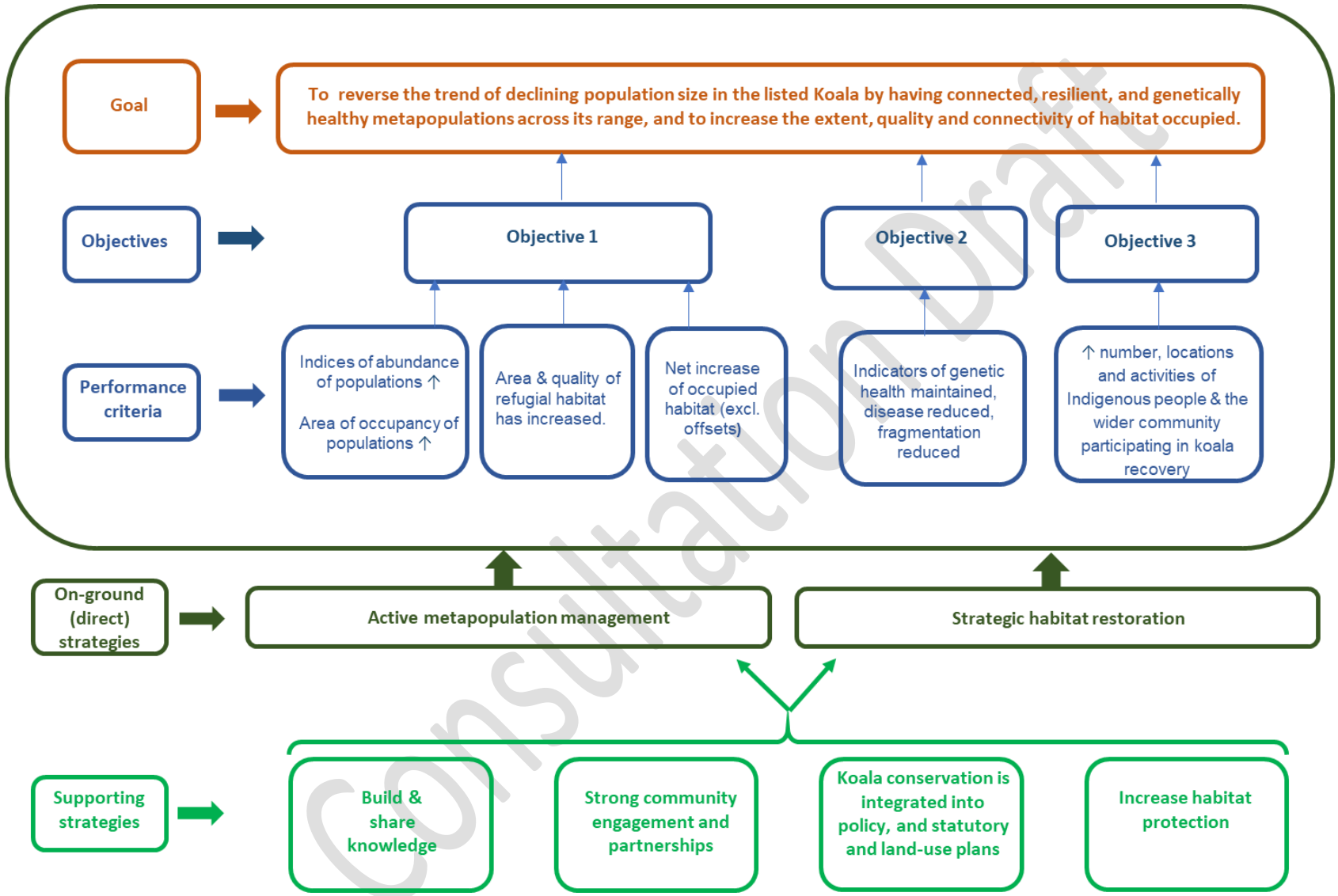

Figure 3. Diagram showing the goal, objectives, performance criteria, and strategies. No single strategy meets a single objective, they are cross-cutting and integrated.

8 Strategies and actions

To meet these objectives, actions are grouped under strategies, or action areas, as a way of organising and implementing coordinated action. Actions from any of the six strategies are cross-cutting to meet one or more objectives (Figure 3). Furthermore, many actions are predicated on other actions; for example, strategic habitat restoration is predicated on having up-to-date habitat mapping information and understanding of the nutritional quality of habitat within the landscape of interest. Also, many actions are re-iterative within an adaptive management framework (section 8). This means that the performance of a single action, or subset of actions, cannot be directly evaluated against a single objective. As such, each performance criterion only applies to the objectives, and no performance criteria or prioritisation is placed against individual actions.

Four supporting strategies and two on-ground (direct) strategies are identified.

Supporting strategies:

Strategy 1: **Build and share knowledge**

Strategy 2: **Strong community engagement and partnerships**

Strategy 3: **Increase habitat protection**

Strategy 4: **Koala conservation is integrated into policy, and statutory and land-use plans**

On-ground strategies:

Strategy 5: **Active metapopulation management**

Strategy 6: **Strategic habitat restoration**

Supporting strategies provide for governance to coordinate actions, led by the Australian Government in partnership with the states and territory. They provide for research and capacity building to improve effectiveness of actions, from enhanced mapping, monitoring and survey methods; improved data collation, curation and analysis; to better sharing and communication of information; and building on community capacity, support and engagement. They also provide for improved planning frameworks and principles for state-level conservation planning for the listed Koala.

Increasing the area of priority Koala habitat that is protected is a key strategy to prevent further habitat loss and fragmentation and prevent further loss of Koala populations (see section 19). Once identified (Actions 1a-c), national areas of priority Koala habitat should include areas of large intact landscapes that have the greatest potential to retain viable populations and have the potential to also act as source populations to adjacent areas.

On-ground (direct) strategies relate to improving habitat quality and restoration, and the suite of collective actions required to ensure metapopulation processes are maintained. The former will generally be implemented at the site-level, while the latter is a holistic landscape-scale approach to metapopulation management.

Many state-level actions have been ongoing, or recently commenced, under various state and territory environment-related, or Koala-specific strategies (for detail, see section 13).

Priorities assigned to actions under each of the six strategies are interpreted as follows:

Priority 1: Urgent. Taking prompt action is necessary for effective coordination, and rather than at implementation, to provide crucial information for planning and management, or to avoid or mitigate the most significant threats for recovery

Priority 2: Essential. Action is necessary to avoid or mitigate direct threats, implement planning and management, undertake research, and develop tools towards the long-term recovery

Priority 3: Highly beneficial. Action is desirable, and while not critical, will provide for longer term maintenance of recovery.

Strategy 1: Build and share knowledge

The actions here comprise knowledge-based inputs or activities that support direct actions in the recovery plan. These inputs will provide information for a strategic and coordinated approach to Koala conservation, now and into the near future using predictive climate change impacts. Without actioning these inputs, the ability to implement an effective recovery plan, and hence listed Koala recovery, will be significantly diminished.

Action No.	Description	Potential Partners/Responsibility	Timeframe (Priority)	Est. cost
1 a	Identify nationally important populations and habitat across the listed Koala range for now, and considering impacts of climate change such as drought, heatwave, and fire, by undertaking habitat distribution and population modelling and analysis (including abundance/density and genetic diversity), allowing for iterative updates using a robust scenario-based approach	Coordinated by the Commonwealth with state and territory government agencies using internal OR external mapping and modelling experts OR Expert Technical Advisory Panel & National Koala Recovery Team OR researchers	Year 1 (1)	TBA

Action No.	Description	Potential Partners/Responsibility	Timeframe (Priority)	Est. cost
1 b	Identify spatially and temporally strategic areas of high priority for: (i) restoration and revegetation based on Koala and eucalypt population viability; (ii) climate and fire refugia; and (iii) corridors facilitating movement and metapopulation processes of Koalas, allowing for iterative updates using a robust scenario-based approach.	Coordinated by the Commonwealth with state and territory government agencies, local government and natural resource management organisation; Or NGOs; Or researchers.	Year 1 and ongoing (1)	TBA
1 c	Develop prioritisation at regional or other appropriate scales for the long-term implementation of actions.	Coordinated by the Commonwealth with state and territory, and local government agencies using internal; external mapping and modelling experts; Expert Technical Advisory Panel & National Koala Recovery Team; researchers	Year 2 (2)	TBA
1 d	In consultation with each range state and territory, including Victoria and South Australia, scope out and establish a fit-for-purpose long-term National Koala Monitoring Program (NKMP) to improve understanding of trends in populations, distribution and population health across the Koala's range, and efficacy of management interventions.	Coordinated by the Commonwealth with state and territory government agencies; community groups; non-government conservation organisations; Koala research community; Koala welfare organisations and the Expert Technical Advisory Panel & National Recovery Team	Year 1 (1)	$ 2 million

Action No.	Description	Potential Partners/Responsibility	Timeframe (Priority)	Est. cost
1 e	Implement National Koala Monitoring Program; review design to ensure it remains fit-for-purpose and adaptive (see section 9).	Coordinated by the Commonwealth with state and territory government agencies; community groups; non-government conservation organisations; Koala research community; Koala welfare organisations and the Expert Technical Advisory Panel & National Recovery Team	Year 1 and ongoing (1)	TBA
1 f	Collate and synthesise existing data that may improve understanding of Koala population dynamics and threat profiles across habitats and scales.	Coordinated by the Commonwealth with state and territory government agencies using internal OR external mapping and modelling experts OR Expert Technical Advisory Panel & National Koala Recovery Team OR researchers	Years 1-5 (1)	TBA
1 g	Mapping of key metrics (distribution, habitat restoration, habitat condition and habitat loss) is reviewed at appropriate timeframes to detect changes, is coordinated across jurisdictions, and provides for landscape management now and at least three Koala generations into the future.	Coordinated by the Commonwealth with state and territory government agencies using internal OR external mapping and modelling experts OR Expert Technical Advisory Panel & National Koala Recovery Team OR researchers	Ongoing (1)	TBA

Action No.	Description	Potential Partners/Responsibility	Timeframe (Priority)	Est. cost
1 h	Coordinate pre-existing national and Koala databases; coordinate and develop data standards (including metadata standards); survey and sampling design standards to improve the quality of Koala monitoring (e.g., Community of Practice).	Coordinated by the Commonwealth with state and territory government agencies; Koala research community; Koala welfare organisations and the Expert Technical Advisory Panel & National Recovery Team	Years 1-5 (2)	TBA
1 i	Establish national research priorities targeted at applied outcomes, that inform and improve Koala management. This action builds on priority research identified by Expert Technical Advisory Panel and the outputs of the first Koala expert elicitation workshop for NSW (Hemming et al. 2018).	Coordinated by the Commonwealth with state and territory government agencies; Koala research community; Koala welfare organisations and the Expert Technical Advisory Panel & National Recovery Team	Ongoing (2)	TBA
1 j	Establish a recurring research forum to enhance existing collaboration among researchers, and between researchers, managers and other interested parties, to make the most effective use of research actions and to identify and address any further key knowledge gaps.	Coordinated by the Commonwealth with state and territory government agencies and Expert Technical Advisory Panel	Annually (2)	TBA
1 k	Facilitate a network to establish and support an active National Koala Recovery Team and Expert Technical Advisory Panel, with strong governance in place.	Coordinated by the Commonwealth with state and territory government agencies	Year 1 (1)	TBA

Action No.	Description	Potential Partners/Responsibility	Timeframe (Priority)	Est. cost
1 l	Share knowledge across experts, government organisations, conservation groups, rescue and welfare groups, Indigenous groups and the general public through regular Koala workshops and conferences. This includes a Koala conference every five years that brings together researchers, policy makers, planners and interested conservation groups and citizens; Exceptional circumstance workshops, such as following responses after major crises (e.g., fire and drought).	Coordinated by the Commonwealth with state and territory government agencies and Expert Technical Advisory Panel & National Recovery Team	5 yearly (3)	TBA

Strategy 2: Strong community engagement and partnerships

Successful Koala conservation relies on a collaborative approach across all sectors, and communities have a key role to play in protecting local Koalas. The high level of community support for the conservation of Koalas provides an opportunity for a range of actions that contribute to shared goals, from formal partnerships for habitat protection to raising awareness. Actions include engaging citizens in Koala conservation science, supporting and training professionals and Koala carers in the community. This includes intangible extension activities.

Action No.	Description	Potential Partners/Responsibility	Timeframe (Priority)	Est. cost
2 a	Grow partnerships with Indigenous and community groups and local government organisations to co-design opportunities for citizens to be involved in long-term Koala monitoring programs and research.	Commonwealth, state and territory government resource in coordination with natural resource management organisations & National Koala Recovery Team & NGOs	Ongoing (1)	TBA

Action No.	Description	Potential Partners/Responsibility	Timeframe (Priority)	Est. cost
2 b	Grow partnerships with Indigenous and community groups, non-government organisations and all level of governments to actively restore priority areas using best-knowledge revegetation guidelines for Koala.	Commonwealth, state and territory government agencies in coordination with natural resource management organisations & National Koala Recovery Team & NGOs	Ongoing (1)	TBA
2 c	Develop active communication, education and extension strategies for businesses (developers, industries and rural land-owners' enterprises) aimed at Koala habitat protection, incentives, partnership and compliance.	Commonwealth, state and territory government agencies in coordination with local government, natural resource management organisations	Ongoing (2)	TBA
2 d	Recognise the cultural and spiritual importance of the Koala to indigenous communities and engage to utilise, improve or reinvigorate their support and knowledge in Koala conservation, citizen science and field activities. Strengthen cross-cultural knowledge exchange and develop partnerships for the management and conservation of Koalas.	Commonwealth, state and territory government agencies in coordination with natural resource management organisations & National Koala Recovery Team & NGOs	Ongoing (1)	TBA
2 e	Implement a comprehensive communication strategy for the plan's realisation.	Commonwealth, state and territory natural agencies & National Koala Recovery Team; behavioural scientists	Ongoing (1)	TBA

Action No.	Description	Potential Partners/Responsibility	Timeframe (Priority)	Est. cost
2 f	Collaborate with existing database infrastructure to develop a user-friendly single-site portal for the general public to report Koala sightings, together with awareness raising and encouragement; embed processes for regular updates and regular communication of information generated from the data.	Coordinated by the Commonwealth with state and territory government agencies; local NRM organisations and local government	Years 2-5 (1)	TBA
2 g	Build on existing guidance information with experts to develop national guidelines for veterinary standards in care, injuries, fertility control, disease treatment, tissue sampling, orphans and release for veterinarians, carers and Koala rehabilitation centres; update and review to incorporate new learnings and knowledge.	Coordinated by the Commonwealth with state and territory government agencies, with input from research & veterinary experts; Expert Technical Advisory Panel; National Recovery Team; RSPCA and Koala welfare organisations	Years 2-5 (2)	TBA
2 h	Implement community engagement programs in urban and peri-urban areas where impacts on Koalas are high that use best-practise learnings on values and attitudes towards Koalas, responsible dog ownership and vehicle collisions and other urban issues resulting in Koala deaths; For example, develop and trial innovative programs in Koala aversion by dogs with owners.	State and territory government agencies in coordination with local government, traffic authorities and natural management organisations and behavioural scientists; dog training organisations; RSPCA	Ongoing (1)	TBA

Strategy 3: Increase habitat protection

Land-use change is the most significant threat to the Koala through habitat loss, fragmentation and degradation. Increasing the total area of protected, connected quality Koala habitat in priority areas will be important to protect and recover Koala populations. As Koalas occur across different land tenures, notably private land, this will require a range of incentive mechanisms, including direct land purchases. Improvements in land management practices can also increase habitat protection without changing land use. While direct habitat protection forms some actions, this strategy primarily consists of developing incentives for such protection and thus this strategy has been included as a supporting strategy.

Action No.	Description	Potential Partners/Responsibility	Timeframe	Est. cost
3 a	Increase the overall area of protected Koala habitat by dedication of Crown land and purchasing land identified as priority Koala habitat for incorporation into the state protected areas. Priority areas include those that support viable populations and those that have the greatest potential for population-level recovery.	States; territories; ; philanthropic investment	Ongoing (1)	TBA
3 b	Establish or expand existing targeted private land incentive mechanisms to increase the area for long-term protection and conservation of areas identified as priority Koala habitats.	States; territories; Commonwealth; philanthropic investment	Ongoing (2)	TBA
3 c	Improve the condition of existing Koala habitat on both private and public land through altered land management practices, including management of vegetation, fire, weed, and introduced species.	State and territory government agencies; non-government land-owners	Ongoing (2)	TBA
3 d	Increase the protection of priority Koala habitat through identification and registration of Critical Habitat where appropriate.	Commonwealth Government agencies; with strategic input from state and territory government agencies	Years 2-5 (2)	TBA

Strategy 4: Koala conservation is integrated into policy, and statutory and land-use plans

Management actions alone will not be sufficient to recover the Koala. Actions are needed to ensure harmonisation of existing and future planning and policy settings such that they collectively contribute appropriately to maximising the chances of long-term survival of Koalas in the wild.

Action No.	Description	Potential Partners/Responsibility	Timeframe	Est. cost
4 a	Review and update EPBC Act referral guidelines for the listed Koala, guided by the recovery plan, to support regulatory decision making.	Commonwealth in consultation with state and territory governments, experts, planners, industry and the wider community,	Yr 1 (1)	$50,000
4 b	Review and revise statutory planning instruments, policies, and compliance controls at all levels of government, including local government, to avoid or minimise impacts of land use or land management on Koala conservation consistent with the recovery plan.	State and territory government agencies in coordination with local government authorities; Commonwealth.	Ongoing (2)	TBA
4 c	Ensure identification and implementation of any offset decisions are strategic, coordinated, tracked in governments' databases, and informed by the recovery plan on advice from the Recovery Team.	Commonwealth, state and territory government agencies in coordination with local governments; National Recovery Team	Ongoing (2)	TBA
4 d	Incorporate the impacts of climate change such as drought, heatwave and fire, into all strategic Koala planning and actions, including restoration guidelines, offsets, translocation guidelines, forestry practices, corridor, reserve and protected area planning, allowing for iterative updates using a robust scenario-based approach	Commonwealth, state and territory government agencies in coordination with local governments	5 yearly (2)	TBA

Action No.	Description	Potential Partners/Responsibility	Timeframe	Est. cost
4 e	Build on existing information to develop national guidelines or standards for Koala-friendly urban design.	Commonwealth to coordinate state and territory government agencies, in consultation with local governments; urban planners	Ongoing (2)	TBA

Strategy 5: Strategic habitat restoration

Restoration increases the overall habitat available for Koalas and increases the connectivity between areas of habitat, which is important to the long-term survival of Koala populations. Many Landcare-type organisations are restoring lost and degraded habitat for many species or improve environmental functions. These activities are to ensure that resources are targeted to the most strategic areas.

Action No.	Description	Potential Partners/Responsibility	Timeframe	Est. cost
5 a	Build on and implement landscape-scaled habitat restoration plans, including NRM regional plans, based on up-to-date mapping and spatial analysis that considers potential carrying capacity and landscape-scale processes such as climate change, fire and drought, and Koala movement patterns.	Coordinated approach between states and territory government agencies; local government; natural resource management agencies; NGOs	Ongoing (1)	TBA
5 b	Develop and implement best practice revegetation and restoration guidelines appropriate to local conditions that include planning for drought, heatwave, fire, and eucalypt responses to climate change using a robust scenario-based approach, consistent with national standards for ecological restoration (SERA 2017)	Coordinated between state and territory government agencies with input from research experts; Expert Technical Advisory Panel; natural resource management agencies and local community groups; NGOs	Years 1-5 (2)	TBA

5 c	Implement on-ground revegetation or restoration programs. These should include trialling the establishment of climate resilient and nutritious feeding trees outside traditional ranges of Koala habitat trees.	Coordinated approach between states and territory government agencies; local government; natural resource management agencies and local community groups	Years 1-5 (2)	TBA

Strategy 6: Active metapopulation management

Metapopulation management concerns the movement of individuals and genes between populations. It is a complex and multi-faceted discipline. Adaptive management is the core of metapopulation management excellence. It requires consideration of cross-tenure land management, fire planning and operations, understanding of Koala movement patterns and behavioural ecology, genetics, infection and disease, and fine-scale and macro-scale habitat needs, among other factors. To complicate these actions, planning instruments (e.g., development zoning) and forest harvesting practices are spatially variable, making it difficult to be prescriptive.

This strategy relies heavily on relevant and up-to-date habitat and distribution mapping and modelling for spatial prioritisation, climate change modelling, principles of landscape processes, and research into Koala disease, population genetics habitat requirements, movement patterns, and biology. Management of fire, forest harvesting, and human activities and developments all influence Koala metapopulations processes and must be managed to mitigate adverse impacts.

Action No.	Description	Potential Partners/Responsibility	Timeframe	Est. cost
6 a	Develop meaningful and measurable triggers for and metrics of health, genetics, population and distribution, at relevant planning scales. Integrate these triggers into metapopulation management, decision-making and programs. Implement response plans.	Commonwealth, state and territory government agencies, with input from research experts; National Koala Monitoring Program; Expert Technical Advisory Panel & National Recovery Team	Years 1-5 (1)	TBA

Action No.	Description	Potential Partners/Responsibility	Timeframe	Est. cost
6 b	Build on existing best-practice Koala translocation and post-care release guidelines for wild and captive populations, ensuring they are fit-for-purpose, informed by the latest research in metapopulation processes, genetics, disease and gut flora. Ensure the translocation guidelines are reviewed and updated within the life of this plan to integrate new understandings. If translocations are required, implement Koala translocations in accordance with an appropriate decision framework and national guidelines (Wildlife Health Australia 2020), legislative requirements and consistent with international standards (IUCN/SSC 2013).	Coordinated by the Commonwealth with state and territory government agencies, with input from research experts; Expert Technical Advisory Panel & National Recovery Team; Koala welfare organisations and RSPCA	5 yearly (3)	TBA
6 c	Regionally assess the feasibility, risks and cost-effectiveness of fire management options that seek to deliver long-term, strategic and landscape scale enhancement of the extent, and quality of current and future suitable habitat across tenures.	State and territory agencies with input from fire research experts; Expert Technical Advisory Panel & National Recovery Team; local fire authorities and local government	Years 1-5 (1)	TBA
6 d	Develop and implement fire management that effectively secures and promotes long-term, strategic and effective protection of known populations and suitable habitat.	State and territory agencies with input from fire research experts; Expert Technical Advisory Panel & National Recovery Team; local fire authorities and local government; Koala welfare organisations and RSPCA	Years 1-5 (1)	TBA

Action No.	Description	Potential Partners/Responsibility	Timeframe	Est. cost
6 e	Develop and implement response and decision-support tools for individual and population management in emergencies such as bushfire, drought and floods. These include support and coordination of carer networks.	Coordinated by the Commonwealth with state and territory government resource agencies, local government agencies, natural resource management agencies and Koala welfare organisations, with input from research experts; Expert Technical Advisory Panel & National Recovery Team	Years 1-5 (1)	TBA

9 National Koala Monitoring Program

Adaptive management will underpin effective conservation of the listed Koala. Adaptive management is a structured, iterative approach to decision-making that incorporates formal learning process (both technical and social) into conservation actions to improve their effectiveness in the face of uncertainties (Williams & Brown 2014). An adaptive management framework for the listed Koala will be developed.

Measurement of performance against the three national objectives, and by implication the effectiveness of actions at local scales, requires monitoring of Koala populations in a statistically robust manner. Monitoring Koala populations is essential to document existing conditions, detect trends and increase predictive capacity and to understand the local threats and drivers of decline or recovery. To meet this end, a National Koala Monitoring Program is being designed in consultation with states and territory, and researchers across the entire species' range (Action 1d & e).

The National Koala Monitoring Program is intended to complement and augment existing state and territory monitoring and reporting programs, targeting spatial and temporal information gaps. The states and territory have established or ad-hoc Koala monitoring programs of varying size and effort (in space and time), based on a range of methods and tailored to reflect each jurisdiction's needs and questions.

The design, analysis and synthesis of the National Koala Monitoring Program will account for strengths, weaknesses and biases of the many survey methods commonly used. A Community of Practice in survey methods (Action 1h) will be developed as a guide to assist researchers and citizen science groups in employing the most suitable method for given circumstances.

Because of the large geographic range of the Koala, partners and citizen scientists will play a significant role in the National Koala Monitoring Program. This recovery plan aims to support and build capacity of interest groups and individuals to establish a long-term monitoring program with the support of researchers and governments of all levels.

PART III Implementation

10 Principles

Conservation planning and recovery for the listed Koala is a long-term proposition and commitment. Collective action undertaken over the ten-year period of this plan will contribute to slowing and reversing the rate of the current decline in populations and thereby contribute to the plan's goal. Importantly, these actions will provide a basis and momentum for promoting recovery and managing the species over the medium to long-term.

The recovery objectives, strategies and actions proposed are informed by a set of general principles and requirements. These include that:

- the ultimate purpose of this recovery plan is to reverse the decline and support the recovery of the listed Koala so that its chances of long-term survival in nature are maximised, consistent with the requirements under the EPBC Act.
- Koala populations are subject to different and interacting threats across their range and one program will not fit all locations. A national recovery plan will only be effective if a regional (and local) approach is adopted in its implementation.
- actions complement and augment existing state and territory strategies and plans. Actions build on current strategies by providing overarching national actions that improve coordination, reduce duplication, and assist in the allocation of resources to strategic actions that will contribute to achieving the objectives.
- whereas long-standing threats, for example, land-use change, continue to threaten Koala habitat and populations, the emerging threat of climate change must be considered in planning for long-term recovery and that planning must consider all threats and their interactions, and not just focus on one or two in isolation.
- conservation success will not be achieved by management actions alone but will depend also upon enhancing existing and future planning and policy environment, supported by an engaged community, such that these contribute appropriately to the long-term survival of the listed Koala in the wild.
- actions are feasible, and the Australian, state and territory governments are willing and have the capacity to act; communities are adequately supported to build capacity in on-ground recovery actions and to participate in planning and policy decision-making.
- there remain uncertainties about some conservation management actions (such as effective fire and climate change mitigation options), so implementation of this recovery plan should address these knowledge gaps and be flexible, and responsive to new information. Implementation of the recovery plan will be underpinned by science-based adaptive management.

11 Governance and structure

Implementation of this recovery plan will require commitment, and collaboration between partners, with the Commonwealth taking a lead role in national coordination. Potential implementation partners will be identified for every action. Broadly, these may include government agencies with statutory responsibilities to protect and manage the listed Koala and its habitat, landowners, forestry-based industry groups, mining industry groups, non-government conservation organisations, Koala health and welfare organisations, community organisations, Indigenous communities and research institutions (Appendix 1).

As a priority, a detailed national Implementation Plan is to be developed and subject to negotiation with major partners through which agreement is reached on partner responsibilities, contributions, governance arrangements, risk management, commitment to agreed actions, and reporting structure, once the recovery plan is in place. This recovery plan will also be augmented by appropriate regional scale plans (section 14).

11.1 Recovery Team

A Recovery Team will be the nucleus to collaborate and coordinate recovery effort, and will form in accordance with best practice governance guidelines established by the Australian Government (http://www.environment.gov.au/biodiversity/threatened/recovery-teams). It will monitor progress in implementation, share and review information, identify funding opportunities and report on progress. Expert Technical Advisory and Community Advisory sub-committees will be established to provide advice to the Recovery Team as required.

The time required to commit to a Recovery Team and any supporting sub-committees will likely be significant and therefore it is anticipated that most members will be supported by their parent organisation. To share the anticipated workload fairly, the structure of the Recovery Team may need to be made up of multiple members representing various disciplines.

The Recovery Team will be representative of the diversity of those engaged in Koala research, management and community activities and as such will provide the opportunity for emerging early career researchers, students and staff of partner organisations to gain valuable experience through mentoring by senior personnel.

12 Schedule and costs

The conservation of the listed Koala across a large geographic range will require considerable investment from partners, interest groups, volunteers for non-tangible resources and funds to undertake the actions.

Implementing this recovery plan is subject to budgetary and other resource opportunities and constraints affecting partners. The cost of implementing this recovery plan should, where possible, be incorporated into the core business expenditure of partner organisations and through additional funds obtained for the explicit purpose of implementation.

The majority of actions have draft prioritisation against each (categories 1-3), while most costings have not been determined at this stage for the following reasons:

- Actions are cross-cutting across multiple threat management actions and supporting actions.
- The risk presented by each threat varies across the distribution of the Koala, hence the priority for actions varies by location.
- Action priorities at specific locations are likely to change within the life of the plan, and the complexity of threat management actions preclude prescribing priorities.
- Threat management is adaptive, and therefore effort will need to change in space and time.
- Knowledge of the effectiveness of threat management actions is incomplete, and therefore new knowledge informed by research may alter management approaches.
- Many actions cannot be accurately costed, or are weather and bushfire dependent, or are part of existing core business and resourcing.
- Some actions are predicated on outcomes of other actions (e.g., mapping) or research.
- Planning legislation, regulations and policies, and how they influence local threat management actions, varies widely at the state and local government level.
- Many actions are underway by state and local governments, and conservation groups.

A key action upon formation of a governance structure to steer implementation of the recovery plan will be the development of an Implementation Plan. This will, in collaboration with partners, prioritise and assign relative budgets against these.

13 Current Koala recovery action

Many actions, or parts of actions in this plan, are underway through Commonwealth and state-led investment programs, plans or other Koala conservation efforts.

13.1 Australian Government

In November 2020, the Australian Government committed $18 million to the conservation of the Koala. This includes $2 million to the establishment of a National Koala Monitoring Program (including Victoria and South Australia) (section 9), which will build on and complement existing monitoring led by the states and territory governments and other organisations. Another $2 million is committed to support Koala health research and $14 million to habitat restoration projects through the Regional Landcare Program under the National Heritage Trust funds.

13.2 NSW Government

The NSW government has committed $44.7 million over three years to listed Koala recovery in NSW, including $2.8 to fund listed Koala research (https://Koala.nsw.gov.au/nsw-government/).

Under the NSW Koala Strategy, as of February 2021, $20 million for the purchase of quality Koala habitat has supported the purchase of 4,300 ha for addition to the NSW national park estate. To improve the safety and health of Koalas, the NSW Government has also committed $3.3 million to fix priority roadkill hotspots across NSW, through the construction of Koala exclusion fencing and wildlife underpasses. A genetic biobank has also been set up with the Australian Museum to consolidate genetic data and to improve knowledge about Koala genetics. Following the devastation of the 2019-20 bushfires a further $1 million was added to the $4.05 million committed under the Strategy to support wildlife rehabilitators and veterinary care.

13.3 ACT Government

The ACT Government protects suitable Koala habitat within Namadgi National Park. The ACT Government manages Namadgi National Park and its surrounds for fire, weeds and other threats. Habitat in the ACT may be suitable for the establishment of insurance populations to retain and conserve local genetic diversity, or as future translocation sites. These areas are also potential refugia in the future under climate change.

Although the ACT Government does not directly manage wild populations of Koalas, ad-hoc surveys are undertaken in areas that may potentially support them. At Tidbinbilla Nature Reserve, the ACT Government breeds Koalas, originating from Victoria, in captivity for display and educational purposes.

13.4 Queensland Government

The Queensland government has commenced the implementation of the South East Queensland Koala Strategy with funds for $2 million to deliver habitat restoration, and $1.55 million for health care infrastructure (https://statements.qld.gov.au/statements/89020).

The Queensland Government's direction for Koala conservation and Koala habitat protection is detailed in the South East Queensland Koala Conservation Strategy 2020-2025 (https://environment.des.qld.gov.au/__data/assets/pdf_file/0016/211732/seq-Koala-conservation-strategy-2020-2025.pdf). This Strategy establishes a vision to halt the decline of Koala populations in the wild in South East Queensland. The Strategy has been built around six action areas for habitat protection and restoration, threat management, improved mapping monitoring research and reporting, community engagement, and partnerships and strategic coordination. It was guided by the findings of the 2017 Koala Expert Panel report.

Key targets have been developed to track progress against the vision, including stabilising Koala populations in South East Queensland, securing a net gain in Koala habitat, restore Koala habitat and introduce threat reduction programs. A number of the actions in the Strategy have already commenced, including the development of state-of-the-art Koala habitat mapping for South East Queensland and amendments to the land use planning framework to deliver an increase in both the size and level of protections for Koala habitat in South East Queensland.

A detailed Implementation Plan and Monitoring, Evaluation, Reporting and Improvement framework is under development in partnership with a range of key delivery partners.

14 National coordination, regional implementation

Due to the heterogeneity of threats (section 18), social and economic interests, land-use, and natural patterns of variation across the distribution of the Koala, this recovery plan will be implemented through appropriate regional scale implementation plans.

Bioregions represent one potential scale as a basis for intermediate level planning at a scale that can be informed by the recovery plan and state/territory-level strategies, while also having the capacity to incorporate fine-level habitat analysis, planning and an understanding of the nature and risk of local threats to listed Koala recovery.

Implementation of the recovery plan will require the refinement of priorities of the strategies and actions outlined here. Additional mapping, ground truthing, monitoring and research may be required to develop these bioregional plans. The development of the plans themselves will require prioritisation, with bioregions where key populations are under most threat, and not currently addressed in state or local level planning as highest priority. These will be developed in partnership with state and local governments and key interest groups relevant to the bioregion.

The *South East Queensland Koala Conservation Strategy 2020–2025* (DES 2020) represents a planning approach at a bioregional scale that is fit for purpose and is a bespoke response to the issues affecting the management of Koalas in South East Queensland. The alignment of the national recovery plan with such regional implementation plans, potentially represents a model to implement across other priority regions.

15 Community interests and roles

15.1 Indigenous communities

Indigenous communities have had a relationship with the Koala extending back many thousands of years (section 1.1). The relationship is both an economic, land management, and cultural one, with Koalas found in some areas where indigenous people are continuing to lead management of healthy country. Interested indigenous communities, organisations and individuals will be actively sought and encouraged to be involved in the actions set out in this plan and be consulted in decision-making and co-design of projects for the recovery of the listed Koala. Along with other members of the wider community, individuals and groups will be encouraged to contribute as professional land managers or ecologists or to citizen science projects on both traditional owner managed lands and other land tenures.

15.2 Community Koala conservation

This recovery plan recognises the many small groups and individuals who are committed to conservation of the Koala in their local areas through habitat restoration activities, caring of injured and sick animals in rehabilitation, or involvement in research (citizen science). It outlines actions to support and build capability of these groups. Likewise, representatives of these many groups will be activity sought to be involved in the actions set out in the plan and contribute to the recovery of the listed Koala.

16 Potential benefits and impacts

16.1 Broader biodiversity benefits

The Koala is an archetypal umbrella species, whereby actions to manage and protect its habitat may likely provide benefits to many other species and enhance ecosystem functions. Vegetation coinciding with the geographic distribution of the listed Koala supports more than 150 other threatened species and ecological communities listed under the EPBC Act.

Notably, the Greater Glider (*Petauroides volans*) (Vulnerable) and the Yellow-bellied Glider (*Petaurus australis*), and other arboreal mammal species such as possums and bats, as well as forest owls, will benefit, and in turn provide ecosystem services such as pollination and pest control. Species that occupy the lower stratum of Koala habitat such as the Southern Brown Bandicoot (*Isoodon obesulus*) (Endangered) and small native rodents, especially those in urban fringes, might benefit from greater protection and reduction of threat from dog attack and vehicle strike. In the more arid landscapes of central Queensland and NSW, a different suite of species of open woodlands also occupies listed Koala habitat, notably nine listed Brigalow Belt reptiles, the Superb Parrot (*Polytelis swainsoinii*) (Vulnerable) and the Grey-headed flying fox (*Pteropus poliocephalus*) (Vulnerable).

The listed Koala is dependent on large tracts of forests and woodlands across eastern Australia. Revegetation of areas of previous koala habitat currently cleared across these landscapes will provide wider benefits to ecosystems and people by decreasing CO_2 in the atmosphere; reducing the extent and magnitude of drought (McAlpine et al. 2009); increasing connectivity between isolated habitat patches for other species; and enhancing thermal comfort and microclimate conditions for biota as well as humans.

16.2 Social and economic considerations

The implementation of this recovery plan is expected to have social and economic benefits and costs. As habitat critical to the survival of the listed Koala is identified, proposed activities, including development, may need to be modified and adjusted to reduce the likelihood of a significant impact upon the listed Koala. Measures to assist recovery of this species that involve restrictions on the use or management of land may result in economic impacts to affected industries. Conversely, engaging positively with the sectors may provide benefits in terms of achieving sustainability certification, such as for forestry through forestry industry certification bodies, and 'Koala-friendly' suburbs may be attractive to residents and a way for developers and residents to demonstrate their commitment to sustainable communities and increase the amenity of landscapes.

As an iconic Australian species, enabling the recovery of the listed Koala is likely to assist the tourist industry in terms of providing a positive image of Australia and encouraging visitors to regions where Koalas are recovering, in addition to areas where they currently exist. The recovery of the listed Koala will be an exemplary representation of broader efforts to manage Australia's environment sustainably into the future.

16.3 Partners and affected interests

Government institutions likely to be both major partners and affected by the actions proposed in this plan include Australian and state government agencies, local government, particularly where there are environmental, transport and road, urban planning, resources or forestry responsibilities. Timber production, agriculture, mining, and commercial and residential development interests are also likely to be affected.

Other potential partners or those groups and individuals with a strong interest in the recovery of the listed Koala include Koala advocacy and Koala welfare groups, researchers, Natural Resource Management organisations, Indigenous communities, land holders (farmers, rural residential and developers), non-government conservation organisations, wildlife interest groups, individuals and Citizen Scientists (Appendix 1).

Habitat for the listed Koala spans most land tenures, with over half on private lands (Table 2) ranging from small residential housing to large tracts of rangelands, woodlands or forests. Consequently, successful consultation and engagement with all types of land-owners will play a major role in the success in meeting the recovery plan's goal and objectives. To facilitate this, a comprehensive communication and engagement strategy is proposed for the implementation of this plan (Action 2i).

Table 2. Proportion of forest or woodland by land tenure across the listed Koala's range and states (ABARES 2018; Runge, Rhodes & Lopez-Cubillos 2021)

Land tenure	Listed Koala	Qld	NSW	ACT
Private	57.2 %	55.4 %	61.4 %	<0.1 %
Leasehold	13.9 %	20.5 %	0.7 %	18.3 %
Multiple-use public	12.0 %	12.5 %	11.0 %	11.0 %
Nature conservation reserve	13.4 %	8.6 %	22.5 %	60.8 %
Other crown land	3.5 %	3.0 %	4.4 %	9.8 %

17 Monitoring, evaluation and adaptation of the recovery plan

The recovery plan will establish a monitoring, evaluation, reporting and improvement framework that measures the progress of the plan's actions. Monitoring of the plan will require ongoing assessment of the implementation and success of all actions, with regular reporting to the Recovery Team.

A mid-term review (five years) of the plan will be conducted in accordance with the EPBC Act requirements. This review will inform the need for any adaptation required within the plan, to identify and resolve any unexpected impediments, and to re-assess priorities for actions. The review will be coordinated by the Recovery Team.

A comprehensive review of the implementation and success of the plan will be undertaken ten years after the making of this plan as a foundation for the development of a revised ten-year plan. This review will consider, among other things, trends in the status of the listed Koala and its habitat, effectiveness of actions described in this plan, new research findings and emerging issues, policy context, management capability and resourcing, and partner satisfaction with governance and other matters. The review will be conducted independently with input from the Recovery Team and other partners involved in the plan's implementation.

PART IV Threats & impacts

18 Introduction

Land-use threats from urbanisation; agricultural expansion; mining and energy extraction and its associated transport infrastructure; the modification of natural processes of fire, hydrology and soil erosion are impacting the Koala. Climate change-induced droughts, heatwaves and changes to fire regimes, along with disease, are exacerbating these impacts (Figure 2).

These threats change ecological processes, impacting Koalas. These can be grouped into landscape processes including habitat loss, fragmentation and degradation, and metapopulation processes. Disease can be thought of as both a naturally occurring direct threat in the case of epidemics, and an ecologically threatening process where land-use change and climate change increase stress and disease in Koalas (Narayan & Williams 2019).

Changes in landscapes include changes in overall coverage of habitat, changes to patch size and number, changes to forest structure, loss of refugia, increased isolation and reduced connectivity, which collectively overall reduce habitat suitability and quality for Koala populations. These landscape effects in turn disrupt metapopulation processes at all scales via several pathways, such as:

- Increased and sustained patch isolation may lead to inbreeding, reducing genetic health of isolated populations, ultimately reducing fecundity.
- Reduced habitat quality (e.g., loss of food and shelter trees, changes in hydrology, loss of suitable microhabitats, exposure to dogs and vehicles), can place increased physiological stress on individuals, increasing cortisol and other adverse inflammatory pathways in individuals which, in turn, increase susceptibility to disease and reduce fecundity.
- Habitat loss directly reduces carrying capacity of a given landscape, making populations more susceptible to extinction (the small population paradigm, Caughley 1994).
- Loss of connectivity reduces natural movement such as the ability of individuals to disperse safely, therefore reducing gene flow and healthy levels of genetic exchange among adjacent populations.
- Fragmentation can increase mortality during movements made through the intervening matrix, for example, by dog attack and car strikes.

These landscape effects also disrupt natural processes which sustain Koala habitat, impacting the mortality, recruitment, nutrition, and climate adaptation of their food and shelter trees.

19 Direct threats

19.1 Climate change

Climate change is a serious threat to Koala persistence across much of its distribution, as a result of habitat becoming climatically unsuitable as heatwaves and droughts increase, and fire regimes alter (see section 20.4).

Climate change is impacting Koalas through: direct mortality induced by their limited tolerance to drought and heatwave (section 30); reduced fecundity brought about by stress and reduced habitat quality (Lunney & Pat 2012; Davies et al. 2013)(section 23); increased disease rates (Lunney et al. 2014); changes in the distribution and availability of their preferred tree species (Adams-Hosking et al. 2012; Drielsma et al. 2017; Hughes, Cawsey & Westoby 1996; Shabani et al. 2019); and altered fire regimes (section 0). In coastal areas, climate change is adding to the cumulative impacts on already stressed populations (Lunney et al. 2014). Victoria, which holds unlisted populations of Koala, will become increasingly important as a habitat stronghold (Adams-Hosking et al. 2011a). Where ecosystems are already stressed from habitat modification and degradation, climate change is likely to exacerbate those stresses (Mac Nally et al. 2009; Steffen et al. 2009). Historic and ongoing habitat loss and degradation intensifies the effects of climate change on Koala populations by reducing the availability of critical refugial and recovery resources (Smith et al. 2013; Sullivan et al. 2004).

Loss of climatically suitable habitat as a result of climate change may outpace losses from land-use change within the next decade. By 2030, 20.9 % of listed Koala habitat is likely to be seriously affected by climate change under high global emissions scenarios (Adams-Hosking et al. 2011a; Briscoe et al. 2016; **Table 3**). Recent rapid and substantial declines of Koalas in regions west of the Great Dividing Range from drought and heatwave have been attributed to climate change (Seabrook et al. 2011; Lunney et al. 2017; section 23). Under high global emissions scenarios, there is a risk of widespread climate-driven extinction of Koalas within the next 50 years in most western populations including the Brigalow Belt, Mulga Lands, Mitchell Grass Downs, Darling Riverine Plains and Desert Uplands bioregions (Adams-Hosking et al. 2011a; Briscoe et al. 2016; McAlpine et al. 2015; Appendix 2). Isolated individuals may survive in local refugia, where microclimates, groundwater and habitat characteristics are favourable (Lunney et al. 2017; McLaughlin et al. 2017; Seabrook et al. 2014a).

Drought and heatwaves are the predominant means by which climate change impacts Koalas (section 30). By 2100, near-normal and wet years will become much less frequent. Under current climate trajectories, the frequency of extreme drought is predicted to increase by 2100 (CSIRO & BOM 2015; Herold et al. 2018). These changes will severely limit the ability of Koala populations, and other biota, to persist throughout Australia.

Table 3. Estimated losses of Koala distribution due to climate change under a high global-emissions scenario (A1FI or RCP8.5). Estimates are summarised across 13 projections of future koala habitat (Adams-Hosking et al. 2011a, Briscoe et al. 2016).These estimates consider the impacts of climate-change driven changes to droughts and heatwaves but not fire. Note that climate change in 2030 is relatively insensitive to future emissions. Estimates represent the change in area that was climatically suitable for Koala based on conditions for the period 1961-1990 (Hoskings) or 1991-2009 (Briscoe), and compared to the area that is expected to be climatically suitable for Koala in 2030, 2050 and 2070, within areas where koalas or their habitat are known or likely to occur (DAWE 2021). Negative values indicate a gain in climatically suitable area.

Population	Median % loss by 2030 (min, max)	Median % loss by 2050 (min, max)	Median % loss by 2070 (min, max)
Listed Koala	20.9 (0, 48.7)	35.2 (0, 67.4)	45.2 (0, 83.3)
Queensland	29.9 (0, 78.4)	58.4 (0, 97.6)	67.8 (0, 99.5)
New South Wales	11 (0, 23.6)	19 (0, 45.3)	25.4 (0, 69.3)
ACT	0 (-9.1, 5.1)	0 (-9.5, 77)	0 (0, 100)
Victoria	2.6 (0, 20.4)	10.5 (0, 33.8)	16.3 (-0.2, 64.3)
South Australia	2.5 (0, 25.5)	6.6 (0, 53.3)	12.8 (0, 91.3)

In addition to affecting Koalas directly, climate change also impacts Koala trees. Drought, and subsequent tree death, reduces the availability of preferred browse and shelter trees. Large areas of Koala habitat are becoming climatically unsuitable for the tree species currently there (Adams-Hosking et al. 2012; Hughes Cawsey & Westoby 1996), though some *Eucalyptus* species may be able to adapt to warming conditions (Jordan et al. 2017). Higher levels of atmospheric CO_2 may reduce the nutrient quality and palatability of Koala browse trees (Barton et al. 2010; Hovenden & Williams 2010; Moore et al. 2010). Whether this translates into changes to tree chemistry in the wild, how this affects Koala choice of browse trees, and how any effects on Koalas might be managed, remains unclear (Lunney et al. 2012; Moore et al. 2010).

19.2 Land-use change

Land -use policy and practices causing the loss, modification, and fragmentation of native vegetation cover is considered the most threatening of processes for decline in global biological diversity (Fahrig 2003; Maxwell et al. 2016) and is currently the main threat to Koala populations in Australia (Cresswell & Murphy 2016; McAlpine et al. 2002, 2006a, 2015; TSSC 2012b).

In Australia, land-use change affecting Koalas is driven by clearing of Koala habitat for agriculture and resource extraction, steered in part by Australia's role as a global exporter of food, forestry and energy resources, and by a growing urban population and consequent urbanisation of Koala habitat (McAlpine et al. 2009). The pursuit of these economic goals and housing needs, with the associated development of infrastructure such as roads and rail, has impacted Koalas throughout their range.

Over one million hectares of forest and woodland within the Koala's range was cleared between 2000 and 2017 (Ward et al. 2019). The koala distribution was revised in 2021 and this number would be expected to be higher if calculated using the new koala distribution. Clearing for grazing during this period was the major driver of loss of Koala habitat, accounting for most of the deforestation within Koala distribution (Evans 2016; McAlpine et al. 2015). Clearing for grazing has occurred across the range of the Koala. Large areas of woodland have been lost in western parts of the species range, including the Brigalow Belt, Mulga Lands, Darling Riverine Plains, Einasleigh Uplands and Desert uplands since 2000 (Ward et al 2019). These areas are home to large Koala populations (Adams-Hosking et al. 2016). Most clearing events occurred on freehold or leasehold land (Ward et al. 2019). Land clearing continues to impact habitat across the Koala's range (DES 2018; DPIE 2018). Clearing for mining and urbanisation has localised impacts on the Koala (Evans 2016; Ward et al 2019). Urban expansion is concentrated along the eastern seaboard fringe of Queensland and NSW (Clarke & Johnston 2016), which is also a stronghold of the Koala. Low density and peri-urban development are expanding into forested and agricultural landscapes in these areas, while clearing for agriculture continues to occur across the Koala's distribution. The expanding coal and coal seam gas developments of the past two decades and recent clearing for renewable energy projects represent additional but localised impacts to Koalas (McAlpine et al. 2015). Land-use decisions affecting Koalas have been influenced, both positively and negatively, by the policy environment and social attitudes around land-clearing (Heagney et al. 2021; Simmons et al. 2021).

Although not a focus of this recovery plan, it is also important to note that land-use change can increase Koala abundance. An example of this is the increased Koala abundance seen in plantation forests in Victoria, although this can have long-term impacts on local population viability through boom-and-bust cycles driven by over-browsing (Ashman et al. 2020).

Mortality from dogs and vehicles

Direct mortality and trauma caused from dog attack and vehicle strike is a major, though localised, effect of urbanisation, especially in the rapidly expanding urban and peri-urban areas where high-density Koala populations coexist with people (Beyer et al. 2018; Dique et al. 2003a; Lunney et al. 2002). Juvenile males in particular are susceptible to vehicle strike (Canfield 1991; Dexter et al. 2018; Dique et al. 2003a). Mortality from dogs and vehicles is not solely restricted to urban areas, as wild dogs and major highways also occur in relatively intact landscapes (Beyer et al. 2018). Trauma from vehicle strike and dogs account for a high proportion of veterinary clinic admissions (Beyer et al. 2018; Gonzalez-Astudillo et al. 2019).

Although mortality and trauma to Koalas from vehicles and dogs is widespread, the relative proportion of attribution to mortality and impact on local Koala populations (often along with disease) vary significantly depending on local landscape context (e.g., Beyer et al. 2018; Gonzalez-Astudillo et al. 2019; Lunney et al. 2002; Rhodes et al. 2006) and is influenced by road density and the volume of vehicle traffic (Dique et al. 2003a; McAlpine et al. 2006a & b; Rhodes et al. 2006; Ashman et al. 2020). Where populations are small and isolated, mortality from vehicles and dogs may result in population sinks (Dias 1996) where populations are essentially unviable and can only be retained through immigration from nearby source populations, rather than through intrinsic growth (e.g., Iluka population, NSW, Lunney et al. 2007). Dogs are implicated in exacerbating population declines in fire-affected fragmented landscapes (Lunney et al. 2007).

Actions addressing the impacts on Koalas from dogs and vehicles reside mainly with local government authorities (e.g., compliance and traffic control planning; McAlpine et al. 2007), and interventions have shown to be effective in local population recovery (Beyer et al. 2018). Further research into novel approaches to human social behaviour on dog-Koala interactions (Rundle-Thiel et al. 2019) and Koala aversion training for dogs (David et al. 2019) may also provide some new tools for reducing mortality and trauma from dog attacks.

19.3 Natural systems modification

Native forestry

The distribution of the listed Koala overlaps with areas managed under Regional Forest Agreements in NSW, as well as areas managed for timber production in Queensland. Timber production can have a variety of impacts on Koala populations. Koalas are known to commonly use logged areas within a mosaic of logged and unlogged forest (Jurskis & Potter 1997) for foraging (Ashman et al. 2020; Kavanagh, Stanton & Brassil 2007; Woodward et al. 2008) and movement (Kavanagh, Stanton & Brassil 2007; Schalgoth et al. 2008; Woodward et al. 2008). Koalas are also known to retain home ranges in selectively logged coupes (Kavanagh, Stanton & Brassil 2007).

Long-term research on these aspects, the impacts of the bushfires in 2019/2020, nutritional quality of forests and demographics is ongoing in NSW forests (Natural Resource Council, NSW). Between 2015 and 2017, the NSW Department of Primary Industries forest scientists undertook a large-scale study on Koala occupancy in the forests of north-east NSW, including the response of Koala to timber harvesting. Koala occupancy was not influenced by timber harvesting intensity, time since harvesting, land tenure, landscape harvesting extent, or old-growth forest extent (Law et al 2018).

Occupancy monitoring is continuing on an annual basis. The NSW Natural Resources Commission is undertaking targeted research to better understand the response of Koala to different types of harvesting in forests on the North Coast of NSW. This work will also investigate how Koala and their habitat are responding after the 2019/20 wildfires. The report on the findings of this research will be provided to the NSW Government in June 2021.

Under the Regional Forest Agreements, each state has a set of compliance rules and minimum standards for conducting native forestry operations on public land to deliver ecologically sustainable forest management.

Altered fire regimes

Fire regimes across the Koala's range have been altered over the past two centuries by both changes in burning practices and the effects of climate change. Projected climate change, resulting in a warmer and drier environment over much of Australia will affect fire regimes (intensity, scale, frequency and seasonality) and increase the incidence of extreme fire-danger days (BOM & CSIRO 2020; Dowdy 2020; Sharples et al. 2016). The most significant changes are predicted for sclerophyll dominated vegetation such as forests of south-eastern Australia (Williams et al. 2009), in which the Koala occurs. Climate change has complex effects on vegetation production through elevated CO_2 (section 25, for discussion on potential impact on habitat quality), effects on fuel and fire weather, and ignitions, which collectively will influence future fire regimes (Williams et al. 2009).

Altered fire regimes, together with climate change, will have complex feedback interactions with biodiversity, both positive and negative (Williams et al. 2009). Understanding the impact of fire regimes on individual species responses is complex because of the individual nature and context in space and time of any one fire event and the complexity of associated environmental variables (Whelan 2002; Williams et al. 2009). This complex response, along with balancing the need of social and economic factors, makes managing fire risk for species conservation challenging, now and into the future, (William et al. 2009; Clarke 2008).

Of major concern for biodiversity are large infrequent fires (>10,000 ha) in temperate eucalypt forests on the eastern seaboard (Bradstock 2008). Droughts, exacerbated by climate warming, are inextricably linked with large, infrequent fires (Bradstock 2008; Hughes 2003) and are responsible for the loss of significant numbers of animals and species survival (DELWP 2020; van Eeden et al. 2020). Fires which burn the forest crown pose a direct threat to arboreal species found in these forests, including the Koala (Jurskis & Potter 1997; Phillips 1990; Phillips, Walllis & Lane 2021; van Eeden et al. 2020).

In 2019/2020, Australia experienced bushfires of unprecedented scale, with estimates of 3 billion native animals killed – mammals, birds, reptiles and frogs, among many other orders of animals – including an estimated 61,000 Koalas killed, injured or affected in some way (van Eeden et al. 2020). Listed Koala populations were directly impacted (Phillips, Wallis & Lane 2021). Fires removed 3,659,625 ha (9%) of the area within which the listed Koala and its habitat are known or likely to occur, with the majority lost in NSW (3,466,578 ha or 94% of the total area burned). Despite the initially devastating impact of large fires, evidence indicates biota generally recover (Bradstock 2008) and that it is the frequency of fires (which incorporates both unplanned and prescribed burning) that has the strongest effect on biota (Bradstock 2008). Whether this concept holds up for the recovery of all species following the scale of the bushfires in 2019/2020 remains to be seen.

Fire threatens Koala populations through immediate mortality and injury, and via altered habitat that reduces food availability and increased exposure to predators (Lunney et al. 2007; Phillips, Wallis & Lane 2021; Zylstra 2019). It is also likely that changes in energy balances caused by increased exposure to temperature extremes (either heat or cold) increases physiological stress to individuals (Davies et al. 2013; Lunney et al. 2014; Narayan & Williams 2016) that survive fires, also reducing population recovery. The landscape configuration, proximity to source populations, and the intensity and extent of fire will influence how quickly Koalas repopulate habitat following fire (Lunney et al. 2002, 2004) as does the level of exposure to post-fire threats, such as dogs (Melzer et al. 2000; Lunney et al. 2007). However, at the landscape level, there is a paucity of research on the impacts of fire regimes and the influence of the resulting shifting habitat mosaic on recolonisation (e.g., attributes of *in-situ* refugia) and population-level recovery for the Koala.

Prescribed burning

Prescribed burning to reduce fire risk is an issue of concern regarding species' decline (Clarke 2008; Driscoll et al. 2010). There is a potential for prescribed burning to affect biodiversity adversely because of an inadequate understanding or consideration for species' responses to different fire regimes (Clarke 2008; Driscoll et al. 2010; Whelan 1995, 2002). Inappropriate burning practices can cause inadvertent and irreversible changes and may lead to the loss of local populations or extinction (Baker 2000).

Prescribed burning to reduce fire risk is widely used as a management tool to protect life, natural and built assets in Koala habitat across QLD, NSW and the ACT. Multi-layered policies, strategies, planning procedures, tools and research guide fire management activities. Implementation varies markedly, depending on local vegetation type, land tenure, the organisation/s undertaking the fire management action and objectives.

Little data exists on the impact of prescribed burning on Koalas at the individual or population level, however initial work in this area indicates that risks to Koalas is high regardless of fire suppression approaches. Modelling of fuel behaviour in dry sclerophyll forests of the Southern Tablelands, where low or moderate-intensity fires can cause significant canopy scorch (Cheney 1981), found that even low-intensity burns substantially increase the risk of injury and mortality to Koalas (Zylstra 2019). Fire behaviour simulation models of dense coastal forests near Bega, in south-eastern NSW, found that although substantial and expensive fuel reduction approaches to protect life and Koala habitat reduced bushfire size and probability, the residual risk remains high (Bentley & Penman 2017). While treatment of large areas can reduce the likelihood of a fire spreading, under severe fire weather conditions the amount of fuel becomes less important than weather as fire can still spread through areas with low fuel loads (Bradstock et al. 2010), as was evident in the 2019/20 bushfires.

The alternative view, at least for south-eastern Australia, is that repeated low-intensity burning, similar to Indigenous cultural burning practices, can lead over time to healthy forests containing mature trees with relatively low nutritional status for Koala yet able to support stable, widespread, low-density populations (Jurskis 2017).

Disease

Koalas carry a range of pathogens and parasites. Of concern are infections of *Chlamydia* spp. and the Koala retrovirus (KoRV) that that can cause disease (Bachman et al. 2015; Fabijan et al. 2019; Grogan et al. 2017, 2018; McCallum et al. 2018).

Infections of chlamydia causes conjunctivitis (pink eye) leading to blindness, urinary tract disorders (wet bottom/dirty tail), pneumonia and infertility in females (Phillips 1990; Polkinghorne, Hanger & Timms 2013; Fabijan et al. 2019). Chlamydia is the major reason for admissions of Koalas for clinical care in some regions (Beyer et al. 2018; Gonzalez-Astudillo et al. 2019).

Chlamydia infection is almost ubiquitous among Koala populations (McCallum et al. 2018; Polkinghorne, Hanger & Timms 2013). Disease from chlamydia is considered a major agent of decline in contemporary populations (Rhodes et al. 2011; Robbins et al. 2019) and was thought to be responsible for decimating past Koala populations during 1887-89, 1900-03 and 1920s-1930s (Phillips 1990). A longitudinal study in a wild population of Koala in South East Queensland found almost two thirds of chlamydial infections progressed to disease (Robbins et al. 2019), however weak associations between infection and disease found in other studies challenge the notion that it is a major driver of population decline (McCallum et al. 2018).

It is plausible that multiple interacting intrinsic and extrinsic factors are involved in varying infection and disease rates, and clinical disease (Narayan & Williams 2016) may therefore be correlated with population decline but not be its cause (McCallum et al. 2018). Chronic stress to individual Koalas from poor nutrition, reduced habitat quality (habitat loss, fragmentation, degradation and drought),

exposure to unnatural situations (predation, dogs and traffic), heat-stress, bushfires or other factors, is likely to lead to the production of glucocorticoids (stress hormones), which can inhibit reproductive hormones and immune responses, reducing individual health (McAlpine et al. 2017; Narayan & Williams 2016). Where these factors become widespread and chronic, such as in areas of urban and peri-urban landscapes or in areas of marginal habitat quality (Davies et al. 2013), it is possible that loss of fertility due to disease and reduced recruitment due to habitat fragmentation will cause populations to decline and may inhibit recovery efforts.

KoRV is a gamma retrovirus that has been found to have integrated into the Koala germ line (endogenization) of northern Koala populations and therefore transmitted from parent to offspring (Ishida et al. 2015). Little is known of the impacts of KoRV, however it is implicated in immunodeficiency. KoRV may be responsible for leukemia and lymphoma as well as making individuals more susceptible to infectious diseases such as chlamydia (Fabijan et al. 2017; Ishida et al. 2015; Quigley et al. 2019), although this last point is disputed (Sarker et al. 2020).

There is no means to control these diseases in wild populations efficiently or effectively, and vaccination programs at present are limited largely to treating Chlamydia-infected individuals in care. There is a lack of field-based population-level disease studies across the geographical range that have examined the prevalence of chlamydia and the underlying cause of disease in Koala populations and its relative importance on Koala demography and individual fitness, population and regional-level dynamics (Grogan et al. 2017, 2018; McCallum et al. 2018; Narayan & Williams 2016;). Further studies on chlamydia, KoRV and other emerging Koala diseases, particularly in relation to identifying environmental stressors and associations, are needed to guide conservation management and prioritise investment.

An emerging disease that affects Koala habitat is Myrtle Rust (*Austropuccinia psidii)*. Myrtle Rust, a plant disease caused by the introduced fungal pathogen, arrived in Australia in 2010 and affects plant species in the family Myrtaceae (eucalypts, lillipillies, paperbarks and tea-trees) which dominate many Australian ecosystems. The disease leads to defoliation, loss of reproductive capacity and death; and seedlings are particularly vulnerable (Makinson 2018). The disease is naturalised along the east coast of Australian, with the most serious infections in New South Wales and southeast Queensland (Makinson 2018). Although not yet identified as a threat to the Koala, emerging diseases like Myrtle Rust that impact the health of eucalypt ecosystems may potentially indirectly affect the Koala via decline in habitat quality, although impacts are likely to be minor compared to other threatening processes (Fensham et al. 2020).

20 Ecological threatening processes

20.1 Habitat loss and fragmentation

Land-use practices causing the loss and fragmentation of habitat are considered the primary ecological threatening process to Koalas, to which they are particularly sensitive (McAlpine 2006a & b; Reed & Lunney 1990; Rhodes et al. 2006, 2008). The Koala depends on trees, forests and woodlands for food and shelter (section 25), and has limited capability to traverse the intervening matrix safely, especially in built environments (section 28.4; Lunney et al. 2002; McAlpine et al. 2006a & b).

Since European settlement, Australia has lost nearly 40% of its forests, with the loss disproportionately occurring on productive fertile soils near to the coast. This also coincides with high quality habitats for Koala (Bradshaw 2012; Lindenmayer & Fischer 2006; McAlpine et al. 2002, 2006a& b). Since the 1970s, substantial forest loss has occurred in high-density Koala populations of south-eastern Queensland and northern NSW (Bradshaw 2012), although the majority of habitat loss within the Koala range occurred within the large but low-density Koala populations of the Brigalow Belt and Mulga Lands (Evans 2016). There appears to be a threshold of habitat coverage below which Koalas rapidly decline from landscapes, which ranges from 10-60% depending on the region (McAlpine et al. 2002, 2005; Rhodes et al. 2008).

Landscape configuration changes disrupt metapopulation processes for the Koala (McAlpine et al. 2006a & b) by directly decreasing population sizes or causing localised extinction through reduced carrying capacity within the landscape via reduced resource availability (Zannette et al. 2000; McAlpine et al. 2006a & b); increasing the isolation of populations (McAlpine et al. 2006b); reducing connectivity between populations (Lunney et al. 2002; McAlpine et al. 2006b; Thompson 2006; TSSC 2012a & b); increasing mortality risk from dogs and vehicles (Lunney et al. 2002; McAlpine et al. 2006b; Rus et al. 2021; see below); disrupting social systems (Thompson 2006); and influencing movement patterns (McAlpine et al. 2006b; Rus et al. 2021). Chronic stress to Koalas from these factors is thought to also increase their susceptibility to disease (Davies et al. 2013; Narayan & Williams 2016)(Figure 2).

Extinction debt (Tilman et al. 1994), whereby the local loss of Koala populations after habitat loss has tipped over the threshold for long-term persistence, can take up to 100 years to manifest itself (Seabrook et al. 2014b). Random fluctuations or perturbations in population growth rates due to chance events of individual mortality and reproduction (demographic stochasticity or drift) or environmental stochasticity (e.g. natural catastrophes) are exacerbated in isolated populations (Soulé et al. 1986). These processes have led to local losses of Koala populations (TSSC 2012a) such as reduction of Koala populations throughout its urbanised coastal range (Seabrook et al. 2014b).

20.2 Habitat degradation

The key threats driving habitat degradation for the Koala include timber harvesting using silvicultural systems that do not retain habitat trees, agriculture, altered hydrological regimes from land clearing, soil erosion and water extraction (Cowie, Thornton & Radford 2007); fire and fire management; and climate change. Habitat degradation reduces the availability or increases the mortality of food and shelter trees, reduces the nutrient value and water content of food trees, and changes the configuration and relative abundance of Koala trees. These changes impact Koalas by making it more difficult for them to find food and shelter resources, increasing stress levels and disease, and leading to reduced breeding success and increased mortality. Habitat degradation is common in landscapes that are also subject to progressive land-use change. It can lead to habitat loss as native vegetation is slowly changed to a composition and structure that no longer resembles the original state (Lindenmayer & Fischer 2006). Habitat degradation also reduces availability and quality of resources for species and can drive population declines over the long-term (extinction debt, Tilman et al. 1994).

20.3 Genetic effects

Land-use change also adversely affect the genetic structure of populations by eroding genetic diversity and increasing genetic differentiation (Charlesworth & Charlesworth 1999; Thompson 2006). As populations become more isolated in smaller remnants that are disconnected, gene flow tends to decrease. The resultant smaller populations are more prone to the effects of genetic drift and inbreeding (Bouzat 2010; Hedrick & Fredrickson 2010). Indeed, Koalas do not appear to exhibit inbreeding avoidance behaviour, a characteristic thought to making them vulnerable to inbreeding (Schultz et al. 2020). Inbreeding increases the probability of homozygosity and the likelihood of the accumulation of recessive deleterious alleles, inbreeding depression and the reduction of population viability (Bouzat 2010; Charlesworth & Charlesworth 1999; Hedrick & Fredrickson 2010; Schultz et al. 2020), although this is not always found to be the case in wild populations (Milot et al. 2007).

Studies into genetic structuring within and between populations of the Koala have provided insights into social structuring within a locality (Thompson 2006), inbreeding (Seymour et al. 2001; Johnson et al. 2018), immunity (Lau, Griffith & Higgins 2014; Johnson et al. 2018), bottlenecks and patterns of movement (Thompson 2006; Norman et al. 2019) and therefore is a valuable tool for conservation of the Koala.

Levels of inbreeding varies across regions and is more prevalent in the southern unlisted populations (Houlden et al. 1996; Johnson et al. 2018) that have experienced sequential translocation events (Menkhorst 2008). Fortunately, although listed Koala populations are under the most threat from habitat loss and fragmentation (TSSC 2012a; 2012b; DERM 2009), high levels of contemporary genetic diversity exist within many of these populations (Houlden et al. 1996; Johnson et al. 2018; Kjedlen et al. 2016; Thompson 2006). Nevertheless, genetic evidence indicates that fragmentation of habitat is impacting heterozygosity within populations (Thompson 2006) and presenting an impediment to gene flow (Thompson 2006). Strategies to maintain linkages in populations threatened by habitat loss and fragmentation, such as revegetation or genetic augmentation, are required to mitigate potential adverse genetic affects in these landscapes.

PART V Distribution, genetic structure, population trends & habitat

21 Distribution

21.1 National

The Koala is endemic to Australia and has a wide but patchy distribution across coastal and inland areas of eastern and southern Australia (Martin & Handasyde 1999) (Figure 4; DAWE 2021a). Its natural range extends from far north-eastern Queensland to the south-east corner of South Australia, including some coastal islands, and is restricted by altitude (Melzer et al. 2000; Menkhorst 2008; Munks et al. 1996; TSSC 2012b). The exact extent of the Koala's natural boundary at the margins of its distribution is poorly defined in some regions, especially the inland semi-arid and arid regions in western Queensland (Mitchell Grass Downs, Desert Uplands and Einasleigh Uplands bioregions) and western NSW (e.g., Mulga bioregion) where survey effort has been relatively low and cyclic droughts cause localised contraction and expansion of populations.

Several Koala populations are now established outside the species' natural range due to historical translocations. In South Australia, the species was presumed extinct in the 1930s (TSSC 2012b) and subsequently Koalas, sourced mainly from Victoria, were introduced to Kangaroo Island, Eyre Peninsula, Riverland and Adelaide Hills (Phillips 1990; TSSC 2012b). In Victoria, to arrest population declines in the late 19th and early 20th centuries, Koalas were introduced to islands along the coast and in the Murray River in addition to reintroduction to many inland areas. Of these islands, populations persist to today on French Island and Phillip Island in Western Port Bay, and Snake Island and Raymond Island in east Gippsland (Menkhorst 2008). Koalas were also introduced to Yanchep National Park, near to Perth, in the 1930s (Phillips 1990; Menkhorst 2008).

Although the extent of the Koala's range prior to European settlement is poorly understood (Phillips 1990), between the late 1800s until the 1930s the Koala suffered a precipitous decline in the central and southern areas of its distribution as a result of habitat loss, drought, bushfires, disease and intense exploitation for fur (Melzer et al. 2000). Due in part to protective legislation and cessation of hunting, Koalas have returned to parts of their former distribution (DECC 2008; Martin & Handysyde 1999; Menkhorst 2008).

2019/2020 bushfires

In 2019/2020, Australia experienced severe bushfires across the country. The coastal areas of southeast Queensland, NSW and eastern Victoria were particularly affected (van Eeden et al. 2020; Table 4). The majority of Kangaroo Island in South Australia was also burned. Together, these areas supported significant populations of Koalas: listed, unlisted and introduced.

For the listed Koala, 9 % (3,659,625 ha) of the area within which the listed Koala and its habitat are known or likely to occur were burned. The proportion burned ranges from <1% in the drier inland areas to 30% in the temperate coastal forests which support high-quality Koala habitat and areas of

contiguous habitat. The coastal areas of northern and southern NSW areas were most impacted (Table 4, DAWE 2021b). Further analysis of the fire extent for the modelled distribution of the listed Koala by bioregions, state and territory is in Appendix 3.

Table 4 The area and percentage of land burned in the 2019/2020 bushfires within the area where the listed Koala and its habitat is known or likely to occur, by Natural Resource Management areas. Estimates for likely plus known only are provided, excluding may occur, using the previous version of koala distribution mapping (2013). Note: modelled distribution does not equate to Koala habitat (see section 21.2 below for further explanation on distribution modelling). '-' = not affected'. Source: DAWE 2021b.

NRM region, State	Extent burned within likely + known koala distribution, ha (%)
South East NSW, NSW	934,799 (30%)
North Coast, NSW	899,006 (29%)
Northern Tablelands, NSW	580,707 (20%)
Hunter, NSW	397,701 (15%)
Greater Sydney, NSW	331,974 (29%)
Central Tablelands, NSW	250,520 (16%)
Murray, NSW	19,295 (3%)
North West NSW, NSW	43,282(1%)
Western, NSW	-
Central West, NSW	9,282 (<1%)
Riverina, NSW	13 (<1%)
South East Queensland, QLD	86,152 (4%)
Fitzroy, QLD	55,544 (1%)
Desert Channels, QLD	-
Condamine, QLD	30,061 (2%)
Burnett Mary, QLD	15,331 (1%)
Wet Tropics, QLD	-
Southern Gulf, QLD	-
South West Queensland, QLD	-
Northern Gulf, QLD	-
Maranoa Balonne & Border Rivers, QLD	3,024 (<1%)
Burdekin, QLD	1,930 (<1%)
Mackay Whitsunday, QLD	1,005 (<1%)
ACT	21,140 (23%)
TOTAL	**3,659,625 (9%)**

21.2 The listed Koala

The Department's modelled distribution for the listed Koala shows a widespread distribution extending from just north of Cairns in far north Queensland, down the east coast of Australia, to the Victorian border (Figure 4, DAWE 2021a). The majority of known habitat is concentrated along the coast of south-eastern Queensland and central to northern coast of NSW. Major riparian areas, including parts of the Murray River, the Darling River system (NSW) and the Carnarvon region (central Qld) are likely to, or may, support Koalas in landscapes otherwise devoid of Koalas.

The listed Koala represents about 84% of the modelled distribution for the entire species. The total area of modelled distribution where Koalas and their habitat are known or likely to occur (Figure 4, shown in purple and dark pink) is the area of major focus for action under this recovery plan. This does not preclude actions in areas beyond these boundaries, where genetically unique populations may exist, or unmapped quality habitat may occur.

The categories likely to occur and may occur in the Koala distribution shown in Figure 4 were generated by combining information on the distribution of Koalas (DAWE 2021a) using MaxEnt software (maximum entropy modelling, Phillips, Anderson & Schapire 2006), with, where available, expert-elicited and vegetation-based mapping of Koala habitat and models of Koala food trees (DES 2020; DPIE 2019; Runge, Rhodes & Lopez-Cubillos 2021). MaxEnt predicts species occurrence based on presence-only data and available biophysical environments. The category known to occur was generated by spatial buffers around recorded observations of Koalas. It is important to note that modelled distribution is indicative only for recovery planning purposes, and that ground-truthing is required to examine site-level habitat suitability, quality and the presence of Koalas. The area within the modelled distribution may include areas that are not Koala habitat (e.g., grasslands or wetlands).

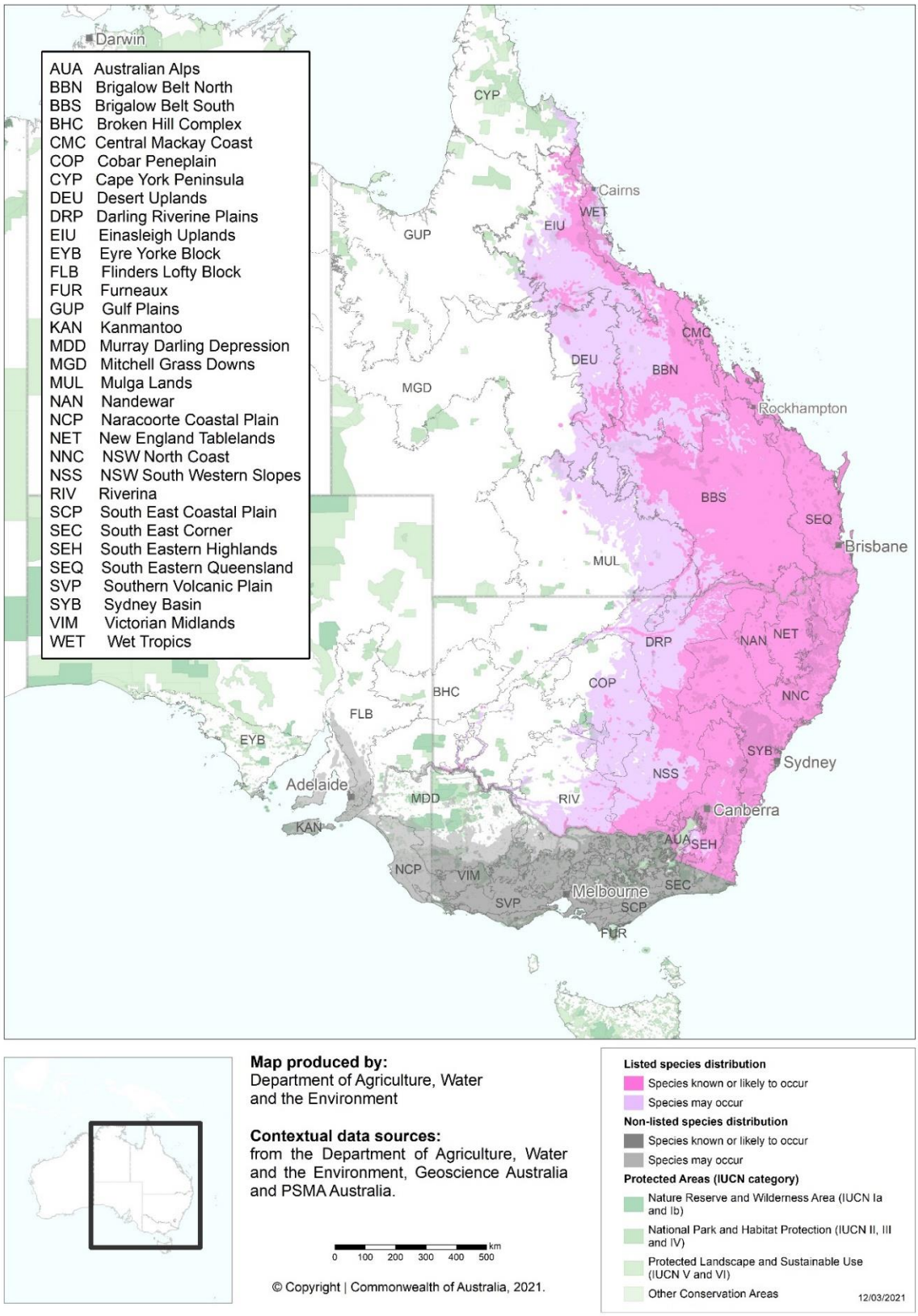

Figure 4. Modelled distribution (geographic range) of the listed Koala and non-listed Koala (DAWE 2021a).

Caveat: The information presented in this map has been provided by a range of groups and agencies. While every effort has been made to ensure accuracy and completeness, no guarantee is given, nor responsibility taken by the Commonwealth for errors or omissions, and the Commonwealth does not accept responsibility in respect of any information or advice given in relation to, or as a consequence of, anything containing herein.

Species distribution mapping: The species distribution mapping categories are indicative only and aim to capture a) the specific habitat type or geographic feature that represents the recent observed locations of the species (known to occur), b) the suitable or preferred habitat occurring in close proximity to these locations (likely to occur); and, c) the broad environmental envelope or geographic region that encompasses all areas that could provide habitat for the species (may occur). These presence categories are created using an extensive database of species observation records, national and regional-scale environmental data, environmental modelling techniques and documented scientific research.

21.3 Predicted 2070 distribution under climate change

Koala distribution appears to be contracting in a manner consistent with expected impacts of climate change on the species, with recent declines in previously healthy Koala populations at the species range limits attributed to drought and heatwave (Gordon, Brown & Pulsford 1988; Lunney et al. 2012, 2017; Seabrook et al. 2011)

Koala distribution is predicted to dramatically contract southward and to the coast over the next 50 years under a high global emissions scenario, a consequence of changes to the intensity and frequency of droughts and heatwaves brought about by climate change (Adams-Hosking et al. 2011a; Briscoe et al. 2016; Figure 5). This will result in a reduction in the total area of distribution of the Koala, as the southern and eastern range limits are constrained by the Australian landmass.

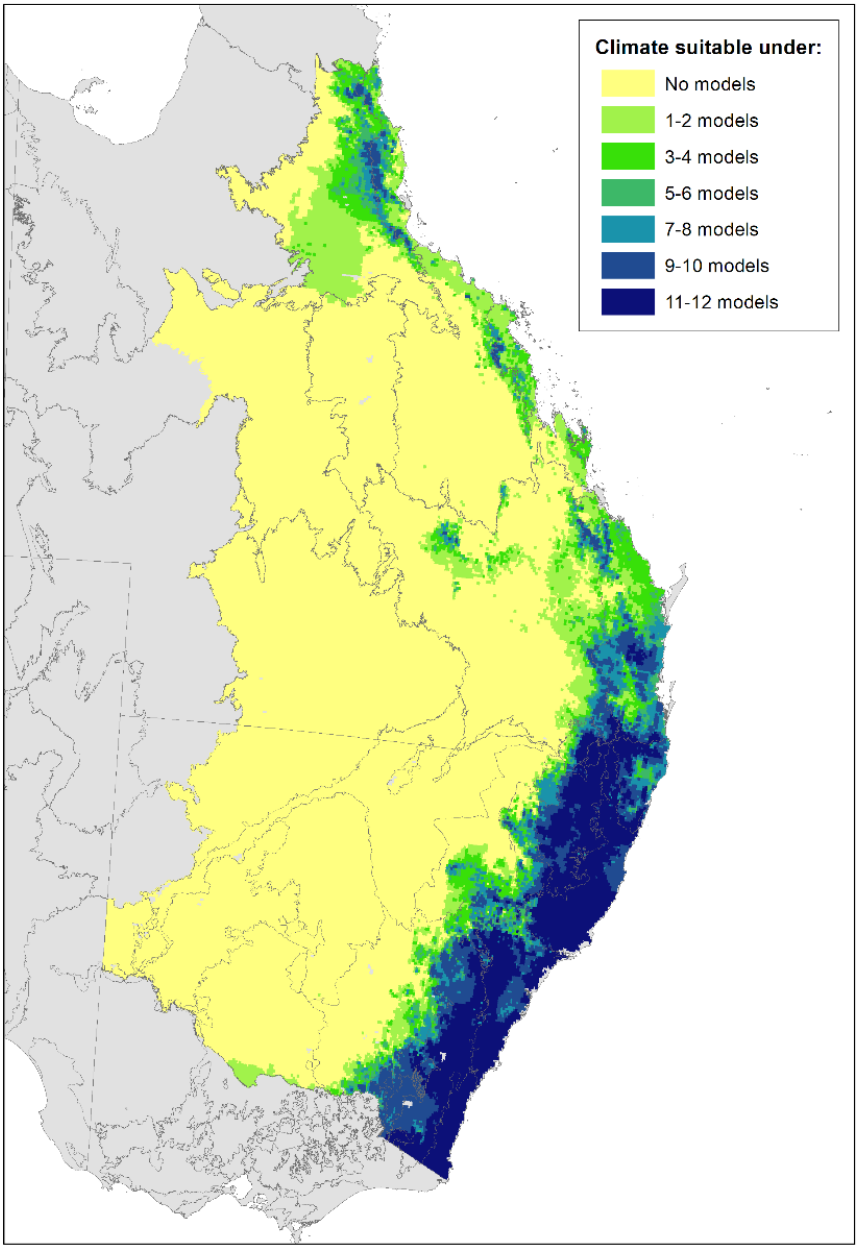

Figure 5 Predicted Koala distribution in 2070 under a high global emissions scenario (RCP8.5) considering the impacts of climate-change driven changes to droughts and heatwaves on koalas. Colour indicates the degree of certainty that a given area will be climatically suitable for Koalas, indicated by the number of models out of a maximum of 12 that predict that area will be climatically suitable. Blue indicates high confidence that an area will be suitable for Koalas. Yellow indicates high confidence that an area will be unsuitable for Koalas. Data from Briscoe et al. (2016).

The northern and western edges of Koala distribution are limited by the physiological constraints of the Koala, and influenced by temperature, humidity, and water availability (Adams-Hosking et al. 2011a; Briscoe et al. 2016; Clifton et al. 2007; DPIE 2019; DES 2020; Law et al. 2017; Seabrook et al. 2014a). Extreme climatic events such as drought and heatwave drive the distributional limits of

Koala (Briscoe et al. 2016; Seabrook et al. 2014a), mediated by Koalas' vulnerability to water stress (section 30). During favourable wetter years, Koalas may recolonise habitat at the edge of their distributional limits, only to become locally extinct during the next drought or heatwave. Both extreme heat events and extreme drought are becoming more frequent under climate change (CSIRO & BOM 2015; BOM & CSIRO 2020; Herold et al. 2018). The long-term re-establishment of Koala populations in climate change-affected areas will become increasingly unlikely.

Widespread climate-driven extinction of Koalas within the next 50 years is a risk in most western populations including the Brigalow Belt, Mulga Lands, Mitchell Grass Downs, Darling Riverine Plains and Desert Uplands bioregions (Adams-Hosking et al. 2011a; Briscoe et al. 2016; McAlpine et al. 2015). Isolated individuals may survive in local refugia, where microclimates, groundwater, and habitat characteristics are favourable (McLaughlin et al. 2017; Seabrook et al. 2014a).

There is some uncertainty surrounding where the northern and western edges of Koala distribution will fall under climate change (Adams-Hosking et al. 2011a; Briscoe et al. 2016). These differences are driven by differences in the types of models, the datasets used and choices of model parameters. All models, both correlative and mechanistic, support climate-driven range contraction.

21.4 Queensland

In Queensland, the Koala has been recorded as far north as Cooktown, in the central west (Julia Creek region) and central southwest (Charleville region), with the main concentration of Koalas along the south-eastern coast (Gordon, Hrdina & Patterson 2006). Koalas also occur on islands off the Queensland coast. The population on North Stradbroke Island is probably natural, whereas those of Brampton, St. Bees, Newry, Rabbit and Magnetic Islands are introduced (Melzer et al. 2000).

Information on distribution of the Koala in Queensland prior to European arrival is scant and therefore the true extent of its natural range and subsequent contraction in distribution is uncertain. However, analysis of historical data indicates that between the late 1800s and the end of the 20th Century the Koala has contracted in extent of occurrence by 27% and area of occupancy by 23%. This contraction has occurred mainly in the northern and western margins of distribution, with local losses in the areas of concentrated settlement along the coast (Gordon, Hrdina & Patterson 2006).

21.5 New South Wales

In New South Wales, the Koala is found along much of the coast, with major populations in the northern coastal areas, bordering southern Queensland, and more scattered populations in the southern coast (Lunney et al. 1997, 2009, 2017; Phillips 1990; Reed, Lunney & Walker1990). Towards central and western NSW, west of the Great Dividing Range, distribution is increasingly disjunct and scattered with a major population surrounding Gunnedah in north-western NSW (DECC 2008; Lunney et al. 2009; Phillips 1990; Reed, Lunney & Walker 1990). The most westerly sightings reported between 1985-2007 are around Bourke, Ivanhoe and Wilcannia in central and north-central NSW and Deniliquin near the Murray River. The Koala is absent in the far west (DECC 2008; Lunney et al. 2009).

A synthesis of surveys between 1949 and 1987 indicate that the distribution of the Koalas has contracted significantly in NSW, notably in the north-western and southern margins (Phillips 1990; Reed, Lunney & Walker 1990). These contractions have continued in recent years (McAlpine et al.

2015). Localised declines in the distribution of Koalas have been noted in coastal areas that are subject to high anthropogenic pressure (McAlpine et al. 2015). Some areas have seen localised, though possibly temporary, expansions (Ellis et al. 2017; Lunney et al. 2009, 2012).

21.6 Australian Capital Territory

In the Australian Capital Territory, reports indicate that Koalas were common throughout the region when the territory was established (Phillips 1990). There have been several introductions of Koalas from Victoria and escapees from enclosures, and it is likely that surviving small populations in the ACT, should they exist, are derived in part from these introduced animals. Their likely descendants have been recorded in the Brindabella Ranges and Namadgi National Park (Phillips 1990; TSSC 2012b). However, few of these individuals would have survived the 2003 bushfires (TSSC 2012b), of which any recovering populations would have also been impacted by the 2019/20 bushfires. Excepting an intensely managed small population at Tidbinbilla Nature Reserve, no wild Koalas are known to persist in the ACT in 2018 (R. Brawata, pers. comm).

21.7 Victoria

In Victoria, the Koala is widespread in lowland and foothill eucalypt forests and woodlands across much of those parts of the state where the annual rainfall exceeds about 500 mm. It is generally found in central, and southern Victoria, and largely absent from the semi-arid woodlands of the far north-west and high-altitude areas of the north-east of the state (DSE 2004). The distribution of the Koala in Victoria has fluctuated greatly over the past century and late 1800s because of Koala harvesting, localised overabundance and declines of populations and extensive translocation programs (Menkhorst 2008). Currently the Koala is considered broadly stable in the state (TSSC 2012b).

21.8 South Australia

The distribution of the Koala in South Australia prior to European settlement is also poorly documented, but Koalas were probably common in the south-east where clearing has since reduced available habitat (Melzer et al. 2000). A series of introductions has expanded its distribution in the state – initially to Kangaroo Island from Victoria, and then to mainland areas of the Adelaide Hills, Eyre Peninsular and sites along the Murray River. Koala distribution in South Australia is probably constrained by the lack of availability of suitable habitat, and where they have been introduced, over-browsing by the localised expansion of populations is a significant management issue (Melzer et al. 2000; Phillips 1990).

22 Genetic structure and diversity

Investigations of the contemporary phylogenetic structure of the Koala support the existence of a single species (Houlden et al. 1999; Johnson et al. 2018; Kjeldsen et al. 2019; Neaves et al. 2016; Takami et al. 1998) rather than the three subspecies *P. c. cinereus*, *P.c. victor* and *P.c. adustus* postulated by Troughton & Cayley (1957).

At the scale of the entire geographic population, the Koala is considered relatively genetically diverse indicative of a healthy outbred species (Houlden et al. 1996; Johnson et al. 2018; Kjeldsen et al.

2016, 2019; Lee T et al. 2010), although genetic diversity varies at the population level (Lee KE et al. 2010; Wedrowicz et al. 2018; Kjeldsen et al. 2019). Southern populations of Victoria and South Australia generally show lower genetic diversity, consistent with bottlenecks and founder events from translocations (Houlden et al. 1996; Johnson et al. 2018; Kjeldsen et al. 2019; Wedrowicz et al. 2018). South Gippsland, however, is an exception and is thought to be a remnant population (Wedrowicz et al. 2018).

The species exhibits spatial structuring at multiple scales (Houlden et al. 1999; Johnson et al. 2018; Thompson 2006), with a large proportion of genetic variation among populations explained by geographic distance (Kjeldsen et al. 2019). At a continental scale, Neaves et al. (2016) found four shallowly divergent lineages within three geographic clusters corresponding to two known Pleistocene biogeographic barriers – the Brisbane River and Clarence River Valley, consistent with three linages described by Houlden et al. (1999). An additional barrier associated with the Hunter Valley has also been described (Johnson et al. 2018). Pleistocene barriers may have historically influenced mtDNA structure of the Koala, but evidence of contemporary gene flow indicates biogeographic features are no longer barriers to movement (Johnston et al. 2016; Neaves et al. 2016).

At finer scales, populations show significant levels of differentiation attributed to contemporary habitat fragmentation (Lee KE et al. 2010; Thompson 2006) or relative isolation such as those of islands (Lee T et al. 2010; Wedrowicz et al. 2018) and the Sydney Basin (Kjeldsen et al. 2019).

23 Population Trends

Assessment by the Threatened Species Scientific Committee of population trends over 20 years across the Koala's national range found there are substantial uncertainties in the estimates of population sizes and, where sufficient data exists, population trends are not uniform (TSSC 2012b). Expert elicitation in 2016 estimated a total population size of 329,000 (range 144,000-605,000), with an estimated average decline of 24% over six generations. The greatest estimated loss was for Queensland (53%), followed by NSW (14%) and Victoria (3%) (Adams-Hosking et al. 2016).

In Victoria, populations are considered broadly stable, although individual population trajectories vary (Menkhorst 2008; TSSC 2012b). Recent Koala abundance modelling for Victoria estimates a state-wide Koala population of 459,865 (range 324,772-519,578 credible intervals 95%) in native forests and woodlands, and an additional 46,917 (range 35,998-60,054 credible intervals 95%) in eucalypt plantations (Heard & Ramsey 2020). This figure is substantially greater than 182,505 estimated for Victoria and the total population by Adams-Hosking et al (2016), reflecting the different methods used and also illustrating the challenges in accurately estimating total population size for widespread species. In South Australia, the most substantial population is that of Kangaroo Island, which, prior to the 2019/2020 fires, was declining as a direct result of management interventions to protect habitat from over-browsing (TSSC 2012b). Collectively, Queensland, NSW and the ACT have declining populations, warranting their listing as Vulnerable (TSSC 2012b).

In NSW, Koala populations declines have been severe in many areas, the most significant reported is for the population in the Pilliga Forest, followed by areas of the northeast NSW. The best overall estimate for NSW is a decline of 33% (31,400 to 21,000) over 20 years between 1990 and 2010. At the time of the 2012 listing assessment, the populations of Campbelltown (southeast of Sydney) and

Gunnedah were increasing, however these trajectories were not sufficient to balance the overall decline at the state-level. For the same 20-year period, 1990 to 2010, a 43% decline was estimated for Queensland representing a decrease in abundance from 295,000 to 167,000, while no wild Koalas are known to exist in the ACT (TSCC 2012ba). Further details on population-level analysis can be found in the Threatened Species Scientific Committee Listing Assessment Report (TSSC 2012b).

As the TSSC noted in the 2012 assessment, deriving broad-scale Koala population estimates is difficult and has hampered the understanding of the Koalas national and state-level status and trends. In response to this, in November 2020, the Minister committed funds to the establishment of a National Koala Monitoring Program towards addressing this deficiency (section 9).

23.1 Western populations

Previously large and stable western populations (those west of the Great Dividing Range) of Koala have declined dramatically in recent years (TSSC 2012b). This decline has been attributed to the combined impacts of drought and changed land use practices (Lunney et al. 2017; McAlpine et al. 2015; Seabrook et al. 2014a). These populations are at greatest and most urgent risk from climate change. Most western populations are likely to decline severely in the next decade and become extinct by 2070 unless climate change is halted (Appendix 2). These populations may contain traits and genetics adapted to drought and heatwaves, and be important to the survival of the Koala under climate change (Kjeldsen et al. 2016; Lunney et al. 2017). Work is underway to determine which populations have adaptive traits and to develop conservation actions for their genetic persistence (Seddon & Schultz 2020) in a project collaboratively funded in partnership with the Australian Government.

Substantial areas of Koala habitat have been cleared in bioregions west of the Great Dividing Range since 2000 (Ward et al 2019). The Brigalow Belt and Mulga Lands lost 1,015,181 ha and 95,253 ha of woodlands within the distribution of Koala respectively between 2000 and 2017. These areas are home to large, low-density Koala populations (Adams-Hosking et al. 2012).

Due to the paucity of Koala surveys within the western range, documented evidence of declines is limited.

In Queensland, Koala numbers declined by 80% between 1997 and 2009 within the Mulga Lands bioregion of south-west Queensland (Seabrook et al. 2011).

In NSW, Koala declined from 80% of occupied sites in the Pilliga between 1991 and 2011 (Lunney et al. 2017). This is the largest population of Koalas west of the Great Dividing Range in NSW. In the same region, in late 2009 heatwaves killed estimated 25% of the Gunnedah Koala population, and reduced breeding rates and increased disease rates in this population (Lunney et al. 2012).

24 Important populations

Populations of the Koala are valued for cultural, social, and economic reasons (section 1) as well as for the species' conservation.

i) For the listed Koala conservation, among other reasons, it will be imperative to maintain populations:

- that have the potential to act as source populations to adjacent areas of suitable, or potentially suitable, habitat;
- that exist in areas of climatically suitable refugia during periods of environmental stress including droughts, heatwaves, and long-term climate change;
- that are genetically diverse;
- or contain adaptive genes to current and future environmental stressors.

ii) Populations are also valued for social, cultural or economic reasons, and may or may not, overlap with populations listed above. Reasons may include, but not limited to:

- cultural and spiritual importance to indigenous people
- the social value and enjoyment of having Koalas in your home neighbourhood
- the economic value brought to local business and tourism.

25 Habitat

Within the geographic range of the Koala (Figure 4), Koala habitat is influenced by the availability and nutritional quality of food trees, presence of suitable resting trees and microclimates, age structure of habitat, history, and barriers to dispersal. These differ regionally because they are strongly influenced by local climatic and landform attributes.

While precise requirements vary regionally, Koala habitat can be considered in terms of the following multi-scale resource requirements in space and time:

- the selection by Koalas of individual trees for food and shelter and other resources within their home range (sections 29 & 30);
- patch size, form and context of home ranges within the landscape, including patches of forest, riparian, linear and roadside vegetation associations, open ground, corridors and scattered paddock trees used for breeding or dispersal (sections 28.4 & 29);
- at larger scales, the regional landscape in which a metapopulation exists; and
- the geographic range of the Koala (section 21).

The Koala is a specialist foliovore that browses predominately on the leaves of *Eucalyptus, Corymbia* and *Lophostemon* species (section 29) and resides in forests and woodlands ranging from tropical forests of far north coastal Queensland to the semi-arid woodlands of central Queensland and New South Wales, to coastal forests of eastern and southern Victoria (Martin & Handasyde 1999; Melzer et al. 2014; Moore & Foley 2000; Phillip 1990; Van Dyke & Strahan 2008). Across NSW and Qld alone, it is associated with over 600 species of food and shelter tree (DES 2020; DPIE 2019; Melzer et al.

2014; OEH 2018b; Sullivan, Norris & Baxter 2003), though in a given region or site only a few species might be used.

Non-food tree species are an essential resource to Koalas. Koalas use these shelter trees to thermoregulate, especially during hot days (Briscoe et al. 2015; Crowther et al. 2014; Ellis, Melzer & Bercovitch 2009; Ellis et al. 2010a; Pfeiffer et al. 2005) and to avoid predators (Melzer et al. 2003). Koalas appear to prefer larger and more shady trees and use a wide range of tree species for shelter, including rainforest trees (Queensland, Pfeiffer et al. 2005), white cypress pine *Callitris glaucophylla* (Pilliga, NSW, Kavanagh, Stanton & Brassil 2007), *Callitris columellaris* (North Stradbroke Island, Queensland, Cristescu et al. 2011; Woodward et al. 2008), brigalow *Acacia harpophylla* and black tea-tree *Melaleuca bracteata* (Queensland Brigalow, Ellis, Hale & Carrick 2002).

Koalas shift between locations for habitat resources in space and time and, therefore, areas can constitute Koala habitat even if a Koala is not present at a given time. Individual Koalas move daily between food and shelter trees (Pfeiffer et al. 2005; Tucker, Melzer & Eillis 2007). Over a longer timescale, individuals' use of habitat is influenced by seasonal changes in food quality (Dargan et al. 2019; Woodward et al. 2008; Wu 2018), changes in habitat caused by drought (Seabrook et al. 2011), disturbance history (Kavanagh, Stanton & Brassil 2007; Lunney et al. 2007; Matthews et al. 2016), the long-term results of a changing climate (Santika et al. 2014; Shabani et al. 2019) and competition with other species (e.g., Bell Miner *Manorina melanophrys*, Wardell-Johnson 2006).

Key factors that influence the *quality* of habitat for Koalas are the presence and density of preferred food tree species (Melzer et al. 2014; Moore & Foley 2000; Stalenberg et al. 2014; Whisson et al. 2016; Woodward et al. 2008); food trees' nutritional foliar chemistry (Ellis, Melzer & Bercovitch 2009; Moore & Foley 2005; More et al. 2004; Wallis et al. 2010)(section 29), and shelter trees and vegetation structure (Ellis, Hale & Carrick 2002; Ellis, Melzer & Bercovitch 2009; Ellis et al. 2013; Pfeiffer et al. 2005; Smith et al. 2013; Woodward et al. 2008). Koalas also use open ground (whether natural or part of the built environment) to travel between trees and patches, and the safety or hostility of this matrix also contributes to the overall quality of habitat (section 28.4). At a broad scale, these factors are determined by climate variables (Hughes, Cawsey & Westoby 1996); local soils (type and moisture)(Davies et al. 2013; Reed, Lunney & Walker 1990; Sullivan, Norris & Baxter 2003; Wu et al. 2019); disturbance history from fire and timber harvesting (Kavanagh, Stanton & Brassil 2007; Lunney et al. 2007; Matthews et al. 2016); and landforms of the natural and built environment (Barth et al. 2019; McAlpine et al. 2006a; Rus et al. 2021; Santika et al. 2014; Sullivan, Norris & Baxter 2003; Wu et al. 2019).

At the landscape scale, the *total* amount of available habitat and habitat quality are the primary environmental factors that influence Koala presence (Barth et al. 2019; Dargan et al. 2019; Januchowski et al. 2008; McAlpine et al. 2006a & b). Also important to Koalas is the relative importance of landscape patch size, form and spatial configuration within context of the wider landscape, which can vary among landscapes and varies regionally. For example, riparian habitats and surface water bodies are essential for the survival of Koalas at the western margins of Koala distribution (Wu 2018), but persistence in these areas is supported by the presence of intact non-riparian habitat (Smith et al. 2013). The use of isolated trees (large trees also used by stock) within grazing paddocks is commonly recorded (Dargan et al. 2019; White 1999). In agricultural and fragmented landscapes of south-east Queensland scattered paddock trees have been found, along

with roadside vegetation, to be disproportionately important to the local Koala population (Barth et al. 2019). Furthermore, riparian vegetation facilitates local movement (Davies et al. 2013) and is important in long-distance dispersal (McAlpine et al. 2006a & b; Norman et al. 2019) (section 28.4).

Over long timescales, and under climate change, habitat areas that provide refuge, or safe havens, during droughts are particularly important in sustaining Koala populations (Adams-Hosking et al. 2011b, Lunney et al. 2017). In drier parts of their range, habitat areas with perennial water and geological features that provide cooler microclimates may support the highest densities of Koalas and provide refuge for Koalas during times of heat and water stress (Lunney et al. 2017; Seabrook et al. 2011; Sullivan et al. 2004). Intact habitat outside watercourses but with higher quality food trees may also support refugial populations, albeit at lower densities (Davies et al. 2013; Ellis et al. 2010a; Smith et al. 2013).

As described above, Koalas need access to different types of habitat attributes at multiple spatial and temporal scales (Dargan et al. 2019). What constitutes Koala habitat is the result of interactions between an individual animal's behaviour, which can be understood from studies of Koala's behavioural ecology, biology and movement patterns (Part VI), and the requirement and selection of environmental resources of the *particular landscape* in which individual Koalas, and the populations they belong to, live (functional ecology). These in turn are influenced by processes at other scales (e.g., fire, hydrology, vegetation clearance and climate change).

Koala habitat in this recovery plan includes the total set of resources required by Koalas (above) to meet the needs of individual survival and reproduction, and the how those resources are arranged in the landscape to maintain viable metapopulation processes:

For an individual Koala, this includes access to sufficiently quality food and shelter trees to meet their daily energetic requirements and reproduction. Koala habitat includes forests or woodlands; roadside and railway vegetation and paddock trees; safe intervening ground matrix for travelling between trees and patches to forage and shelter and reproduce; and access to vegetated corridors or paddock trees to facilitate movement between patches. These resources fall within individual Koala's home ranges and allow for interaction with adjacent individuals.

For a population of the listed Koala, this means sufficient total amount of habitat of adequate quality to support a viable biological population where mortality, survival, and recruitment are balanced or recruitment increasing to optimal carrying capacity and within the bounds of natural fluctuations. Crucial habitat elements include patches, and corridors for gene flow. On longer-time frames this includes climate refugia such as drainage lines, riparian zones and patches that are resilient to drying conditions due to favourable hydrological systems. Additionally, this includes areas which may be temporarily unoccupied, because of seral (age or time) changes to habitat quality that arise through processes such as fire, drought, or disease (shifting habitat mosaic) or degradation, and which are available for future recolonisation.

26 Habitat critical to survival

Habitat critical to the survival of a species is the area that the species relies on to halt decline and promote the recovery of the species, that can be *unambiguously* identified. Under the EPBC Act, the following factors and any other relevant factors may be considered when identifying habitat that is critical to the survival of a species:

(a) whether the habitat is used during periods of stress (examples flood, drought or fire);

(b) whether the habitat is used to meet essential life cycle requirements (examples foraging, breeding, nesting, roosting, social behaviour patterns or seed dispersal processes);

(c) the extent to which the habitat is used by important populations;

(d) whether the habitat is necessary to maintain genetic diversity and long-term evolutionary development;

(e) whether the habitat is necessary for use as corridors to allow the species to move freely between sites used to meet essential life cycle requirements;

(f) whether the habitat is necessary to ensure the long-term future of the species or ecological community through reintroduction or re-colonisation;

(g) any other way in which habitat may be critical to the survival of a listed threatened species or a listed threatened ecological community.

Such areas, if identified, would be expected to include habitat occupied and habitat currently unoccupied, areas necessary for population processes and maintenance of genetic diversity and evolutionary potential, and areas required to accommodate future population increase, recolonisation, reintroduction, or as climate refugia.

Having regards to the above factors and other relevant factors at the time of completing this draft, it is not practicable to identify by describing and to provide spatial information on the habitat critical to the survival of the Koala. This is because there is insufficient knowledge and data to unambiguously identify and spatially delineate habitat critical to the survival of the Koala. The information set out in section 25 above relating to the functional ecology of the Koala and its habitat is likely to form the basis of habitat critical to the survival of the Koala. The functional ecology of the Koala is described in terms of the combined assemblage of habitat qualities (extent, arrangement, attributes) theoretically required to stop decline and promote recovery. This theoretical approach has not been applied to describe or delineate specific areas of biophysical features (i.e. habitat) either through description or through spatial information.

In the absence of a definition for habitat critical to the survival of the listed Koala, EPBC Act referral guidelines are available for potential proponents to navigate the complexity of Koala habitat to identify significant impacts (DotE 2014). The guidelines provide guidance on important requirements, survey planning, and standards for mitigation impacts in context of long-term recovery planning for the listed Koala.

PART VI Biology and ecology

The wide-ranging distribution of the Koala and corresponding need to understand variability of habitat in terms of vegetation associations, landscape context and climate has driven many regional studies. Predictably, substantial location-dependent variation is found in studies of Koala dietary preferences and resource use, patterns of movement, reproductive biology, genetic structure, disease and threats, which in turn affect local population dynamics and persistence.

Information presented in this Part VI is intended to only provide a general overview on Koala biology and ecology relevant to the conservation and management of the Koala through a selection of location-specific examples. Koala conservation managers and decision-makers are advised to draw on the extensive literature for studies relevant to location or undertake further research/surveys where crucial data is lacking to make informed decisions for location-appropriate management of Koalas.

27 Species description

The Koala *Phascolarctos cinereus* (Goldfuss 1817), is the only extant member of the endemic marsupial family Phascolarctidae (Van Dyck & Strahan 2008*)*. It is semi-arboreal, with a stocky compact body, a residual tail, and muscular limbs, with sharp claws on the fore and hind paws for gripping bark when climbing trees. All digits are clawed, except the first (equivalent of a thumb) on the hind feet (Lee & Martin 1988). It has a rounded head, with a large flat, unfurred, black nose-pad, small eyes and large, oval-shaped ears covered in longer, white-tipped fur. Its chin, chest, belly and inside limbs are covered in sparse, short, white fur, while elsewhere its fur is ash-grey to brown, short and thick (or woolly). Some individuals may also have white fur patches on their rump (Martin & Handasyde 1999).

The Koala weighs between 4 to 15 kg and is sexually dimorphic with males up to 50% larger than females (Martin & Handasyde 1990; Martin, Handasyde & Krockenburger 2008). It exhibits clinal variation, with individuals from its southern range being about twice as heavy as those from northern Australia (average of 12 kg in Victoria *cf.* 6.5 kg in Queensland)(Martin & Handasyde 1999). Northern Koalas also tend to have shorter, silver-grey fur, whereas those in their southern range have longer, thicker, brown-grey fur (Martin & Handasyde 1999). This morphological cline is consistent with Bergmann's rule as an adaptation to different environmental conditions (Bergmann 1847), although reasons for the observed variation across the Koala range are likely to be more complicated (Briscoe et al. 2015).

Previously, three subspecies (*P. c. adustus*, *P. c. cinereus* and *P. c. victor*) were described based on this clinal body size and colour variation (Troughton 1957), however there is no genetic support for this (Houlden et al. 1999; Kjelsen et al. 2016; Neaves et al. 2016) and the Koala is now considered a single species.

28 Behavioural ecology and demography

The Koala is an arboreal species spending most of its time in trees of eucalypt forests, however, unlike other arboreal species such as gliders, it mainly uses the ground, rather than the canopy, to travel between trees (Marsh et al. 2014). It is largely sedentary, solitary and nocturnal, with adults having limited social interactions (Martin & Handasyde 1999), although individuals have extensive overlap in home territories (Ellis, Melzer & Bercovitch 2009; Mitchell 1990).

28.1 Social system

The mating system of the Koala has been characterised as male dominance-based territoriality (Gordon, McGreevy & Lawrie 1990; Lee & Martin 1988; Mitchell 1990), but more recent work suggests the mating system is consistent with female mate choice, whereby sexual dimorphism has evolved as a consequence of endurance rivalry promoting vocal sexual advertisements that attract females (Ellis, Hale & Carrick 2002; Ellis & Bercovitch 2011).

28.2 Reproduction

Koala development follows a pattern of sexual bi-maturism with females obtaining reproductive age between 2 and 3 years of age, and males at 4 years (McLean and Handasyde 2007; Martin & Handasyde 1999). Mature females generally produce up to one offspring a year with births occurring between October and May (Close, Ward & Phalen 2017; McLean 2003; Thompson 2006) following a 35-day gestation period (Martin & Handasyde 1999; Tyndale-Biscoe & Renfree 1987). Local factors, including population density, food quality and availability, soil type and climate, influence the timing of breeding (McLean & Handasyde 2007; Ballantyne et al. 2015). Koalas may not breed every year if conditions are unfavourable, and breeding can be unsuccessful due to poor body condition or disease (e.g., Chlamydia) (McLean & Handasyde 2007).

Southern populations have shown seasonal sex biases in offspring (McLean & Handasyde 2007), although this has not been found in Queensland (Ellis et al. 2010b). The newborn joey suckles from inside the pouch for around nine months (240 - 270 days) and is then carried on the mother's back for an estimated three months, until it is weaned at around 12 months (Ellis et al. 2010b; Martin & Lee 1984). The joey remains near the mother for another year before reaching sexual maturity at around two years of age, at which time it may disperse. Males provide no parental care (Mitchell & Martin 1990).

28.3 Demography

Records for wild Koalas report females commonly surviving to 13-14 years (Close, Ward & Phalen 2017) and up to at least 18 years of age (Martin & Handasyde 1990), and more than 12 years for males (Martin & Handasyde 1999), equating to a generation length of 6 to 8 years (TSSC 2012b). Mortality rates and causes vary between age cohorts and are location-dependent, and mainly threat-driven. In the 'Koala Coast' (south-east of Brisbane), disease is the largest single contribution to mortality, followed by natural causes and vehicle strikes, and then dogs (Rhodes et al. 2011). Mortality rates range from 8.5% (subadult males, Queensland) to 40% for adult males in Port Stephens, NSW (cited in TSSC 2012b; Thompson 2006) and > 60 % for 2-3 year old males in the Koala Coast, SE QLD (Rhodes et al. 2011). This last figure contrasts to other studies of the Koala Coast in

peri-urban and remnant bushlands that found survival rates are high for both juveniles (0.89-0.96) and adults (0.81) (Thompson 2006), indicating that the potential for recovery of populations is very good where threats can be mitigated or removed.

28.4 Movement patterns

Studies of home range sizes for the Koala show they are highly variable depending on the location, generally being substantially larger inland in the semi-arid woodlands than in mesic coastal forests, reflecting variation in local patch context and quality. For example, some individuals in Central Mackay Coast bioregion have small home ranges of less than 2 ha (Ellis et al. 2015), whereas in the Mulga Lands bioregion home ranges are up to 169.5 ha (Davies et al. 2013). Home range size can also vary substantially within the same region (Ellis, Hale & Carrick 2002; Kavanagh, Stanton & Brassil 2007) and may shift spatially across years (Ellis, Melzer & Bercovitch 2009). High variability has been found on some islands (6.0-132.4 ha, North Stradbroke Island, Cristescu et al. 2011), while not on others (4.6 to 8.8 ha St. Bees Island, Ellis, Melzer & Bercovitch 2009) and the latter study found individuals in overlapping home ranges rarely used the same trees, indicating resource partitioning on fine scales. Juveniles tend to have relatively smaller home ranges than adults (Thompson 2006). Koalas use both natural and built features as home ranges or boundaries (Close, Ward & Phalen 2017) and for dispersal (e.g., tracks, Lassau et al. 2008).

Both sexes disperse from their natal home-range between about 18 and 36 months of age (Dique et al. 2003b; Mitchell & Martin 1990) where daughters are reported to occupy home ranges embedded within their maternal home range (Ellis, Melzer & Bercovitch 2009; Tucker, Melzer & Ellis 2007) or adjacent areas (Close, Ward & Phalen 2017). Typical of mammal behaviour, the species exhibit male bias dispersal (Dique et al. 2003b; Mitchell & Martin 1990) although this is not perhaps such a dichotomous characteristic in the Koala (Thompson 2006). During natal dispersal, juveniles are susceptible to vehicle strike, especially males (Canfield 1991; Dexter et al. 2018; Dique et al. 2003a). Dispersing individuals are recorded to move up to 20 km from their natal areas (Close, Ward & Phalen 2017; White 1999), with average distances reported at 3.5 km in south east Queensland (Dique et al. 2003b). While studies indicate a predominance of short-range movements (e.g., Dique et al. 2003b), genetic modelling in slightly fragmented landscapes of north-eastern NSW suggests longer movements may be in fact relatively common (15-20 % of movements at 16.8 to 20.3 km, Norman et al. 2019).

The ability to disperse among habitat patches is critical for Koalas in maintaining metapopulation persistence (section 20), although this is not well understood. A decrease in connectivity can precipitate the local population extinction of a dispersal-limited species (Bascompte & Sole 1996) like the Koala in fragmented landscapes. Furthermore, within intact landscapes, a mismatch between the scale of spatially and temporally shifting habitat suitability (shifting habitat mosaic) such as that caused by disturbance from timber harvesting or fire, and the ability of a species to disperse and recolonise, may also have adverse impact on long-term metapopulation persistence (Wimberley 2006).

Analysis of Koala densities before and during drought indicates that Koalas die out from habitat surrounding climate refuges, rather than migrating to refugial areas (Seabrook et al. 2011). Natural

migration away from climate-affected areas cannot be relied upon as a rescue for at-risk Koala populations.

29 Foraging ecology

Koalas are recorded to feed on more than 120 species of *Eucalyptus, Corymbia and Angophora* (Moore & Foley 2000; Phillips 1990), primarily the subgenus Symphyomytrus (Moore & Foley 2005), and a few other genera (Marsh et al. 2014; Moore & Foley 2000; Phillips 1990). Knowledge of feeding species is growing as new habitat locations are studied. Generally, their preferred tree species in the south of their distribution include Manna Gum (*E. viminalis*), Swamp Gum (*E. ovata*) and Blue Gum (*E. globulus*), while in the north Tallowwood (*E. microcorys*), Red Gums (*E. camaldulensis* and *E. tereticornis*) and Grey Gums (*E. puncutata* and *E. propinqua*) are important (Van Dyke & Strachan 2008). The browse species consumed, and the proportion of diet made up by each species, varies considerably among populations and individuals (Moore & Foley 2005), and seasons (Davies et al. 2014; Ellis et al. 2013), even within the same home range (Blyton et al. 2019; McAlpine et al. 2008).

In a given area, Koalas show a preference for browse trees on more fertile soils with a higher nutrient status. Dietary selection is thought to be driven by trade-offs between palpability and the nutritional value of leaves of digestible proteins within and between browse species (measured by available nitrogen or digestible nitrogen) (DeGabriel et al. 2008; Wallis et al. 2012) and concentrations of less desirable secondary plant metabolites including FPCs and tannins (Au et al. 2013; Marsh, Wallis & Foley 2007; Stalenberg et al. 2014; Wallis et al. 2010). Leaf moisture may play a role during times of low rainfall or heat stress (Ellis et al. 2010a). Choice of browse trees is also influenced by physical characteristics including tree size, number of palatable trees nearby, and presence of shelter trees (Crowther et al. 2014; Moore et al. 2010).

The nutritional composition and amount of plant secondary metabolites of *Eucalyptus* species can vary within and between species (More et al. 2010; Wallis et al. 2010) at fine scales, disturbance history and climate conditions (Au et al. 2019; More et al. 2004b; Stalenberg et al. 2014; Youngentob 2015) and temporally between seasons (More and Foley 2000), creating a patchy and dynamic distribution of food quality in space and time across landscapes and use of trees by Koalas (Moore et al. 2010). Koalas living in different eucalypt communities therefore contend with different nutritional and toxicological challenges (DeGabriel et al. 2009).

The Koala has a specialised digestive tract with an extremely enlarged caecum to retain food for long periods to break down food to extract nutrients and degrade toxic plant metabolites by gastrointestinal microorganisms (Cork, Hume & Dawson 1983; Shiffman et al. 2017). Gut microbiomes of Koalas vary (Alfano et al. 2015; Barker et al. 2013) and appear to be influenced by diet (Brice et al. 2019) suggesting that gut microbiomes of Koalas are finely optimised to digest particular species of *Eucalyptus, Corymbia, and Angophora*, and dietary selection by individuals may be therefore limited by their microbiome (Blyton et al. 2019).

This relationship between diet and microbiome has ramifications for Koala translocations, the treatment of sick or injured Koalas, habitat restoration and population management. Sick and injured Koalas treated with antibiotics that knock out gut microbiomes could be inoculated with probiotics to restore functional gut microbiomes, enhance recovery and successful return to the

wild. Inoculations of microbiomes optimised for certain species of *Eucalyptus, Corymbia, and Angophora* could potentially be used to assist in translocations, disease prevention, or shift diets *in-situ*, preventing the need for translocations when managing population numbers (Blyton et al. 2019). Understanding population-level gut microbiomes could also be used to optimise the selection of tree species in habitat restoration targeted at Koalas, or via inoculations, to assist the plasticity of populations to adapt to changing forest tree composition in the future as the local climate changes.

Because of Koala's specialised diet and digestive biology, the species has limited physiological ability to cope with drought or heat stress by increasing their leaf intake and subsequent dietary water intake (Lunney & Pat 2012). Koalas are thus particularly vulnerable to the increased temperatures and water stress encountered across much of their range under climate change.

30 Physiology

Koalas are highly susceptible to extreme temperatures, both hot and cold, and drought, particularly where these occur simultaneously and for extended periods of time (Briscoe et al. 2016; Lunney et al. 2014; Seabrook et al. 2014a). The influence of extreme weather events on Koala is mediated by a combination of physiology, morphology and behaviour.

The acute consequences of extreme heat events on Koalas arise from their physiological and dietary constraints. Koalas are thought to meet most of their water requirements from the leaves they eat. During extreme hot, dry conditions, less dew forms on leaves and the leaves themselves contain less water. At these times, Koalas eat less or not at all, as eating increases their metabolism, requiring them to dissipate more heat through evaporative respiration to remain comfortable (Lunney & Pat 2012). The high level of toxins in their browse species also limits how much Koalas will eat (Moore & Foley 2000). Unable to balance water intake with water loss to evaporation, Koalas becoming dehydrated, leading to death (Gordon et al. 1988; Seabrook et al. 2011). In longer drought and heat events, tree death and subsequent starvation and stress on Koalas also reduce breeding success and survival of young (Davies et al. 2013). Recent work indicates that some Koalas readily use free-standing water when provided, particularly when conditions are hot and dry (Mella et al. 2019, 2020), though this behaviour is thought to be rare (Lunney et al. 2012). Water use may be linked to disease load on Koalas.

Koalas have several behavioural responses that can mitigate heat stress. Koalas move daily between food trees and resting trees, and on hot days feed at night when temperatures are cooler (Crowther et al. 2014; Ellis et al. 2010a). Koala's diet consists of a broad range of tree species but show seasonal and regional preferences for browse species and seek out trees with higher leaf water during drought (Clifton et al. 2007; Davies et al. 2014). During hot days, Koalas seek cool microclimates and take up heat-dispersing postures, such as hugging the cooler trunks of large trees, or splaying limbs (Briscoe et al. 2014). These strategies reduce or eliminate their need for respiratory evaporative cooling and the resulting loss of water. Climate-mitigation by vegetation may be reduced during drought, as trees reduce the transport of cooler underground water through trunks and water-stressed leaves provide less shade and dietary water.

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APPENDICES

Appendix 1 Major current and potential partners, and interest groups

Government organisations	Natural Resource Management organisations
Department of Science and Environment (QLD)	Natural Resource Management (QLD & ACT)
Department of Planning, Industry and Environment (NSW)	Local Land Councils (NSW)
Natural Resources Commission (NSW)	National Landcare Australia
Dept. of Environment, Planning and Sustainable Development (ACT)	Queensland Trust for Nature
Local Government and Councils (NSW, QLD, ACT, Vic., SA)	**Community groups**
Department of Environment, Water, Land and Planning (Victoria)	Indigenous groups
Department for Environment and Water (SA)	Citizen Scientists
Atlas of Living Australia	Individuals
Non-government conservation organisations	**Koala care and advocacy groups**
World Wildlife Fund for Nature (WWF)	Koala welfare carers and rescue groups
Science for Wildlife	Friends of the Koala
Australian Forests and Climate Alliance Inc. (AFCA)	Land for Wildlife
The Nature Conservancy, Australia (TNC)	WIRES
Nature Conservation Council (NSW)	Friends of the Koala (Northern Rivers)
National Parks Association of the ACT Qld, NSW	Port Stephens Koalas
North East Forest Alliance (FEFA)	Koala Conservation Australia
International Fund for Animal Welfare (IFAW)	Australian Koala Foundation (AKF)
Bush Heritage Australia	Koala friends groups (many)
Koala health	**Research organisations**
Australian Veterinary Association	Australian Museum
Koala Health Hub (KHH, University of Sydney)	Australian National University
Zoo and Aquarium Association (ZAA)	Central Queensland University
Port Macquarie Koala Hospital	CSIRO
Zoos: Taronga Zoo (NSW); Zoos Victoria (Vic.); Zoos SA; Lone Pine Koala Sanctuary	Deakin University
Currumbin Wildlife Sanctuary	Federation University
Wildlife Health Australia	Queensland University of Technology
Australian Wildlife Health Institute	University of Melbourne
Magnetic Island Koala Hospital	University of Newcastle
Moreton Bay Koala Rescue Inc. (QLD)	University of Queensland
Australia Zoo Wildlife Hospital	University of Sydney
University of Adelaide – School of Animal and Veterinary Sciences	University of Western Sydney
Koala and wildlife hospitals - Port Macquarie, Port Stephens, Byron Bay, Northern Rivers, Lismore	SA International Koala Centre of Excellence
RSPCA Queensland	**Consultancy businesses**

Appendix 2 Predicted habitat loss under climate change

Estimated changes to Koala distribution due to climate change under high global-emissions scenarios (A1FI or RCP8.5) were made for the years 2030, 2050 and 2070 (Table A). Estimates are summarised across 13 projections of future koala habitat (Adams-Hosking et al. 2011a, Briscoe et al. 2016). Note that climate change in 2030 is relatively insensitive to future emissions. These estimates can be interpreted as representing areas that fall within the physiological tolerance of koalas, accounting for weather conditions including drought and heatwave but not fire. These estimates were calculated from 13 projections of future koala distribution, chosen to represent variation in future climate and emissions scenarios and in variables chosen to represent koala physiological tolerance. All projections predict range contraction of the koala, though there is uncertainty around where the western and northern edges of koala distribution will fall at a given point in time. Several models predict that bioregions known to contain Koala populations, including Mulga Lands, Darling Riverine Plains, and Mitchell Grass Downs, are currently unsuitable for Koalas, based on 1961-1990 or 1990-2009 climate conditions (Table A).

Estimates represent the change in area that was climatically suitable for Koala based on conditions for the period 1961-1990 (Hoskings) 1991-2009 (Briscoe), and compared to the area that is expected to be climatically suitable for Koala in 2030, 2050 and 2070, within areas where koalas or their habitat are 'known' or 'likely' to occur (DAWE 2021). Estimates are summarised for IBRA7 bioregions (DoTE 2012). Negative values indicate a gain in climatically suitable area. Methods follow Table B.

Table A. Estimated changes to Koala distribution due to climate change under a high global-emissions scenario (A1FI or RCP8.5), summarised across 13 models of Koala distribution for the years 2030, 2050 and 2070.

Bioregion	Median % loss by 2030 (min, max)	Median % loss by 2070 (min, max)	Median % loss by 2070 (min, max)	Number of models predicting this bioregion to historically hold < 1000ha of climatically suitable for koalas
Queensland				
Brigalow Belt North	57.1 (0, 97.5)	91.1 (0, 100)	95.3 (0, 100)	
Brigalow Belt South	36.8 (0, 85.3)	80.3 (0, 99.6)	91.3 (0, 100)	
Central Mackay Coast	11.7 (0, 95.1)	65.9 (0, 100)	84.8 (0, 100)	1 of 13
Darling Riverine Plains	98.1 (0, 100)	100 (0, 100)	100 (0, 100)	6 of 13
Desert Uplands	100 (0, 100)	100 (0, 100)	100 (-100, 100)	
Einasleigh Uplands	20.7 (-27.8, 0.9)	29.6 (-29.7, 100)	57.3 (-35.9, 100)	7 of 13
Mitchell Grass Downs	0 (0, 0)	0 (0, 0)	0 (0, 0)	11 of 13
Mulga Lands	0 (0, 100)	0 (0, 100)	0 (0, 100)	9 of 13
Nandewar	0 (0, 51)	8.9 (0, 94.9)	30.5 (0, 99.8)	
New England Tablelands	0 (0, 0.1)	0 (0, 15.2)	0 (0, 75.6)	
South Eastern Queensland	0.8 (0, 63.1)	21.4 (0, 97.4)	43.3 (0, 100)	
Wet Tropics	9.7 (-23.2, 57.3)	22.5 (-27.4, 100)	35.9 (-29.8, 100)	
WHOLE STATE	**29.9 (0, 78.4)**	**58.4 (0, 97.6)**	**67.8 (0, 99.5)**	
New South Wales				
Australian Alps	0 (-1.8, 66.6)	0 (-6.8, 96.3)	0 (-12.7, 98.1)	11 of 13
Brigalow Belt South	33.8 (0, 67.6)	61 (0, 97.1)	81 (0, 100)	

Cobar Peneplain	0 (0, 100)	0 (0, 100)	0 (0, 100)	13 of 13
Darling Riverine Plains	96.4 (0, 99)	100 (0, 100)	100 (0, 100)	9 of 13
Mulga Lands	0 (0, 0)	0 (0, 0)	0 (0, 0)	
Murray Darling Depression	0 (0, 100)	0 (0, 100)	0 (0, 100)	
Nandewar	8.6 (0, 55.3)	20.1 (0, 89.5)	39.8 (0, 96.6)	
New England Tablelands	0 (0, 2.2)	0.1 (0, 10.1)	0.3 (0, 47.1)	
NSW North Coast	0 (0, 9.1)	0.1 (0, 26.3)	0.6 (0, 70.7)	
NSW South Western Slopes	20.3 (0, 57.8)	43.6 (0, 90.7)	57.6 (0, 98.7)	
Riverina	84.7 (0, 100)	99.3 (0, 100)	100 (0, 100)	
South East Corner	0 (0, 0.2)	0 (0, 1.2)	0 (0, 8.7)	
South Eastern Highlands	0 (-1.1, 18.2)	0.3 (-0.9, 48.9)	2.8 (-1.3, 60.1)	
South Eastern Queensland	0 (0, 33.1)	0 (0, 71.4)	4.3 (0, 97.7)	
Sydney Basin	0 (0, 2.6)	0.7 (0, 21.3)	4.8 (0, 54.6)	
WHOLE STATE	**11 (0, 23.6)**	**19 (0, 45.3)**	**25.4 (0, 69.3)**	
ACT				
Australian Alps	0 (-26.3, 9.8)	0 (-28, 94.8)	0 (-28, 100)	
South Eastern Highlands	0 (-5.6, 3.9)	0 (-5.7, 72.5)	0 (0, 100)	
WHOLE TERRITORY	**0 (-9.1, 5.1)**	**0 (-9.5, 77)**	**0 (0, 100)**	

Methods

13 projections of koala distribution under climate change were generated from 7 models. The 13 projections consisted of 7 projections of correlative species distribution models generated using Maxent (source: Briscoe et al. 2016; Adams-Hosking et al. 2011; Maxent: Phillips et al. 2006) and 6 projections of bioenergetics models generated using NicheMapper (Porter & Mitchell, 2006). The variables used to construct each model is summarised in Table B.

Table B. Summary of 13 projected models used to estimate impacts of climate change on koalas.

Tool	Model name (see reference for details)	Variables included in model	General circulation models (GCM), emissions scenario (RCP) used	Historical climate	Threshold	Source
NicheMapper	Poor_high	Energy and water requirements of reproducing females with site-specific morphology and available microclimates – assuming high foliage water content	ACCESS 1.3; RCP8.5	1990-2009	Thresholded to include 95% of koala records since 2000 (equivalent to test omission of 0.05), spatially thinned to 1km	Briscoe et al. 2016
NicheMapper	Poor_high	As above	HadGEM2-CC, RCP8.5	1990-2009	As above	Briscoe et al. 2016
NicheMapper	Poor_med	Energy and water requirements of reproducing females with site-specific morphology	ACCESS 1.3, RCP8.5	1990-2009	As above	Briscoe et al. 2016

Tool	Model name (see reference for details)	Variables included in model	General circulation models (GCM), emissions scenario (RCP) used	Historical climate	Threshold	Source
		and available microclimates – assuming medium foliage water content				
NicheMapper	Poor_med	As above	HadGEM2-CC, RCP8.5	1990-2009	As above	Briscoe et al. 2016
NicheMapper	Poor_low	Energy and water requirements of reproducing females with site-specific morphology and available microclimates – assuming low foliage water content	ACCESS 1.3, RCP8.5	1990-2009	As above	Briscoe et al. 2016
NicheMapper	Poor_low	As above	HadGEM2-CC, RCP8.5	1990-2009	As above	Briscoe et al. 2016
Maxent	Averages	Annual rainfall, Max temp in warmest month, Eucalypt woodland cover, road density	ACCESS 1.3, RCP8.5	1990-2009	As above	Briscoe et al. 2016
Maxent	Averages	As above	HadGEM2-CC, RCP8.5	1990-2009	As above	Briscoe et al. 2016
Maxent	Extremes A	Max run of dry days, 95th percentile temperature, Vapour pressure during hot weather, Eucalypt woodland cover, road density	ACCESS 1.3, RCP8.5	1990-2009	As above	Briscoe et al. 2016
Maxent	Extremes A	As above	HadGEM2-CC, RCP8.5	1990-2009	As above	Briscoe et al. 2016
Maxent	Extremes B	Max run of dry days, max run of hot days, vapour pressure during hot weather, Eucalypt woodland cover, road density	ACCESS 1.3, RCP8.5	1990-2009	As above	Briscoe et al. 2016
Maxent	Extremes B	As above	HadGEM2-CC, RCP8.5	1990-2009	As above	Briscoe et al. 2016
Maxent	-	Mean summer maximum temperature, mean annual rainfall	CSIRO MK 3.5 OzClim, SRES A1FI	1961-1990	Equal sensitivity and specificity (Test omission =0.224)	Adams-Hosking et al. 2011a

As climate projections in Briscoe are available for 2070 only, these published models were interpolated following IUCN/SSC (2019) to generate estimates of the area of land within the koala's physiological tolerances for 2030 and 2050, using the following formula applied to each cell in the projected koala distribution rasters

$$z = x + \frac{(yr2 - yr1)(y - x)}{(yr3 - yr1)}$$

Where *x* is the value of raster at *yr1* (e.g. 2009), *y* is the value of raster at *yr3* (e.g. 2070), and *yr2* is the year for which values *z* are to be estimated (e.g. 2042). This formula assumes a linear interpolation between projections of koala distribution in year 1 and year 3 (Table C). Models were resampled to 10km resolution and GDA 94 Albers projection (EPSG:3577) was used throughout.

Table C. Years used for interpolation of climate estimates.

	Yr1	**Yr3**
Estimate for 2030 (Briscoe)	2009	2070
Estimate for 2050 (Briscoe)	2009	2070

Each raster was thresholded (Table D) and any cell falling within the threshold was designated as suitable for koala. Thresholds were chosen from the baseline projection of each model at 1) BRISCOE: the value of the 'current' model within which 95% of records since 2000 fall (i.e. test omission 0.05) and 2) ADAMS-HOSKING: the equal sensitivity and specificity value (test omission 0.224).

Table D. Thresholds applied to climate suitability rasters.

Model	Threshold value
Adams-Hosking - Maxent	0.407
Briscoe – NicheMapper – poor_low	0
Briscoe – NicheMapper – poor_med	0.454
Briscoe – NicheMapper – poor_high	0.772
Briscoe – Maxent – averages	0.373
Briscoe – Maxent – extremesA	0.387
Briscoe – Maxent – extremesB	0.364

As the models in Briscoe et al. (2016) and Adams-Hoskings et al. (2011a) predict to regions outside the distribution of the koala, each of these rasters was then intersected with areas where koalas or their habitat are 'known' or 'likely' to occur (DAWE 2021) to exclude areas where koalas are unlikely to occur.

These rasters were then intersected with bioregions (DotE 2012; IBRA7) and the area and loss in area of land predicted to be within the koala physiological tolerance was calculated for each of the 13 models. The minimum, maximum and median % loss was summarised across each of the 13 models.

Appendix 3 2019/2020 fire extent

The table below lists the area and proportion of land burned in the 2019/2020 bushfires within the area where the listed Koala and its habitat is known or likely to occur, by IBRA7 bioregion and by state/territory. Numbers for likely plus known koala distribution only are provided, excluding areas where koala may occur. Note: modelled distribution does not equate to Koala habitat (see section 21 for further explanation). Numbers were generated using previous koala distribution mapping (2013). Source, DAWE 2021b.

IBRA Region/ State	Extent burned within known + likely koala distribution, ha (%)	Extent of known + likely koala distribution in region, ha
Queensland		
Brigalow Belt South	66,949 (1%)	5,815,861
Brigalow Belt North	175 (<1%)	3,393,155
South Eastern Queensland	112,310 (2%)	4,513,639
Desert Uplands	(0)	1,747,897
Einasleigh Uplands	(0)	994,082
Mulga Lands	(0)	775,412
Central Mackay Coast	122,44 (2%)	653,062
Mitchell Grass Downs	(0)	496,464
Nandewar	(0)	405,811
Wet Tropics	(0)	278,034
Gulf Plains	(0)	101,562
Darling Riverine Plains	(0)	83,103
New England Tablelands	1,373 (1%)	144,020
Total	**193,051 (1%)**	**19,402,102**
NSW		
Sydney Basin	901,265 (30%)	2,963,881
NSW North Coast	1,111,476 (30%)	3,676,443
South East Corner	503976 (52%)	969,498
South Eastern Highlands	308784 (13%)	2,341,800
South Eastern Queensland	316774 (19%)	1,635,043
New England Tablelands	248,737 (13%)	1,906,295
Darling Riverine Plains	4,358 (<1%)	2,594,995
Brigalow Belt South	8,463 (<1%)	3,368,917
NSW South Western Slopes	24,643 (2%)	1,024,530
Nandewar	37,371 (4%)	880,898
Cobar Peneplain	(0)	260,148
Mulga Lands	(0)	86,266
Murray Darling Depression	- (4%)	23,388
Australian Alps	697 (4%)	19,701
Riverina	29 (<1%)	770,506
TOTAL	**3,446,573 (15%)**	**22,522,309**
ACT		
Australian Alps	10,248 (57%)	17,961
South Eastern Highlands	10,893 (15%)	73,775
Total	**21,141 (23%)**	**91,736**
Listed Koala (combined)		

IBRA Region/ State	Extent burned within known + likely koala distribution, ha (%)	Extent of known + likely koala distribution in region, ha
Sydney Basin	901,265 (30%)	2,963,881
NSW North Coast	1,111,476 (30%)	3,676,443
South East Corner	503,976 (52%)	969,498
South Eastern Highlands	319,676 (13%)	2,415,575
South Eastern Queensland	429,084 (7%)	6,148,681
New England Tablelands	250,110 (12%)	2,050,315
Brigalow Belt South	75,412 (1%)	9,184,778
Brigalow Belt North	175 (<1%)	3,393,155
Darling Riverine Plains	4,358 (<1%)	2,678,097
Desert Uplands	(0)	1,747,897
Einasleigh Uplands	(0)	994,082
Nandewar	37,371 (3%)	1,286,708
Mulga Lands	(0)	861,679
NSW South Western Slopes	24,643 (2%)	1,024,530
Central Mackay Coast	12,244 (2%)	653,062
Mitchell Grass Downs	(0)	496,464
Australian Alps	10,945 (29%)	37,662
Wet Tropics	(0)	278,034
Cobar Peneplain	(0)	260,148
Gulf Plains	(0)	101,562
Murray Darling Depression	(0)	23,388
Riverina	29 (<1%)	770,506
Total	**3,680,764 (9%)**	**42,016,145**