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Review

Conserving koalas: A review of the contrasting regional trends, outlooks and policy challenges

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ABSTRACT

The koala (*Phascolarctos cinereus*), one of the world's most iconic faunal species, was recently listed under Australian government legislation as vulnerable in the northern states of Queensland and New South Wales and in the Australian Capital Territory, but not in the southern states of Victoria and South Australia. This review synthesises empirical evidence of regional koala population trends, their conservation outlook, and associated policy challenges. Population declines are common in the northern half of the koala's range, where habitat loss, hotter droughts, disease, dog attacks and vehicle collisions are the major threats. In contrast, some southern populations are locally overabundant and are now subject to managed declines. The koala presents the problem of managing a wide-ranging species that now primarily occurs in human-modified landscapes, some of which are rapidly urbanising or subject to large-scale agricultural and mining developments. Climate change is a major threat to both northern and southern populations. The implementation of policy to conserve remaining koala habitat and restore degraded habitat is critical to the success of koala conservation strategies, but habitat conservation alone will not resolve the issues of koala conservation. There needs to be concerted effort to reduce the incidence of dog attack and road-related mortality, disease prevalence and severity, and take into account new threats of climate change and mining. Many of the complex conservation and policy challenges identified here have broader significance for other species whose population trends, and the nature of the threatening processes, vary from region to region, and through time.
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1. Introduction

Iconic or charismatic vertebrate fauna serve as symbols for conservation action (Simberloff, 1998; Clucas et al., 2008; Lunney, 2012; Wilson, 1985). Iconic fauna are well-known animal species that gain a disproportionate share of the public's attention and are often used to anchor an environmental campaign. They draw attention to the generic issues of conserving biodiversity, with the potential to benefit all wildlife that suffer similar problems and occupy similar geographical areas. Iconic fauna are most commonly mammals, and mammals are also among the most vulnerable taxa, with nearly a quarter (22%) of the world's species considered to be globally threatened or extinct (IUCN, 2012).

The koala (*Phascolarctos cinereus*), an Australian endemic and one of the world's most iconic mammals, is now recognised as a threatened species across two thirds of its range. Its high public profile and vulnerable status help draw public attention to the diminishing forest fauna and their habitats in eastern Australia. The species presents some unique conservation challenges because it is not uniformly threatened throughout its wide geographic range, and the multiple threats go well beyond the usual responsibilities of conservation managers and environmental policy makers. An earlier national synthesis (Melzer et al., 2000) concluded that the koala had suffered a >50% decline in distribution and numbers since European settlement. Northern populations, especially in New South Wales (NSW), had shown the greatest decline. Larger and more stable koala populations occurred in Victoria and South Australia.

Since the synthesis by Melzer et al. (2000), the state of koala populations has changed, and the situation remains complex. This complexity, along with the koala's iconic status, is highlighted by the fact that its national status was assessed twice by the Australian Government's Threatened Species Scientific Committee, first in 2004 when it was found to be ineligible for listing as threatened under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act), and again commencing in 2007. The second assessment provided a recommendation of ineligibility to the Minister for the Environment in September 2010, but noted that it was "potentially eligible for listing as vulnerable", citing the variability in circumstances across the species' range and the uncertainty in the data. However, before the Minister could make his decision, an unprecedented Australian Government Senate Inquiry into a single species was announced for the koala. The Minister deferred his listing decision until after the Inquiry reported. The Threatened Species Scientific Committee reconsidered their advice in light of the Inquiry's findings, and ultimately advised that the koala should be listed as vulnerable in the northern part of its range but not in the southern part. This latter recommendation was made at the request of the Minister to consider the Inquiry's recommendation to examine the option of "listing the koala as vulnerable under the EPBC Act in areas where populations have declined significantly or are at risk of doing so." It should be noted that circumscription of a part of a species range is an option under the EPBC Act that is used very sparingly (to date 7 times out of 1764 listed taxa). The koala is the only species in which it has been used for a contiguous part of a species' range.

It is against this backdrop of considerable biological and policy complexity that we considered it appropriate to provide a complete synthesis and interpretation of recent regional koala population trends, their conservation outlook, and associated policy challenges across the species entire range. In doing so, we provide an international case study of how a charismatic species can help unravel the ecological and conservation complexities surrounding a wide ranging species which is at once a rallying point for conservation, a bureaucratic headache, a media sensation or media embarrassment, and where the local issues faced vary between the extremes of extinction and pest.

2. Methods

The evidence presented in this paper was initially assembled at a workshop held in Brisbane, Australia, in February 2012, involving 17 of Australia's most experienced koala ecologists representing all the States with koala populations (ACEAS, 2014). This workshop, titled *Conserving Koalas in the 21st Century*: *Synthesising the dynamics of Australia's Koala populations*, aimed to review koala population status and trends across its geographic range, with a regional approach that enabled differences and commonalities among regions to be identified. The workshop identified existing data sets on regional koala populations across its broad geographic range from north Queensland to southern Victoria and Kangaroo Island (see Appendix A). These data were collected using a range of survey methods including direct counts, faecal pellet surveys, radio and GPS tracking, community surveys, and historical records analysis. The data were collected at spatial scales ranging from 1000s to 100,000s of hectares, and temporal scales ranging from a single survey to multiple surveys over 25 years. The data sources included published papers, unpublished reports to government and industry, field surveys by scientists and community groups, and in some cases unpublished data collected by the workshop participants. The data were examined and synthesised to identify the underlying

trends over time frames of 10–40 years, their causes, the emerging threats, and the appropriate management response and priorities.

3. Results

3.1. Regional population trends

3.1.1. Queensland

Queensland koala populations, considered relatively secure at the end of the 1990s (Melzer et al., 2000), have suffered substantial declines in the last 15 years due to a number of interacting threats (Fig. 1). Prominent in these declines are the urban and peri-urban koala populations of south-eastern Queensland, including the far south-east "Koala Coast" population which declined by 75% in density from 1996 to 2012 (de Villiers, 2015; Fig. 2). This is an example of extinction debt, where populations continue to decline long after the main habitat destruction occurred (Tilman et al., 1994). The major destruction of habitat occurred before 1996, with the confounding influence of a massive increase in anthropogenic mortality associated with recent urban expansion. The most rapid declines are in the high density urban and remnant source populations which occur on the high soil fertility coastal lowlands, which are undergoing rapid conversion from agriculture to urban (McAlpine et al., 2006). Nearly all the coastal lowlands have been designated as urban footprint and are earmarked for development. Without these vital source populations (which now find themselves surrounded by the urban footprint), koala populations in the more marginal bushland habitats will not have sufficient immigration to remain viable. Thus, neither the bushland nor the urbanising koala populations appear viable in the long term (Thompson, 2006; de Villiers, 2015).

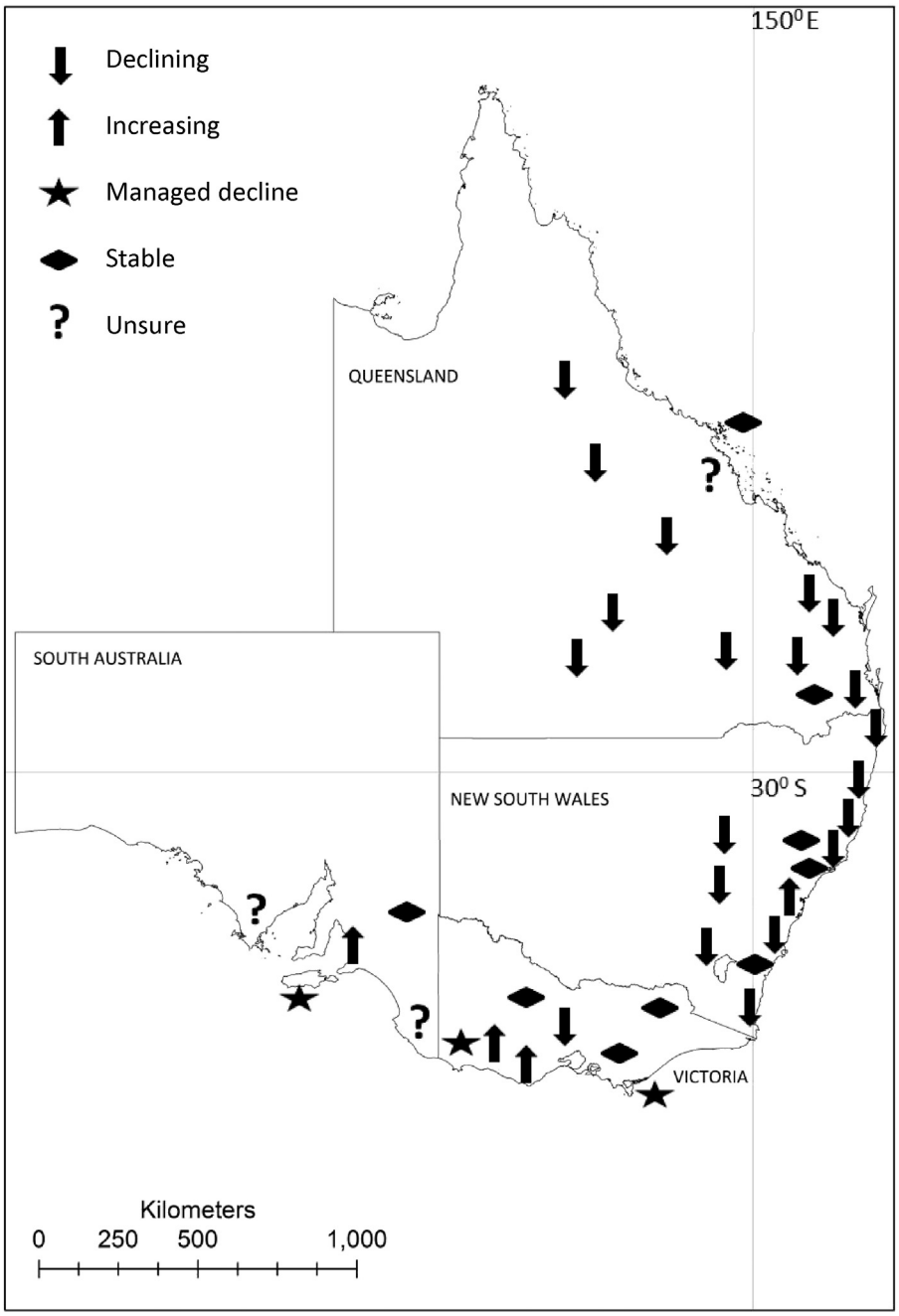

Fig. 1. Koala regional population synthesis map, based on the Australian Centre for Ecological Analysis & Synthesis expert workshop information.

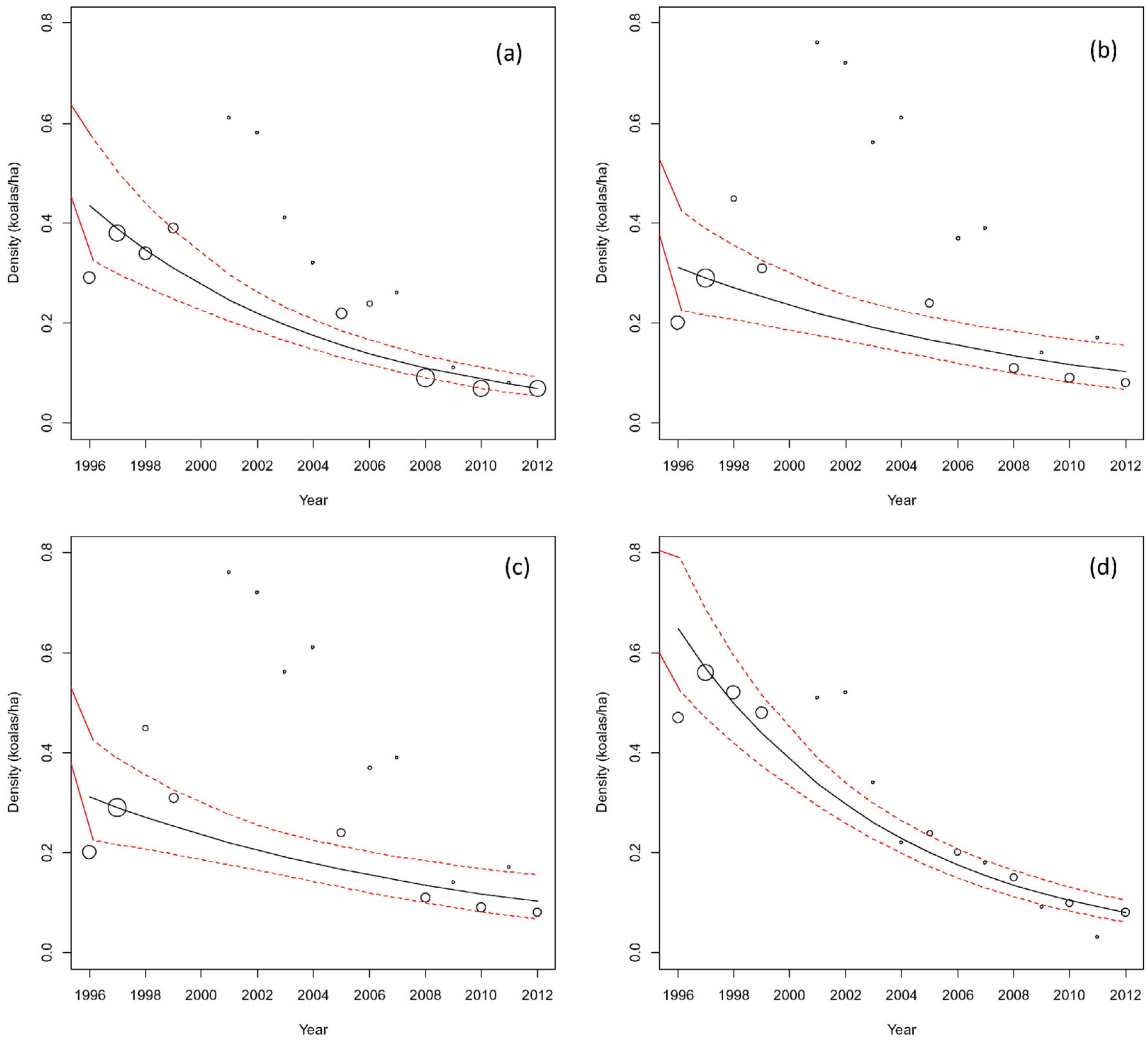

Fig. 2. Weighted regressions of log transformed koala density showing significant declines for (a) all Koala Coast populations Southeastern Queensland; (b) bushland populations; (c) remnant bushland populations; and (d) and urban footprint populations. Survey points are scaled in size to indicate those survey years that were more highly weighted (larger circles) in the regression model. Koala density was estimated for each population category as the number of independent koalas detected per hectare searched. A weighted regression of log transformed koala density was conducted using the total area searched as the weight factor. Red dotted lines indicate 95% confidence intervals. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)
Source: de Villiers (2015).

In south-west and central Queensland there have been substantial declines in populations over the past 10 years, due to land use pressures, extended drought and heatwaves (Fig. 1). These populations are particularly vulnerable to projected changes in climate, including drought and heatwaves (Seabrook et al., 2011; Adams-Hosking et al., 2012). Recent surveys estimate an 80% decline in koala numbers across the Mulgalands bioregion, from a mean of 59,000 (range 44,900 to 69,500, 95% confidence intervals) in 1995 (Sullivan et al., 2004) to 11,600 (range 9843 to 13,430, 95% confidence intervals) in 2009 (Seabrook et al., 2011). In Springsure, central Queensland, a resurvey in 2009 found that, since 1995, koalas were absent at two of four sites, and densities were significantly decreased in the other two (Ellis et al., 2010). Other evidence (e.g. Gordon et al., 2006) shows a contraction in the northern and western margins of the koala's Queensland distribution.

3.1.2. NSW and the Australian Capital Territory

Coastal koala populations in NSW are declining in both numbers and distribution (Appendix A; Fig. 1), from habitat loss and high rates of mortality associated with dogs, vehicles, fire and *Chlamydia* (Lunney et al., 2002, 2007). Some coastal populations are at critically low levels, such as at Eden, where habitat loss and climate change have been major drivers of decline (Lunney et al., 2014), or declined to extinction at Iluka on the north coast (Lunney et al., 2002) with anecdotal reports that new animals have been seen recently. A peri-urban population in south-western Sydney, and another in the Southern Highlands, appear to be small but relatively stable, or to have increased in size in recent decades, however, they remain exposed to proposals for increased urban and motorway development (Lunney et al., 2010). Unpublished data indicates that the Lismore population of north-east NSW appears to be benefiting from the planting of eucalypt trees as windbreaks on the region's orchards (S.P., pers. obs.), and a long-term data set from Coffs Harbour, also on the north coast, showed the population change was best characterised as stable to slowly declining (Lunney et al., in press), while hinterland populations on the New England Tablelands are relatively stable, with some indications of a local increase (Lunney et al., 2009). In the Australian Capital Territory (ACT), a small koala population is present through the Tidbinbilla and Brindabella Ranges (Australian Government, 2013).

A recent dynamic occupancy modelling study of the occurrence of koalas in NSW using historical state-wide koala survey data showed that the probability of occurrence has declined steadily over the last 25 years (Santika et al., 2014). It found that areas with high

anthropogenic pressure were at greatest risk of koala extinction, while semi-arid inland populations also had a high risk of extinction. Declines in inland populations are supported by observational evidence. Kavanagh and Barrott (2001) estimated the Pilliga Forest (the largest area of native forest in inland NSW) supported more than 15,000 koalas at the end of the 1990s, a decade of above-average mean annual rainfall, but a current study shows a substantial decline in koala numbers since then (D.L., R.K., S.P., unpublished data). The observed substantial decline appears due to an extended drought (2001-2009) combined with extended periods of above-average temperatures.

The rich agricultural lands of the Liverpool Plains, central west NSW, support the largest koala population in NSW (Crowther et al., 2009; Lunney et al., 2009). The population neighbouring the Gunnedah township has been increasing since the 1980s, but declined in 2009 due to drought and a severe heatwave, with the remaining population showing a higher prevalence of *Chlamydia* due to sustained stress of drought and heatwaves (Lunney et al., 2012a). Proposed mining for coal seam gas or coal in the Pilliga and Liverpool Plains has the potential for adverse impacts on the koala population.

3.1.3. Victoria and South Australia

Most koala populations in Victoria and South Australia are considered stable, although there has been little formal population monitoring, except for populations that are being actively managed for decline (Fig. 1). During the late 19th and early 20th centuries, koala populations in southern Australia declined precipitously due to hunting for fur, until only a few remnants existed (Menkhorst, 2008). Since 1923, surplus animals from populations that had been deliberately established on islands (conservation marooning) have been used to re-introduce the koala to mainland habitat that had been left vacant by declines, with more than 30,000 koalas released at over 300 sites (Martin and Handasyde, 1999; Menkhorst, 2008, unpublished data). This succeeded in re-establishing populations through most of the historical southern range (Martin and Handasyde, 1999; Menkhorst, 2008), as well as other areas, such as Kangaroo Island and the Eyre Peninsula in South Australia, that are outside the historical range (Masters et al., 2004). Due to genetic bottlenecks associated with the original marooning programme and subsequent translocation, these re-introduced populations have lower genetic diversity than is desirable (Sherwin et al., 2000).

Phillips (2000) detailed a protracted decline over 25 years in the Mount Macedon area of Central Victoria. The exact reasons for the decline are hard to determine, but are likely to be associated with increased peri-urban development and the resultant loss of habitat, increased vehicular traffic and increased dog populations. In some areas (e.g., Mt. Eccles National Park, Cape Otway and Kangaroo Island), over-abundance of koalas has led to severe over-browsing of preferred tree species and widespread tree death (Martin and Handasyde, 1999; Menkhorst, 2008). Some over-abundant populations are subject to managed declines, via sterilisation and/or translocation, aimed at protecting vegetation values and preventing starvation of koalas (Menkhorst, 2008). The population in the Strzelecki Ranges area of South Gippsland is a remnant largely unaffected by the re-introduction programme, and has higher genetic diversity (Lee et al., 2012), requiring different management (DSE, 2004). Koalas have colonised commercial plantations of Tasmanian blue gum (*Eucalyptus globulus*) in south-west Victoria, where they can occur in moderate to high densities, presenting a challenging animal welfare issue during clearfell operations. As there are about 130,000 ha of blue gum plantation within the range of the koala in south-west Victoria the number of koalas using this habitat is considerable, probably greater than 150,000 (Menkhorst, unpublished data). In South Australia, populations in the Adelaide Hills and Mount Lofty Ranges are increasing in density, while the Kangaroo Island population is subject to managed decline (Sequeira et al., 2014) (Fig. 1).

3.2. Conservation outlook

3.2.1. Queensland, New South Wales and the ACT

The outlook for Queensland, NSW and ACT koala populations is a continuing overall decline in numbers (Fig. 2). This is likely to be most pronounced in urbanising coastal regions where koala habitat continues to be destroyed and mortality from domestic dog attacks, vehicle strikes and *Chlamydia* remains high. *Chlamydia* is likely to continue to drive population declines in these regions through reduced fecundity and increased mortality. The threats associated with urbanisation around the coastal cities are likely to become more widespread as regional cities expand, driven by mining and gas developments. The conservation outlook for western koalas is for continued declines due to the extinction debt associated with habitat loss (Tilman et al., 1994) combined with new major mining infrastructure and changes in climate, especially increased frequency and severity of droughts and heatwaves (Seabrook et al., 2014; Tucker and Clifton, 2013), and declining nutritional quality of *Eucalyptus* leaves caused by increased atmospheric CO_2 (Johnson et al., 2009).

Clearing native vegetation for agriculture and resource developments remains a major threat to koalas in both States. In Queensland, the rate of broad-scale clearing of remnant native vegetation has slowed since the introduction of legislation in 2006. Subsequent legislation in 2009 reduced the rate of clearing of high-value regrowth, which represents an opportunity to compensate for losses of remnant vegetation. However, an amendment in May 2013 allowed the clearing of remnant vegetation on high-value agricultural land and removed the protection to high-value regrowth vegetation; including riparian regrowth (Queensland Government, 2013).This relaxation in legislation will result in further loss of critical koala habitat. In NSW, the *Native Vegetation Act 2003* ended broad-scale clearing in 2005, resulting in a 20% decline in clearing of remnant vegetation (Taylor and Dickman, 2014). The NSW government recently announced plans to reform codes governing the management of native vegetation, and legislation relating to vegetation clearance and threatened species is being reviewed in 2015. Revegetation offers opportunities for the recovery of koala populations in these landscapes (Kavanagh and Stanton, 2012; Rhind et al., 2014). However, without protection of remnant vegetation, the conservation benefits will be outweighed by habitat loss.

The rapid expansion of open-cut coal and coal seam gas developments in Queensland and NSW (Fig. 3) presents an added threat to the long-term viability of western koalas (Melzer et al., 2013a; Tucker and Clifton, 2013). In western regions, koalas now occur mainly in riparian vegetation and in eucalypt woodland fragments in highly modified grazing landscapes. These habitats are unlikely to be sufficient to ensure the long-term viability of koala populations (Seabrook et al., 2011), especially if, as predicted, hotter temperatures and more variable rainfall conditions take hold (CSIRO, 2007).

In NSW, the koala's status as a threatened species under State legislation has forced developers, councils and regulatory authorities to focus on potential local impacts and to implement mitigation measures, such as those outlined in the NSW 2008 Koala Recovery Plan (DECC, 2008). While it can be argued that over the last three decades the rate of decline has been slowed by the public, scientific and policy focus on the future of the koala, it is now clear that even more effort is needed to reverse the decline. In the ACT, the small koala population will continue to be vulnerable to wildfire, heatwaves and drought.

3.2.2. Victoria and South Australia

The outlook for mainland populations in South Australia and Victoria is for overall stability but with increases in the Adelaide Hills and Mt. Lofty Ranges, the Otway Ranges and Mt. Eccles region (Fig. 1). This is counteracted by increasing vulnerability due to genetic bottlenecks, land use pressures and the impacts of a warmer and drier climate, including increased frequency and intensity of droughts and wildfires. Like their northern counterparts, southern koalas will also face

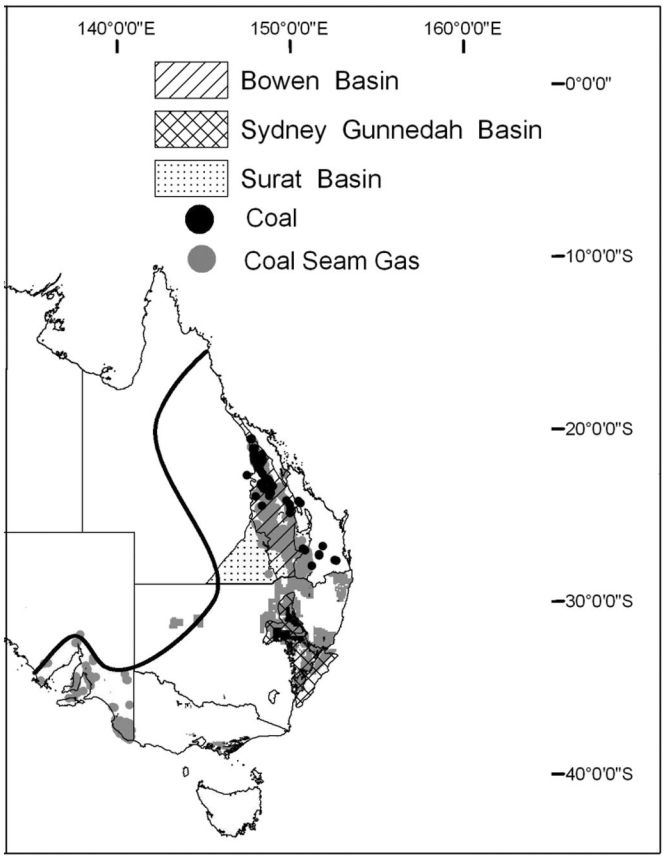

Fig. 3. Current coal and coal seam gas mining activities and exploration zones in the koala's geographic range (defined by black line).

unavoidable pressure from negative impacts on the nutritional quality of *Eucalyptus* leaves caused by increased atmospheric CO_2 (Johnson et al., 2009). Localised instances of over-browsing caused by high koala population densities in coastal habitats dominated by Manna Gum (*Eucalyptus viminalis*) will continue to require active management.

4. Policy challenges

4.1. Overview

The above review of evidence demonstrates that regional koala population trends, and the nature of the threatening processes, vary both from region to region and through time. This makes koala conservation and management particularly complex.

The koala presents the problem of managing a species that now primarily occurs in human-modified landscapes, some of which are rapidly urbanising or subject to large-scale agricultural and industrial developments. Koalas have a patchy, usually low density, but widespread distribution across eastern Australia's remnant forests and woodlands. Low density koala populations occur throughout its range, and they contribute to the long-term survival, but present their own management issues. The existing set of protected areas, for historical reasons mostly situated on infertile soils and escarpments rather than fertile, well-watered lands, cannot provide insurance for the long-term recovery of koala populations in human-modified landscapes. Expanding the protected area network is not enough to conserve the koala population; the koala has to co-exist with human development if it is to survive as a species. Ultimately, this reflects the underlying global problem of an expanding human population incrementally degrading native ecosystems and increasing human-associated threats.

We cannot be certain that these recent population trends will be indicative over the longer term - the koala has proven to be more resilient to change than some Australian mammals (Woinarski et al., 2014). What we are confronting is how to manage koalas in perpetuity, not for a decade or two. Below, we discuss the key challenges for conserving koala populations in the 21st century and the opportunities for recovery where populations are declining.

4.2. Challenge 1: bridging the implementation gap

Koala conservation currently suffers from a lack of effective policy, and planning that has yet to match the recent advances in our understanding of the conservation biology of the species. Notwithstanding the Commonwealth listing decision of 2012, many of the koala conservation policy problems raised by Clark et al. (2000), including lack of a systematic approach to koala conservation, remain 15 years later. While the Commonwealth, State and local governments are each responsible for aspects of koala conservation, the Australian Koala Foundation (a national non-government organisation) has pursued Commonwealth legislative change around koala conservation and undertaken independent characterisation and mapping of koala habitat (Callaghan et al., 2011). The National Koala Conservation and Management Strategy 2009–2014 (Commonwealth of Australia, 2009) provided a policy framework, which aimed to 'conserve koalas by retaining viable populations in the wild throughout their natural range.' The Strategy set out a number of desired short-term (0–10 years) and long-term (0–50 years) outcomes, and major products and tools to be delivered, and took into account regional differences in the dynamics of northern and southern koala populations. A review of the Strategy concluded it was a valuable aspirational document that had been successful in building a national framework to support koala conservation and management (McAlpine et al., 2015). The 2009–2014 Strategy, like its predecessor (Predavec, 2008), lacked a process of implementation and was not funded, hence it had limited effectiveness in delivering real on-ground conservation outcomes for koalas (McAlpine et al., 2015).

The 2009–2014 Strategy was identified in the recommendations by the Senate (2011) koala inquiry as the current guide for undertaking actions. In the event of a national recovery plan replacing the Strategy, the resources required for implementation will be considerable, including consistent funding for research and for converting research into policy and management, and the provision of consistent and sustained policy and planning implementation that both draws on research and identifies emerging threats. Climate change is an example of an emerging threat that was not been adequately identified in previous policy documents.

Here, we are making a case for research to identify and interpret change, examine the drivers of change and their interactions, and to effectively monitor changes including the impacts of development and of restoration strategies. Some large Commonwealth grants for biodiversity actions have included koalas as presumably benefiting from the actions, but they do not go to the heart of the matter as set out in the Strategy, nor do they necessarily advance the cause of koala conservation. We argue that an increase in funding for research, in conjunction with on-ground restoration works, is a more cost-effective way to develop systematic approaches to landscape restoration and the recovery of multiple species, including the koala. Systematic restoration of landscapes takes many decades to achieve the desired goals (Wilson et al., 2011), and is critical for balancing the many human demands for land with the need to restore and protect koala populations and other biodiversity components. Consequently, investing in research pays dividends about how best to plan the restoration of landscapes for koalas (and for other species). This would ensure that the restoration funds are used optimally. Similarly, auditing the process, in terms of governance as well as monitoring the ecological outcomes, is essential. In Australia, the possible effects of stochastic events such as droughts and wildfire

need to be taken into account and are key ecological considerations that need to run concurrently with any restoration programmes.

Despite some successes in areas of koala conservation, the Senate Inquiry revealed that there is a growing awareness of our inability to comprehensively tackle major issues such as habitat loss, disease and roadkill across the species' range. While the Commonwealth listing of 2012 was widely accepted, several political and industry leaders labelled this decision as more 'green tape' (http://statements.qld.gov.au/Statement/Id/79106) that would hinder economic development. This response is symptomatic of divergent community and political opinions on koala conservation, and more broadly, according to Kirkpatrick (2011) and Lunney (2013), the wider treatment of biodiversity in Australia. This is part of a tendency by elements of industry and some governments to repeatedly prioritise economic development ahead of conservation.

It remains to be seen whether the 2012 Commonwealth listing of koalas as vulnerable in Queensland, NSW and the ACT will have any impact on current levels of funding for koala conservation and recovery, or the assessment of issues when koalas are in conflict with major developments. The EPBC Act approvals process occurs on a development-by-development basis, and does not account well for cumulative impacts of loss of habitat and landscape connectivity, or associated threats of dogs, cars and disease, at the regional landscape scale. A strategic regional assessment approach is required that evaluates the potential cumulative impacts of multiple projects across all land uses. The Australian Minister for the Environment can approve strategic assessments under the EPBC Act and the development of bioregional plans for the ecologically sustainable management of biodiversity, heritage and other values. The new EPBC Environmental Offsets Policy (Australian Government Department of Environment, 2013) aims to deliver an overall conservation outcome that improves or maintains the viability of the protected fauna, flora or ecosystem as compared to what is likely to have occurred under the status quo, that is, if neither the action nor the offset had taken place. However, biodiversity offsets place substantial faith in the ability of restoration to recover lost biodiversity (Maron et al., 2012). It therefore remains to be seen whether the policy will have significant benefit for koala conservation.

4.2.1. Ways forward

Bridging the implementation gap is a common problem in conservation and requires addressing sources of division between the scientific community and decision makers (Wiens, 2007; Knight et al., 2008; Gibbons et al., 2008). Researchers and decision-makers operate under different demands, constraints and reward systems (Gibbons et al., 2008). A necessary starting point in bridging the gap is that every researcher and policy-maker should understand the motivations and reward systems of the other when seeking engagement (Gibbons et al., 2008). There is an imperative for the scientific community to conduct research of societal relevance, while decision makers need to realise the benefits of science for decision making (Knight et al., 2008).

Bridging the implementation gap in koala conservation requires fostering close relationships between researchers and practitioners. In recent years, the koala research community has been involved in a series of workshops providing input into the drafting of the National Koala Conservation and Management Strategy (2009–2014), and the EPBC Act Koala Referral Guidelines. Koala researchers also collaborate with state and local governments. The problem is that the science input is often "token", and is not translated into effective policies and management actions for arresting the decline of northern koala populations. The proposed national koala recovery plan provides an opportunity to close the gap between the koala research community and the decision makers. Koala researchers need to directly contribute, along with other stakeholder representatives, to the formulation of the recovery actions and the design and implementation of the final plan. By engaging in all stages of the planning process, koala researchers can continue to interact with decision makers, natural resource managers and the public, thereby helping to ensure the effectiveness of the recovery actions. The longer the research community can stay involved in the plan during and after its implementation, the more likely it is that the plan will deliver both ecologically-effective and cost-effective conservation and restoration outcomes for the koala.

Habitat conservation alone will not resolve the issues of koala conservation. Where populations are declining there needs to be concerted effort to reduce the incidence of dog attack and road-related mortality, and to relate disease prevalence and severity to landscape change, and not just treat individuals for the disease. These policies must also take into account the predicted impacts of climate change. The restoration of eucalypt ecosystems can be effective in restoring elements of koala habitat within a relatively short time-frame of 10 years (Kavanagh and Stanton, 2012; Lunney et al., 2012b). However, in places such as Queensland's Koala Coast, restoring even 100% of non-forested land to koala habitat would not stop further population declines (Rhodes et al., 2011). In order to stabilise the Koala Coast population, a 39% reduction in the total mortality resulting from key threats would also be required, and disease mortality on its own would need to be reduced by 59% to prevent further declines.

The development and implementation of the koala recovery plan will be a test of willingness of all levels of government to fund and implement difficult decisions about conserving biodiversity in human-modified landscapes. These choices are as much a political and social challenge as they are a scientific challenge (Stratford et al., 2000). Ultimately, solutions will require reforming institutional arrangements for koala conservation and management at all levels of government. It will also require strengthening community involvement in koala conservation and recovery programmes such as habitat restoration and accepting planning constraints to mitigate local threats to koalas.

4.3. Challenge 2: adapting to climate change

Recent research (e.g. Crowther et al., 2014; Santika et al., 2014; Seabrook et al., 2014) has established that there are multiple interacting factors that will determine koalas' vulnerability to climate change. There is increasing evidence that koalas and some koala food trees will experience significant range contractions as climate change progresses (Adams-Hosking et al., 2011a, 2012; Seabrook et al., 2011, 2014; Lunney et al., 2014). Climate change is expected to act synergistically with existing threats to produce novel 'threat syndromes' (e.g. Adams-Hosking et al., 2015). For example, drought frequency is projected to increase over most of Australia, and substantial increases in fire weather risk and catastrophic wildfire are predicted in south-eastern Australia (CSIRO, 2007): these factors are likely to result in rapid changes in forest structure and plant composition, as well as increased koala mortality. Some early signs of this are apparent at Springsure, Queensland, where tree species with particular traits (e.g. low drought resilience) are being lost from the ecosystem (Melzer et al., 2013c).

The developing science of conservation planning could be used to prioritise networks of habitat that would remain suitable under the range of climate change scenarios (Moilanen et al., 2009). The extensive ecological research on the koala makes it an ideal study species to test, develop and refine tools and strategies. For example, Adams-Hosking et al. (2015) provide an ecologically-based conservation planning scenario that accounts for parallel shifts in the distribution of tree species and the range contraction of koalas. Similarly, Lunney et al. (2014) demonstrated the long-term contraction of the koala population in southeast NSW can be partly attributed to climate change, and not simply the growth in the human population and high-intensity logging. Hence, regional koala conservation and recovery strategies will need to consider both climate change and land use management. Santika et al. (2015) evaluated modelling approaches on how to allocate $millions in long-term funding in koala conservation in NSW and found that a dynamic occupancy model produced a different allocation than a static

species distribution model, and that as the funding increased, the relative importance of the various recovery actions changed. Koala conservation under the parallel pressures of landscape and climate change must carefully consider priority actions and locations relative to the conservation resources available and recognise the importance of shifting the regional emphasis from one action to another to equalise the value of each recovery action.

Increased concentration of CO_2 in the atmosphere will lower the nutritional quality of eucalypt food resources (Lawler et al., 1997; Moore and Foley, 2005; Hovenden and Williams, 2010; Lunney et al., 2012a). This was one of the factors determining the IUCN's (Johnson et al., 2009) listing of the koala as highly vulnerable to climate change. At any location, koalas depend upon a small number of food tree species, each with different foliar chemistry and nutritional value (Moore and Foley, 2005). The quality of koala habitat and food is closely linked to the distribution of the more nutrient-rich foliage of particular eucalypt species, often occurring on the more fertile soils (Crowther et al., 2009). In addition, a range of non-food species will determine the suitability of habitat by providing microclimatic refuges during heatwaves (Matthews et al., 2007; Ellis et al., 2010; Crowther et al., 2014). Refugia, especially those that provided refuge during previous droughts, are particularly important to maintain koala populations in perpetuity (Adams-Hosking et al., 2011b).

4.3.1. Ways forward

Given these predictions and the time it takes to design and enact effective responses, the systematic implementation of adaptation strategies, such as those identified in the National Koala Conservation and Management Strategy 2009–2014, is urgent. Local efforts to manage the detrimental effects of climate change on koalas are essential, in addition to global measures to address this issue. Conservation planning tools can assist in identifying refugia habitat and networks of suitable habitat that can be prioritised for conservation efforts. Refugial habitat (Keppel et al., 2012) such as permanent water holes in inland rivers (Gordon et al., 1988) offer the best chances for survival under climate change, making their identification important for the conservation of western koala populations. All levels of government need to be willing to devise, implement and promote a range of proactive mechanisms, such as strong land clearing regulations, community engagement through communication and education, appropriate fire management strategies, and financial incentives to landholders to protect, restore and connect koala habitat. We cannot stress too strongly the need to effectively monitor the governance, implementation and conservation value of these programmes, in an adaptive management framework. It is important for conservation managers and decision makers to avoid seeking quick-fix solutions to small parts of the problem, and instead seek integrated approaches that encourage knowledge exchange and innovative solutions. This requires multi-objective conservation plans with objectives set within a medium to long time horizon, normally 15–20 years, with endpoints sufficiently ambitious so as to inspire realistic solutions to koala conservation across all land tenures. Central to this aim is the conservation of remaining habitat because it is so difficult and expensive to restore.

4.4. Challenge 3: conserving koalas in human-populated areas

Human population growth, especially urban growth, represents a major challenge to koala populations. This growth is concentrated along the eastern seaboard, which is a stronghold of the koala, and is particularly concerning in NSW and Queensland. The highest human population scenario for Australia is rapid growth, reaching 36 million (from 23 million in 2014) by 2050 (Kirkpatrick, 2011). Historically, large cities such as Brisbane, Sydney and Melbourne have been the centres for population growth. However, coastal towns and cities are also rapidly expanding, producing low-density, peri-urban development that is intruding into surrounding freehold forested and agricultural landscapes. Here, the complex interactions of multiple threatening processes, combined with high land values, make the effective conservation of koalas increasingly difficult.

Koalas are sensitive to forest loss and fragmentation (McAlpine et al., 2006; Rhodes et al., 2006, 2008). The protection of koala habitat from urban development underpins the conservation of koalas in urbanising regions (Lunney et al., 2010). Other threats including dog attacks, roadkill and increased prevalence of disease need to be recognised in assessing development proposals under the EPBC Act and state legislation, and crucially, recovery actions need to systematically address these threats at the scale of local governments and regions (Rhodes et al., 2011).

4.4.1. Ways forward

Under planning legislation in NSW, koala habitat protection at the local government level is required. Four local governments have implemented shire-wide, comprehensive koala plans of management based on habitat maps, and more are preparing such plans, under State Environmental Planning Policy (SEPP) 44 (Koala habitat protection). SEPP 44 is a land-use planning instrument which focuses on koala habitat and while it is an excellent start, such planning instruments are not enough on their own. Management plans to conserve koalas should consider combinations of threat mitigation measures if they are to be successful in reversing the current decline (Rhodes et al., 2011). Thus, a Comprehensive Koala Plan of Management under SEPP 44 for a Local Government Area should be part of a more inclusive wildlife management plan. This also applies in south-east Queensland, where there have been no detailed planning requirements, although several local governments are working towards koala conservation plans. Sound ecological science is an essential input into the planning process (Rhodes et al., 2008). Both ecologists and urban and regional planners will benefit from cooperative programmes to identify the drivers of koala population dynamics, to understand how these differ among populations, and to design control or habitat restoration programmes. Local community knowledge and values can provide the impetus that will make conservation plans successful. Koalas often compete for the same spaces as humans, necessitating compromises on development if conservation actions are to succeed. This requires recognising that the ecological system, while vital for koala conservation, is one part of a larger system that includes social, economic and institutional components, and that solutions require the active participation of all stakeholders in decision making and implementation.

This raises the issue of effective monitoring of koalas in human-occupied areas, where not only must the koala population be monitored, but the value of any conservation effort needs to be evaluated and reported. Currently, in parts of Queensland and NSW, the major monitoring effort is from the records of koalas being rehabilitated after trauma, or those that are relocated from unsafe locations. These data sets can contribute to a monitoring programme, but were not designed to monitor the success or otherwise of a local plan. We note that neither SEPP 44 in NSW, the NSW 2008 Koala Recovery Plan (DECC, 2008), nor the Commonwealth 2009–14 National Koala Conservation and Management Strategy, require robust and effective monitoring programmes. The next generation of plans needs them to be in place. However, monitoring needs trigger points for intervention, and some notion of what that intervention should be. Todd et al. (2008) provide a useful model for monitoring koala population fluctuations and habitat condition.

There is much in the grey literature, including internal reports, which would be valuable for assessing the efficacy of past programmes. These should be accessible to the public and included in the statutory publications, such as Environmental Impact Statements, that are a requirement for consideration of development applications where the developments have the potential to reduce, modify or bisect koala habitat, create impediments to movement, or use off-sets as a trade for clearing koala habitat.

4.5. Challenge 4: managing the threats associated with rapidly expanding resource industries

Across much of eastern Australia, rapidly expanding coal and coal seam gas developments represent new and multifaceted threats to koalas. Koalas and their habitat are lost wherever they occur within the footprint of any resource development or ancillary activity. The intensified traffic on road and rail corridors, combined with changes to the timing of peak traffic loads to suit a mobile workforce, increases the likelihood of koala deaths from vehicle and train strike (Tucker and Clifton, 2013). Thousands of kilometres of infrastructure corridors containing road, rail, pipeline and conveyors connect these resource developments, expanding dormitory and administrative centres, and bulk port loading facilities which are required at their node. This is of increasing importance as coal and coal seam gas mining expand.

The cumulative impacts arising from the fragmentation of koala populations are less obvious. The extensive footprint of the resource projects, together with the network of infrastructure corridors and the expansion of associated urban and peri-urban development, is imposed on a landscape that typically has already been extensively cleared for agriculture (e.g. Melzer et al., 2013b). The outcome is very likely to be the loss of significant numbers of koalas from otherwise stable populations through the fragmentation of populations, and the loss of populations in areas where roadkill is severe or where direct clearing reduces the carrying capacity of the local ecosystem.

There is a need to plan for population recovery over the life of a mine (about 30 years). Koala habitat restoration may be possible (Woodward et al., 2008; Fitzgibbon et al., 2012, 2013; Lunney et al., 2012b; Baker, 2013; Melzer et al., 2013c), but the long-term persistence of post-mining reconstructed habitat has yet to be demonstrated. The likelihood of widespread, post-mining restoration is at best uncertain, because mines may close down for pragmatic economic reasons. Already there are 50,000 abandoned mine sites in Australia.[1]

4.5.1. Ways forward

The priority must be to look at where the footprint of mining will fall, not just at the mine site, and to ensure that the conditions of mining take account of the impact, with a fully-funded programme of mitigation and rehabilitation as part of the life-of-mine economic evaluation of each project.

The pressure on koala habitat from mining will continue due to ongoing demand for natural resources and consequent intensification of infrastructure networks. The efficacy of the current project-by-project approach to environmental impact assessment, ecological management, mitigation, offsets and restoration is uncertain (Maron et al., 2012). A considerable level of effort and expertise is required for the recovery of koala populations; hence more certainty for conservation investment can be achieved through a systematic regional planning approach. Such approaches allow multiple threats and land uses to be considered spatially and strategically. Opportunities for secure koala conservation investment may be identified where future resource and infrastructure conflicts do not exist, while more complex and less certain restoration and mitigation options are pursued within resource- and infrastructure-intense regions (Melzer et al., 2013b).

5. Conclusions

The koala as an iconic fauna species has drawn public attention to many generic issues of conserving Australia's biodiversity. Irrespective of its iconic status, conserving the koala is a major challenge for Australian society and governments. Our aim was to synthesise the regional trends, challenges and predictions for conserving koalas across the species' range. Many of the complex conservation and policy challenges identified here have broader significance to other species whose population trends, and the nature of the threatening processes, vary from region to region, and through time. Below we point to three priority issues that need to be considered in the future efforts to conserve and sustainably manage koala populations across their range.

The first is to recognise that koala populations are responding differently across their range and that one programme will not fit all locations. National programmes for conserving and managing koalas will only be effective if a regional approach is adopted for the implementation of the National Koala Conservation and Management Strategy 2009–2014, its successor, and any other strategy or planning mechanisms. Any such strategies or plans need to be ecological and effective, and while the Senate (2011) enquiry into the status of the koala made 19 recommendations, not all were ecologically sound or defensible as being effective (Shumway et al., 2015).

The second is to recognise that new threats are looming, such as climate change and mining, whereas the long-standing threats remain undiminished. In that context, policy makers, land use planners and conservation managers must consider all threats and their interactions, and not just focus on one or two. Even though habitat loss remains the dominant threatening process, other factors (dogs, cars, fire, disease, climate change and mining) rise in importance as the area of habitat diminishes and what is left continues to be destroyed, degraded and fragmented. With respect to habitat loss, we note with optimism that some restoration efforts have been successful, but to date these have been only for small areas and are indicative of potential that has yet to be realised.

The third point is that diverse research programmes are essential for any sustained conservation and management programme. The conservation of the koala across its range will be expensive. Investment in this species will not only conserve the koala, it will advance the conservation for fauna more generally, enhance local amenity and ecosystem services for towns and cities, provide alternative economic benefit (e.g., koala eco-tourism) and generate local pride in conserving a national icon. Interacting with nature, including the koala, can deliver measurable benefits to people.

However, the reality is that, if the resources and political will are not forthcoming, the koala faces regional extinctions in the northern and western areas of its range, and increased vulnerability in southern parts of its range. Integrated conservation actions, interacting with research programmes, need to be unequivocal, substantial and long-term. There has been progress in the last 15 years but much more needs to be done to recover the koala populations of Queensland, ACT and NSW, and sustainably manage the koala populations of Victoria and South Australia.

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