Conserving Koalas in the 21st Century: Regional trends, challenges and prognoses

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An increasing proportion of the world's biodiversity is in decline, with mammals amongst the most vulnerable taxa. The koala (*Phascolarctos cinereus*), an arboreal marsupial and one of the world's most iconic faunal species, was recently listed in Australia as vulnerable in the states of Queensland and New South Wales and in the Australian Capital Territory. Here, we synthesise empirical evidence of regional trends in the distribution and size of koala populations across their entire geographic range and provide a conservation outlook for these populations over the next 20 years. Population declines are common in the northern half of

the koala's range, where habitat loss, climatic extremes, dog attacks and vehicle collisions are the major threats. In contrast, some southern local populations are locally overabundant and are now subject to managed declines. Four issues need to be considered: i) broad programs for conserving and managing koalas will only be effective if a regional conservation planning and management approach is adopted; ii) new threats are looming, such as climate change and large-scale mining, whereas the long-standing threats remain undiminished; iii) habitat restoration can be successful, but these to date have been for small areas only; and iv) conservation of the koala across its range will be expensive, but will improve the conservation outlook for fauna more generally, and enhance local amenity and ecosystem services. If the resources and political will are not forthcoming, the koala potentially faces regional extinction in the northern areas of its range, and increased vulnerability in the southern parts of its range.

1. Introduction

Humans now dominate the earth's ecosystems (Vitousek et al., 1997, Steffen et al., 2007, Rockström et al., 2009), resulting in an increasing proportion of the world's biodiversity being listed as threatened (Pimm et al., 2006; IUCN Red List, 2012). Habitat loss remains the main driver of species declines and extinctions, but it acts synergistically with other drivers, such as biological invasions, over-harvesting, disease, pollution and now climate change (Brooke et al., 2008; Mantkya-Pringle et al., 2012). Large species, rare species, and habitat specialists are particularly prone to extinction (Sodhi et al., 2008). Mammals are among the most vulnerable taxa, with nearly one-quarter (22%) of the world's mammal species considered to be globally threatened or extinct, 63% considered not to be threatened, and the remaining 15% have insufficient data to determine their threat status (IUCN Red List 2012). Seventy-six mammal species are considered to have gone extinct since 1500 (Baillie and Butcher 2012), with 22 of these being Australian, mostly arid zone species (McKenzie et al., 2007).

The koala (*Phascolarctos cinereus*), an arboreal marsupial, is one of the world's most iconic faunal species whose habitat consists of forest and woodland associations containing the preferred *Eucalyptus* tree species (Melzer et al., 2000). It has a wide geographic distribution in eastern Australia, spanning the states of Queensland, New South Wales, the Australian Capital Territory, Victoria and South Australia. Melzer et al., (2000), in an assessment of the conservation status of the koala, concluded that it has suffered a >50% decline in distribution and number since European settlement, with New South Wales - where it had been listed as vulnerable since 1992 - showing the greatest decline. In Queensland, the koala has been listed as vulnerable since 2004 in the rapidly urbanising southeast region. Elsewhere in Queensland, its widespread range is contracting in western and northern regions (Gordon et al., 2006), although the exact distribution and population size is not well understood (Melzer et al., 2000). More stable and large koala populations occur in Victoria and South Australia. The koala also is listed as threatened under the U.S. Threatened Species Act (U.S. Fish and Wildlife Service, 2000).

In 2011, the Australian Government's Senate Standing Committee on Environment and Communications conducted an Inquiry into the status, health and sustainability of Australia's koala population (The Senate, 2011). That Inquiry found that the problem of koala conservation is complex, and made 19 recommendations for conserving koalas across their geographic range. The Inquiry identified that there was a lack of integrated knowledge on the abundance of the koala across its range. Whether the koala should be listed as a threatened species nationally was raised as a prominent issue. Following, but otherwise independently of the Inquiry, the Australian Government on 2 May 2012 listed the koala as vulnerable in Queensland, New South Wales and the Australian Capital Territory under the *Environment Protection and Biodiversity Conservation Act 1999*. This listing is a further warning that the species is facing substantial regional declines and extinction, unless the threats to its survival are mitigated.

In this paper, we synthesise empirical evidence of regional trends in the distribution and size of populations of the koala across its entire geographic range and provide a prediction of the

conservation outlook for these populations over the next 20 years. The evidence was assembled at a workshop[1] held in Brisbane in February 2012 with 17 of Australia's experienced koala ecologists. This workshop aimed to review koala population status and trends geographically, with a regional approach that enabled differences and commonalities among regions to be identified.

2. Overview

The workshop recognised that current data on koala population sizes and distribution were patchy (Fig. 1). There was widespread recognition in the workshop that short-term changes in populations are rarely perceptible, for example, there are only a few published accounts of an observed decline in a local population (in Springsure in inland Queensland and Gunnedah in inland NSW, both during heatwaves; see Gordon et al., 1990; Lunney et al., in review), but decade by decade, or longer, the changes have been considerable. Accurate population assessment is complicated by short-term population fluctuations, such as from drought or fires that potentially mask long-term trends, the lack of any systematic long-term monitoring, and no reliable and consistent method of estimating population size and thus changes in population numbers. Estimating changes in distribution has been utilized to assess population change because this approach is repeatable, economical and well-accepted, but it does not allow all the causes of changes to be assessed because demographic data are missing, particularly birth and death rates, movement patterns and health status. Consequently broad trends, such as climate and land clearing have dominated in the interpretations of change.

Overall, populations in Queensland and New South Wales have decreased, while populations in some Victorian and South Australian regions have increased. Reports of population declines are common in the northern half of the range of the koala (e.g. Seabrook et al., 2011; Lunney et al., 2002), while some southern local populations are locally overabundant (Masters et al., 2004; Duka and Masters 2005; Wilks 2008). Several southern koala populations, such as those on Kangaroo Island, are now subject to a managed decline and

have decreased substantially in numbers. Below, we expand on the population trends and drivers of these trends for each state where koalas occur.

2.1 Queensland

Queensland koala populations, considered relatively secure at the end of the 1990s by Melzer et al., (2000), have suffered substantial declines in the last 15 years due to a number of interacting threatening processes. The evidence resulting from the workshop identified that koala populations of coastal and western Queensland are mostly declining (Fig. 1), although some low density mainland populations (e.g. eastern Darling Downs) and island populations (Lee et al., 2013a) appear relatively stable. Prominent in these declines are the urban koala populations of south eastern Queensland, and rural populations of southwest and central Queensland. Populations on the eastern Darling Downs and island populations (Lee et al., 2013a; Melzer et al., 2013a) are relatively stable. Urban and peri-urban koala populations in southeast Queensland have experienced a dramatic decline over the past 15-20 years. Monitoring of the Koala Coast population, east of Brisbane, has indicated a 60% decline in koala numbers from 1996-1999 to 2010 (DERM, 2009). In southwest and central Queensland, there have been substantial declines in population sizes over the past 10 years, due to increasing land use pressures, extended drought conditions and heatwaves. These populations are particularly vulnerable to projected changes in climate, especially extreme weather events during drought (Adams-Hosking et al., 2012, Melzer et al., 2013b). In central and southern inland Queensland, the rapid growth and intensification of coal mining, and more recently, coal seam gas developments and associated infrastructure, pose a significant threat (Fig. 2; Melzer 2013c).

The Mulgalands biogeographic region, in semi-arid south-western Queensland, was identified as supporting large numbers of koalas through the 1990s (Sullivan et al., 2004). This evidence was used by the Threatened Species Scientific Committee in their 2006 recommendation to reject an application to nationally list the koala as a threatened species under the EPBC Act (Threatened Species Scientific Committee 2006). However, recent surveys have identified an estimated 80% decline in koala numbers across the Mulgalands

bioregion, from a mean population of 59,000 (range 44,900 to 69,500) in 1995 (Sullivan et al., 2004) to 11,600 (range 9,843 to 13,430 at 95% confidence interval) in 2009 (Seabrook et al., 2011). The main causes of this decline were drought and vegetation clearance for cattle pastures. The region experienced a severe drought from 2001 to 2009 (referred to as the Millennium drought), with most summers during this period being hotter and drier than average (Australian Government, 2011). There also was a contraction of koala distribution across the region to more riverine woodlands, revealing that koalas had vacated poplar box (*Eucalyptus populnea*) woodlands located away from watercourses during the drought. Between 1995 and 2008, approximately 25% of koala habitat in the eastern Mulgalands was cleared for cattle pastures (Seabrook et al., 2011).

A resurvey of sites in Springsure, central Queensland, in 2009 found that, since 1995, koalas were not found at two out of four sites, and densities were significantly decreased in the other two (Ellis et al., 2010). Property owner accounts of declines in abundance and local range contractions near Tambo and Hughenden (Mitchell Grass Downs bioregion) are consistent with Gordon et al.'s (2006) finding that a contraction in the overall range has occurred on the northern and western margins of the koala's distribution. This trend is consistent with a recent Mulgalands assessment (Seabrook et al., 2011). Declines in the Springsure region followed a series of extreme weather events during extended severe drought, and were associated with a population collapse in riparian open forest (Melzer et al., 2013c).

2.2 Prognosis

The prognosis for Queensland's mainland koala populations is a continuing overall decline in numbers and a range contraction from the west and northwest (Figure 1). The decline is likely to be most pronounced in the southeast region where urbanisation continues to destroy koala habitat and cause high rates of mortality from dog attacks and vehicle strikes. In addition, the disease *Chlamydia* is likely to continue to drive population declines in this region. Should this be expanded at all? E.g. Will the threats associated with urbanisation continue to spread beyond the immediate South East corner…

The prognosis for western and central Queensland koala populations is for continued declines due to the extinction debt associated with habitat loss (Tilman et al., 1994), combined with new major mining resource infrastructure developments and projected changes in climate. Remnant native vegetation on freehold and leasehold tenures now exists in a highly fragmented state across most of Queensland's extensive dryland cropping and grazing lands, with important consequences for the viability of koala populations. The capacity of many of Queensland's eucalypt ecosystems to regrow from lignotubers represents an opportunity to compensate for losses of habitat, and remnant and high-value regrowth vegetation were, until recently, protected under the Queensland native vegetation legislation. However, an amendment to this legislation made in May 2013 allows the clearing of remnant vegetation on high-value agricultural land and the removal of protection to high value-regrowth, including riparian regrowth (Queensland Government 2013a). This relaxation in legislation will result in the further loss of critical koala habitat (e.g. *E. populnea* woodlands and riparian *E. camaldulensis* regrowth or secondary forests).

The rapid expansion of open-cut coal and coal seam gas developments in the Bowen Basin, central Queensland, and more recently in the Surat Basin (see Fig. 2 for location details) presents an added threat to the long-term viability of koala populations in these regions (Melzer 2013b, Tucker and Clifton 2013). From isolated foci of intense mining activity through the 1960s to early 1990s, coal extraction now extends as a series of almost contiguous mines spanning hundreds of kilometres (Fig. 2). The active mine "footprints" cover tens of thousands of hectares and bring off-site impacts associated with service infrastructure, in particular heavily utilised road corridors (Melzer 2013b). Currently, there are several coal projects approved in the Bowen, Surat and Galilee Geological Basins in Queensland, which have significant potential impacts for koalas. Queensland's CSG industry has grown rapidly over the past 15 years (Queensland Government 2013b) with predictions suggesting that up to 40,000 wells may be sunk with the current operational plans, with many of these wells and associated infrastructure located in the Bowen and Surat Basins.

In far western regions outside the coal basins, 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 (Smith et al., 2013a,b; Seabrook et al., 2011), especially if hotter temperatures and more variable rainfall conditions take hold as predicted by climate models (CSIRO, 2007), with the resulting increased risk of drought-related tree death (Fensham et al., 2009).

2.3 New South Wales and the Australian Capital Territory

The workshop concluded that most of the coastal koala populations of northern New South Wales are declining in both numbers and distribution, that loss of habitat has been the major cause of population decline, and that this impact is aggravated by high rates of mortality associated with dogs, cars, fire and *Chlamydia*. With the majority of coastal populations experiencing declines, some populations are at critically low levels, e.g. Eden, where climate change has been a major recent driver (Lunney et al., in review). Iluka, a peninsula at the mouth of the Clarence River that was extensively mined for beach sand in the post-war years, suffered the localised extinction of the local koala population by 1999 (Lunney et al., 2000, 2002): motor vehicle collisions, dogs, wildfire and *Chlamydia* were factors that contributed to the loss. Recently, occasional observations of individual koalas suggest immigration from an adjacent National Park, as it recovers from the severe wildfires of 1989 and 1994. However, other coastal or near-coastal populations (e.g. Lismore-Ballina-Byron on the north coast; Campbelltown, a peri-urban population in western Sydney; and the Southern Highlands) appear to be relatively stable in recent decades. The Lismore-Ballina-Byron population appears to be benefiting from the planting of eucalypt trees as windbreaks on the region's fruit and macadamia nut orchards.

In a NSW State-wide survey in 1986-87, Reed et al., (1990) concluded that the State's koala population had declined by between 50-75% since European settlement. In an historical study, Lunney and Leary (1988) identified the presence of two koala skinning factories at the end of the 19th century in the Bega district NSW, where the koala is now rare. Knott et al., (1998) were able to assess the sharp contraction of the koala population in Port Stephens

Local Government Area (LGA), central coast of NSW, since European settlement and Lunney et al., (2007) predicted a rapid decline from dogs and fire in the remaining population. As part of the preparation of the 2008 Koala Recovery Plan for NSW –where the koala is a threatened species- a State-wide, community-based survey was undertaken (Lunney et al., 2009), with local web-based surveys undertaken in 2009-11 for specific studies, such as in Eden (Lunney et al., in review). These surveys focused mainly on private lands because the surveys went to residents, although information was forthcoming for protected areas, including the Bongil Bongil National Park on the north coast and the Pilliga forests near the western (more arid) edge of the New South Wales range.

In northwest NSW, the Pilliga forest (the largest area of native forest in inland NSW) koala population has declined in the past decade, presumably due to drought and wildfire. This interpretation is based on anecdotal evidence, and it is noted that most of the areas affected by wildfires over the past 60 years are not considered to be high quality habitat for koalas – indeed most of the population is located in the western half of the Pilliga (> 500,000 ha of continuous forest) where there has been no fire for more than 60 years. The Pilliga population (like many others in semi-arid forests and woodlands) has undergone population fluctuations – probably in response to cycles of drought and years of good rainfall. Kavanagh and Barrott (2001) reviewed historical accounts of population fluctuations in the Pilliga and provided an estimate of more than 15,000 koalas by the end of a decade of above-average mean annual rainfall (1990s). There has been no change to the area of the Pilliga forests, but there are reliable clues of a major decline following the recent Millennium drought. The Pilliga forests are currently the subject of a new study to establish whether population recovery is underway and to identify important drought refuges for koalas within this major inland forest.

Coal seam gas developments are proposed for the Pilliga forest, and the potential exists for an adverse impact on the koala population because of habitat loss, the impact of infrastructure and vehicles, as well as an increased risk of fire from the well sites and the high number of industrial workers. The rich agricultural lands of the Liverpool Plains around Gunnedah also lie in NSW. This area may hold the largest currently known koala population in NSW

(Crowther et al., 2009; Lunney et al., 2009): it had been increasing since the 1980s, but declined sharply in 2009 due to drought and a severe heatwave, with the remaining population now showing signs of a high prevalence of *Chlamydia* in the wake of the sustained stress of drought and heatwaves (Lunney et al., 2012a). This population is also facing new pressures from major coal mining as well as coal seam gas developments (Lunney et al., 2012b). Koalas were rare in Gunnedah in the 1970s, with the first local koalas not seen until the late 1970s (D. Lunney unpublished data). Understanding the dynamics of this population will require sustained investigation, and the accounts so far indicate that change is slow. Recovery is slow, but catastrophic losses can occur due to wildfire, drought and heatwaves and they can set back steady recovery, such as from tree planting, or mask gradual losses, such as from dogs and cars. Such studies are also showing where the prime koala habitat was located, often in the fertile areas, near creeks and rivers, and thereby predisposing the local koala populations to inevitable losses.

A recent dynamic occupancy modelling study of these data showed that the probability of occurrence of koalas in New South Wales has declined steadily over the last 25 years (Santika et al., in review). That study found areas with high anthropogenic pressure in New South Wales, i.e. areas with low *Eucalyptus* forest cover, and areas with combination of low *Eucalyptus* forest cover and high housing density, were at greatest risk of koala extinction likelihood. Western areas with high mean annual and maximum summer temperatures also had a high risk of extinction likelihood. In the Australian Capital Territory, koalas are thought to be present through the Tidbinbilla and Brindabella Ranges (Australian Government, 2013).

2.4 Prognosis

The future for NSW koala populations is similar to that of Queensland, with the majority of populations that have been studied continuing to experience declines or large fluctuations in numbers (Fig. 1). Coastal populations are likely to continue to decline due to the pressures of habitat loss, *Chlamydia*, dog attacks and vehicle collisions associated with urban

development. However, several coastal populations including Lismore-Ballina-Byron and Campbelltown were identified as relatively stable over the next 20 years (3 generations). The majority of the western koala populations are likely to slowly decline due to habitat loss, climate change and major resource infrastructure developments. Populations on the New England Tablelands were assessed to have a more stable future, with some indications that there were local increases.

2.5 Victoria and South Australia

The situation in the southern states of Victoria and South Australia differ from that in Queensland and NSW. During the late 19th and early 20th centuries, koala populations in southern Australia declined precipitously due to hunting pressures for the fur trade until only a few remnants existed (Gordon and Hrdina, 2006). Beginning in 1923, surplus animals from populations that had been deliberately established on islands (conservation marooning) have been used to re-introduce the koala to habitat that had been left vacant by these declines (Warneke 1978; Martin and Handasyde 1999; Menkhorst 2008). This re-introduction program continued for 80 years and involved more than 25,000 animals released at more than 250 sites. It has succeeded in re-establishing populations through most of the historical range of the species within the two States (Martin and Handasyde 1999; Menkhorst 2008), and some 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 program and subsequent sub-sampling for translocation, these re-introduced populations have lower genetic diversity than is desirable (Houlden et al., 1996; Sherwin et al., 2000). Although there is no evidence that this has yet resulted in lower genetic fitness, higher rates of testicular malformations have been detected in heavily bottlenecked populations (Seymour et al., 2001; Critescu et al., 2009).

Most populations in Victoria and South Australia are considered stable, although there has been little formal population monitoring except for those populations that are being actively managed for decline, such as Mt Eccles National Park (western Victoria) and Kangaroo Island (South Australia). Some local populations are increasing in numbers and density (e.g.

in the Adelaide Hills and Mount Lofty Ranges). In some areas (e.g. Mt Eccles National Park, Cape Otway and Kangaroo Island) overabundance of koalas leads to severe over-browsing of preferred food tree species and widespread tree death (Martin and Handasyde 1999, DSE 2004, Duka and Masters 2005, Menkhorst 2008). Some over-abundant populations are subject to managed declines, via sterilisation and/or translocation, aimed at protecting vegetation values and preventing koala starvation (DSE 2004, Duka and Masters 2005, Menkhorst 2008; Todd et al., 2008). The population in the Strzelecki Ranges area of South Gippsland, Victoria, is a remnant largely unaffected by the re-introduction program and has higher genetic diversity (Houlden et al., 1996; Lee et al., 2012), and requires a different management approach (DSE 2004).

2.6 Prognosis

The prognosis for mainland populations in South Australia and Victoria is for overall stability but with increases in the Adelaide Hills and Otway Ranges (Fig. 1). Population increases due to commercial tree planting schemes have occurred in southwest Victoria and southeast South Australia. This is counteracted by increasing vulnerability to land use pressures and the impacts of a warmer and drier climate, including increased frequency and intensity of wildfires. Like their northern counterparts, southern koalas will also face unavoidable pressure from the negative impacts on the nutritional quality of *Eucalyptus* leaves caused by increased levels of atmospheric CO_2 (see below). Localised instances of over-browsing caused by unsustainably high koala population densities in coastal habitat dominated by Manna Gum (*E. viminalis*) are expected to continue to require active management.

3. Challenges and Prospects for Recovery

Today, the koala is an Australian icon, although it is less than a century since it was actively hunted for the fur trade (Gordon and Hrdina 2006). To many Australians, koala conservation is both an emotive issue and a national priority. However, where it is declining, its conservation is challenging, as the results of the workshop show. Yet it is not declining in all locations, hence the confusion and the challenge. Over most of the koala's range, koalas are

present as widespread low density populations within which local higher density populations may occur. There are many gaps in occurrence. The pattern appears to be irrespective of the relative nutrient status of the forest. In Queensland, for example, koalas occur in trees growing on the deep sands on Stradbroke Island, but are absent from many forests on alluvium soils. Koala population trends, and the nature of the threatening processes, vary from region to region, and through time.

The koala presents the problem of managing a species that occurs in human-modified landscapes, some of which are now rapidly urbanising. Koalas have a patchy, usually low density, but widespread distribution across eastern Australia's remnant woodland and forest estate, including State Forests or National Parks. There are some striking exceptions, and the interpretation is that, by and large, koalas depend upon the eucalypt forests and woodlands that grow on the nutrient-rich, well watered soils: land that has become farmland and towns. However, there are low density koala populations in many locations throughout the range of the koala, on lands that have not been cleared for farms or over-exploited, and these populations also have their own contribution to the long-term survival, and present their own management issues, such as fire management. A low-density koala population in a large national park not far north of Sydney is one example (Curtin et al., 2002). Expanding the protected-area network is not enough to conserve the koala population; human development has to co-exist with the koala if it is to survive as a species. Ultimately, this reflects the underlying global problem of an expanding human population destroying and degrading native ecosystems. The 225 years since European occupation of eastern Australia is a very short time in the evolution of the koala whose fossil records currently date to the Late Tertiary (38-1.6 million years ago) (e.g. Stirton 1955; Pledge 1992; Black & Archer 1997). But it has been more than enough time to see range contractions, regional population declines and even local extinctions. One argument is that we cannot be entirely sure that this says much – the koala has proven to be more resilient to change than many Australian mammals, where some were extinct within 50 years of European arrival in the more arid regions of the country. What we are confronting here is how to manage into the future, not a decade or two,

but in perpetuity. Below, we discuss the key challenges for conserving koala populations in the 21st century and the opportunities for recovery where they are failing, and management or control where the issues of overpopulation are creating a concern.

3.1 Challenge 1: Bridging the implementation gap.

Koala conservation currently suffers from a lack of effective integration of science, policy and planning (Ellis et al., 2013). Three levels of government (Commonwealth, state and local) are responsible for aspects of koala conservation in Australia. The National Koala Conservation and Management Strategy (2009-2014) (Commonwealth of Australia, 2009) provides an overarching strategy guiding koala conservation across its range. It aims to "conserve koalas by retaining viable populations in the wild throughout their natural range". It replaces the 1998 National Koala Conservation Strategy, which lacked a clear process for implementation (Predavec, 2008). In short, it was not funded. The 2009-2014 strategy sets 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. It takes into account regional differences in the dynamics of northern and southern koala populations, and builds on a considerable amount of koala research, planning and management activity since 1998. The 2009-2014 strategy is likely to become a working draft for a national koala recovery plan, which has been foreshadowed to be developed in 2014. It was also identified in the recommendations by The Senate (2011) enquiry into the koala as the current guide for undertaking actions. However, if a recovery plan is to be successful, the resources required to implement it will need to be considerably more than the amount allocated to date for the 2009-2014 strategy. This shows up a particular problem in funding. Here, we are making a case for research to correctly identify and interpret change, examine the drivers of change and their interaction, and to effectively monitor changes and the impacts of development and of restoration strategies. We are aware that some large Commonwealth grants for biodiversity actions have included koalas as benefitting from the actions, but we point out that 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. It is our view that the continuing Government prevarication of direct support

for research on the basis that the best approach is to direct millions of dollars to community restoration programs, is a failure of governance.

Despite some major successes in areas of koala conservation, The Senate (2011) inquiry revealed that there is a growing appreciation of our inability to comprehensively tackle major issues such as habitat loss and climate change across the species' range. While the Commonwealth listing decision of May 2 2012 was widely accepted, several political and industry leaders labelled this decision as more 'green tape', hindering economic development. This 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 and an increasing willingness of industry and governments to prioritise economic development ahead of biodiversity conservation. Recent examples from Queensland include the wind-back of vegetation protection laws, the recent State approval of mining within nature reserves (e.g. Brimble Box Reserve, central Queensland), allowing cattle grazing in Queensland national parks, and the proposed logging of national parks. Even where the evidence is available for mitigation of threats, there is a reluctance to incorporate this evidence into management programs (e.g. incorporate mitigation works at known road kill hot spots, especially in regional areas).

JUST A SUGGESTION…

In NSW and Queensland, the implications of federal listing of the koala are minor for areas covered by an existing Commonwealth-State Regional Forest Agreement but are substantial for all other areas. Avoidance of a "significant impact" of proposed development on koala populations is now receiving greater attention under the EPBC Act than under existing State legislation (e.g. NSW *Threatened Species Conservation* Act 1995) where the species is currently managed (in conjunction with others) as part of a "landscape approach" rather than for its own specific requirements. Similarly, threat abatement procedures and other mitigation options are likely to include greater emphasis on the designation and management of "habitat offsets" that are known to be currently occupied by the species, rather than just providing habitat which appears to be suitable. The establishment of eucalypt plantations including koala food tree species on existing cleared lands, a practice which has been shown to be effective in restoring habitat for the koala within a relatively short time-frame (Woodward *et al*. 2008, Kavanagh and Stanton 2012), is now likely to receive greater emphasis. However, it should be noted that koala referral guidelines under the EPBC Act have not yet been finalised.

I'm getting a bit rusty on it, but Jonathon Rhodes etc. had some very good work on costing of some recovery/protection actions. It might be useful to acknowledge the reality that some action will be very costly and/or variable in effectiveness. Dan?

3.2 Ways forward

The conservation of the koala will be a test of societal willingness 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 require reforming governance arrangements at all levels, and transforming community values towards biodiversity in general and koala conservation in particular. Koala ecologists, besides their detailed research, have an important role in raising public awareness of the issues and a supportive role in helping to set objectives for koala conservation and ensuring these objectives are achieved in a cost-effective, timely and socially-acceptable manner.

3.3 Challenge 2: Adapting to climate change

There is increasing observation and modelling evidence that the koala will experience significant range contractions as climate change progresses (Adams-Hosking et al., 2011a, Melzer et al., 2013a; Seabrook et al., 2011). Climate change is expected to act synergistically with existing threats to koalas to produce 'threat syndromes'. For example, drought occurrence is projected to increase over most of Australia, and a substantial increase in fire weather risk and wildfire occurrence is predicted as likely at most sites in south-eastern Australia as (CSIRO 2012): these factors could result in rapid changes in forest structure and plant species composition as well as increased koala mortality. Some early signs of this may be apparent at sites such as Springsure where tree species with particular traits (e.g. low stomatal resistance and, consequently, low drought resilience) are being lost from the ecosystem (Melzer et al., 2013d). Increasing changes in the distributions of some koala food trees as well as range contractions have been predicted as climate change progresses (Adams-Hosking et al., 2012). Refugia, especially those that are thought to have provided refuge

during previous climate changes or other environmental challenges, are considered particularly important (Adams-Hosking et al., 2011b; Melzer et al., 2013a; Williams et al., 2012).

The quality of koala habitat and food resources is closely linked to the distribution of the more nutrient-rich foliage of particular eucalypt species (Degabriele 1983). These species often occur on more fertile soils (Moore et al., 2004; Crowther et al., 2009). In addition to a range of non-fodder species that may determine the suitability of habitat by providing microclimatic refuges (Ellis et al., 2002; Matthews et al., 2007), koalas depend upon a relatively small number of food species (predominantly eucalypts) at any location, each with different foliar chemistry and nutritional value (Moore & Foley, 2005; Moore et al., 2010).

Increased concentration of CO_2 in the atmosphere will affect the nutritional quality of the koala's eucalypt food resources (Hovenden & Williams, 2010; Moore & Foley 2005; Hughes 2000; Lunney et al., 2012a). This is one of the factors determining the IUCN's (2009) listing of the koala as highly vulnerable to climate change. In addition, the distribution of its food trees is predicted to contract as climate change progresses (Hughes et al., 1996). Recent research has established that as the temperature rises, tree choice by the koala changes, i.e. tree choice is influenced by the weather, and in turn will be affected as the climate changes (Crowther et al., 2013). This finding not only warns of climate change, but it also provides a guide to restoration strategies and that includes detailed studies where major disturbance is being planned - rather than just a list of food trees, shelter trees and shrubs also matter. Ultimately, it will be climate mitigation actions on a global scale that are essential, but by the time that is achieved the risk status of the koala will have increased. Therefore, local adaptation strategies such as those that have been identified in the National Koala Conservation and Management Strategy 2009-2014 (Commonwealth of Australia 2009) are essential.

3.4 Ways forward

The global challenges of mitigating climate change notwithstanding, efforts to manage the detrimental effects of climate change on koalas are essential. Conservation planning decision support tools (e.g. Moilanen et al., 2009; Adams-Hosking et al., 2012) can assist in prioritising 'koala conservation refugia' so that the most suitable areas can be targeted for conservation efforts. Willingness at all levels of government to engage in a range of proactive mechanisms, for example, strong land clearing regulations, community engagement through communication and education, and financial incentives to landholders to protect and restore koala refugia and connecting bushland, with koala populations in mind for fire management, need to be implemented.

3.5 *Challenge 3: Conserving urban koala populations*

Human population growth, especially urban population growth, represents a major challenge to koala populations. This growth is concentrated along the eastern seaboard which is a stronghold of the koala. The highest human population scenario for Australia is a rapidly growing population reaching 36 million (from 23 million in May 2013) by 2050 (Hugo 2011; Kirkpatrick 2011). Historically, large cities such as Brisbane, Sydney and Melbourne have been the centres for population growth (Hugo 2011). This focus is likely to continue, however, coastal towns and cities also are rapidly expanding producing low-density peri-urban development that is expanding into surrounding free-hold forested and agricultural landscapes. Here, the complex interactions of multiple threatening processes, combined with high land values, make the effective conservation of koalas particularly challenging. This applies from south-east Queensland, where there is a precipitous decline in koala numbers as well as the large population of koalas living in the peri-urban Adelaide and into the Adelaide Hills, where local scientists are currently working to estimate the population. Here the koalas face the same challenges of those in other urban areas, cars, dogs, habitat fragmentation and disease. This conundrum of increasing koala populations in the southern part of their range, versus the declines in the north, is evident in the two editions of the national koala management strategy (Commonwealth of Australia 1998; 2009) and the fact that the

Victorian and South Australian koala populations were not included in the national listing as a vulnerable species by the Commonwealth.

Koalas are highly sensitive to forest loss and fragmentation (McAlpine et al., 2006; Rhodes et al., 2006, 2008; Reed and Lunney, 1990). The protection of koala habitat from urban development, and targeted habitat restoration programs (e.g. Kavanagh and Stanton 2012; Rhind et al., in press), are critical for the conservation of koalas in urbanising regions. However, other threats to koala populations, including dog attacks, vehicle collisions and increased prevalence of disease need to be acted on. Recovery actions need to systematically address these threats at the scale of local governments and regions (Rhodes et al., 2011).

3.6 Ways forward

The implementation of koala conservation plans focused at the local government and regional level are critical for the conservation of koalas in urbanising regions. Under NSW planning legislation, which provides directions to Local Government, four local governments have implemented koala habitat plans, and more are preparing such plans under State Environmental Planning Policy #44 (Koala habitat protection). This holds its focus on koala habitat, and while it is an excellent start, such plans are not enough on their own. A plan to conserve koalas must consider combinations of threat mitigation measures if they are to be successful in reversing the current decline (Rhodes et al., 2011). Thus a SEPP 44 plan would be part of a more inclusive wildlife management plan. This also applies to Queensland, especially in southeast Queensland. Sound ecological science is an essential input into the planning process (Ellis et al. 2013; Rhodes et al., 2008). Koala ecologists need to work alongside urban and regional planners to identify the drivers of koala fecundity and mortality, understand how they differ among populations, and design control or habitat restoration programs to alter these drivers to achieve sustainable koala populations. Local community knowledge and values must be considered if koala conservation plans are to be successful (sensu Raymond et al., 2009). However, koalas often compete for the same spaces as humans, and trade-offs are inevitable. This raises the issue of effective monitoring, where not

only must the koala population be monitored, but the value of any conservation effort needs to be evaluated, reported and acted upon. At the moment, the major monitoring effort is from the records of the koalas that go into rehabilitation after trauma, or those that are relocated from threatened locations. These data sets can contribute to a monitoring program, but these were not designed to monitor the success or otherwise of a local plan. We note that neither SEPP 44 in NSW, nor the NSW 2008 Koala Recovery Plan (DECC 2008), nor the Commonwealth 2009-14 National Koala Conservation and Management Plan has robust and effective monitoring programs, and the next generation of such plans need them in place. Indeed, the same applies to the southern Australian koala populations where controls are being implemented to keep koala populations down to sustainable levels. There is much in the grey literature and internal reports that would be valuable to assess the efficacy of past programs and feedback on current endeavours.

3.7 Challenge 4: Managing the threats associated with rapidly expanding resource extraction industries

Across much of eastern Australia, the koala's distribution overlaps with extensive energy and mineral reserves. The rapidly expanding open-cut mining of coal and coal-seam gas resource developments represent new and nationally significant threats to koalas. Local studies have pointed to the need to plan for the life of a mine, over 30 years, (Lunney et al., 2012b) and that with planning and sustained research, some short term successes have been recorded (Fitzgibbon et al., 2012). These developments are located primarily in the Bowen, Galilee and Surat Basins of Queensland, and the Gunnedah and Sydney Basins of New South Wales (Figure 2). The impacts on koalas are multifaceted. Koalas and their habitat are lost wherever they occur within the footprint of any resource development or ancillary activity. More significantly, 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 are required at their node to support these projects. This matter is of pressing importance as coal and coal-seam gas mining are set to expand. We do not want to wring our hands with frustration in 20 years' time and simply quote our words of caution after the infrastructure and traffic has taken its toll, irreversibly in many locations. The point here is to look at where the footprint of mining will fall, not just at the mine site, and ensure that the conditions of mining take full account of the impact, with an assured, fully-funded program of rehabilitation that takes place during the operation of - and as part of the economic evaluation of - each project. The current statutory arrangement that has led to the growing legacy of abandoned toxic mine sites does not augur well for the future of any species, let alone the koala.

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 imprinted on a landscape that has already been extensively cleared for agriculture (e.g. Melzer 2013b). From an evolutionary perspective, the term 'refugia' refers to core habitats where organisms are able to persist during periods in which their wider geographic distribution becomes uninhabitable (Svenning et al., 2008; Heikkinen et al., 2009). Koala populations are often already largely restricted to refugia such as riparian vegetation, and less-productive landscapes prior to the recent expansion of mining infrastructure, but as Kavanagh and Barrott (2001) note, after decades when above average annual rainfall was experienced in the Pilliga forests, they recorded koalas right across the landscape following a decade of good conditions. New rail lines and road infrastructure, as well as the clearing currently underway, fragments and destroys large patches of koala habitat, which influences population demographics and genetics (Lee et al., 2013b). The resource-related developments have eliminated some refugia. New rail lines and road infrastructure, as well as the clearing currently underway, will fragment and destroy large patches of koala habitat. The resource-related developments have eliminated some refugia and isolated the remainder until such time

as ecological barriers can be removed (post mining) and after suitable habitat conditions can be restored. The outcome is very likely to be the loss of significant numbers of koalas from otherwise stable populations through the fragmentation of populations that are dissected by infrastructure, and the loss of populations in areas where the road impacts are severe or where direct clearing reduces the carrying capacity of the local ecosystem below a viable population. Koala habitat restoration may be possible (Woodward et al., 2008; Baker 2012; Fitzgibbon et al., 2013; Melzer 2013d), but the long-term persistence of post-mining reconstructed habitat is yet to be demonstrated. The likelihood of widespread post-mining restoration is at best uncertain as pragmatic economic decisions are made around mine-closure. The influence of anthrosol soil chemistry on leaf fodder quality is unknown, and some post-mining landscapes are likely to be alienated almost permanently (ref?).

3.8 Ways forward

The pressure on much koala habitat is set to continue in the face of steadily increasing Australian human populations, ongoing demand for national resources and consequent intensification of infrastructure networks. The efficacy of the current project-by-project approach to environmental impact assessment, management, mitigation and restoration is uncertain (e.g. Maron et al., 2012). A considerable level of effort and expertise must be factored into any claims that rehabilitation of koala populations is possible, hence more certainty for conservation investment may be achieved through a systematic regional planning approach. Such approaches allow multiple threats and multiple land uses to be considered spatially and strategically (e.g. Andersen et al., 2004; Bartolo et al., 2012). In the koala's case, opportunities for secure 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 2013b).

4. Conclusion

Our aim was to synthesise the regional trends, challenges and predictions for conserving koalas in the 21st century across the koalas geographic range. We conclude that it is far easier

to look back at lost opportunities than it is to manage populations that are still extant. Conserving the koala will test the capacity of Australian society and governments to manage our future with the best tools available. As scientists, we can do only so much, but we can contribute to making a grand vision of our wildlife conservation a reality. Without a sound scientific underpinning, the chances for the koala's survival will be much diminished. We point to three issues that need to be considered in the next iteration of the conservation effort. The first is to recognise that koala populations are responding differently across the range of the koala, and that one program will not fit all locations. Consequently, broad programs for conserving and managing koalas will only be effective if a regional approach is adopted for the implementation of actions. 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, we urge all those who are setting out to conserve a koala population to consider all threats, and not just focus on one or two threats. Even though habitat loss remains the dominant threatening process, other factors (dogs, cars, fire, disease, climate change, 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 the bright spot where restoration efforts have been successful, but these to date have been for small areas only. The third point we make is that diverse research programs are essential for any sustained conservation and management program. Far too often have we seen one viewpoint dominate in discussions, funding allocations or conservation and management actions. Their limitations are often not clear because of the low level support for effective monitoring of the ecological, health and social dimensions of the matter. The conservation of the koala across its range will be expensive. Such an investment will not only conserve the koala, it will improve planning laws for fauna more generally, enhance local amenity and ecosystem services for towns and cities, provide alternative economic benefit (koala-eco-tourism) and generate local pride in conserving a national icon. Interacting with nature, including the koala, will deliver measurable benefits to people (sensu Keniger et al., 2013). However, if the resources and political will are not forthcoming, the koala potentially faces regional extinction in the northern areas of its range, and increased vulnerability in southern parts of

its range. We are not painting a grim picture, we are being realistic. Too often scientists hedge their predictions. The need for conservation actions, interacting with research programs, for the koala conservation and management needs to be unequivocal, substantial and long-term. There has been much progress in the last 30 years, as is evident from this review, but we conclude that more, much more, needs to be done to recover the koala populations of Queensland and New South Wales, and sustainably manage the koala populations of Victoria and South Australia.

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Can we add a red dot with 'I MD' to indicate Mt Eccles in south-west Vic?

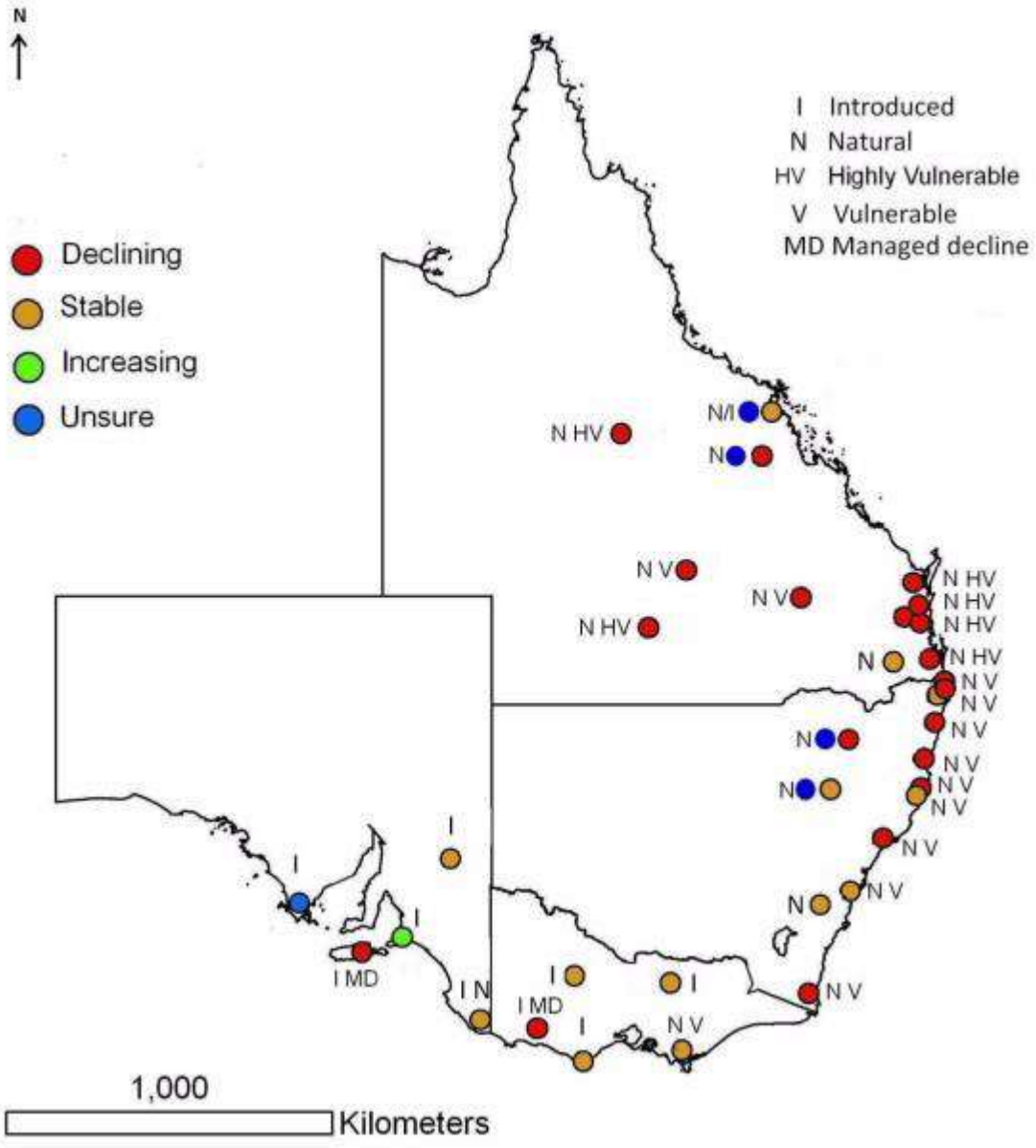

Figure 1 Koala prognosis map across the current koala range, based on the expert workshop information.

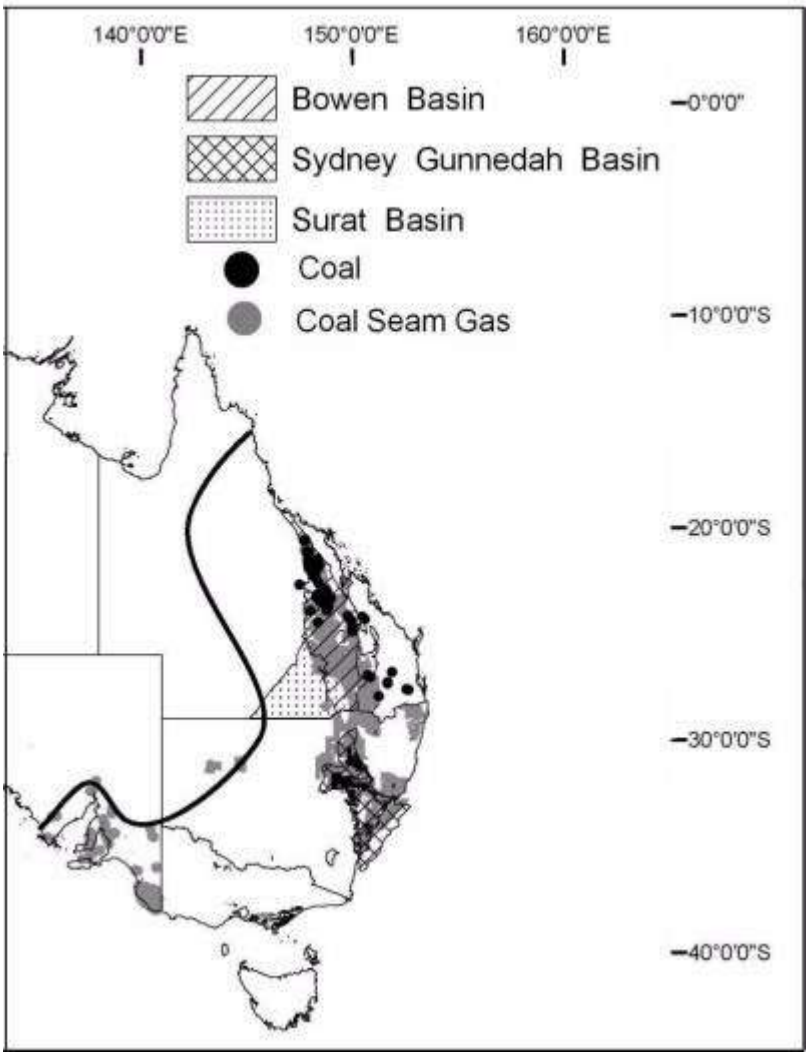

Fig. 2 Current **c**oal and coal seam gas mining activities in the koala's Australian range (defined by black line).

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