

REVIEW

When an iconic native animal is overabundant: The koala in southern Australia

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Abstract

Management of overabundant native species is challenging at the best of times but is even more so when it involves an iconic species that is threatened in part of its range. Here, we examine koala overabundance, a situation that arises in some locations within the species' southern range. We consider the variable conservation status of the koala throughout its range, discuss where and why overabundance occurs, and its consequences. Programs to manage koala overabundance and impacts are generally ineffective, relying on costly and slow acting fertility control and translocation, and implemented only when a crisis already has occurred. A change in management approach is needed. Decisions should be based on an evidence-based and transparent decision-making framework that involves predicting where overabundance is likely, where damage costs will be high, and where proactive management is likely to be effective. With more than 65% of Australia's koala population occurring in the south and declining northern populations, a more considered approach to managing southern koalas for conservation of the species is needed.

KEYWORDS

culling, fertility control, overabundance, *Phascolarctos cinereus*, southern koalas, translocation

1 | INTRODUCTION

World-wide, many native wildlife species have become locally abundant or have increased in geographic range (Garrott, White, & Vanderbilt White, 1993). In some situations, this has had negative consequences including impacts on human health or livelihood, damage to ecosystems through unsustainable browsing or grazing on preferred resources, introduction or spread of infectious diseases and parasites to new areas, and a reduction in species diversity or the relative abundance of sympatric species (Garrott et al., 1993; Noss, 1990; Soulé, 1990). There are numerous examples of such conflicts. In east

Africa, populations of elephants (*Loxodonta africana*) in some reserves have increased and now are damaging their environment and coming into conflict with local communities (O'Connell-Rodwell, Rodwell, Rice, & Hart, 2000). In Japan, the Sika deer (*Cervus nippon*) has expanded its range by almost 70%, resulting in considerable browsing damage to crops and native vegetation (Takatsuki, 2009). In Australia, populations of the once endangered saltwater crocodile (*Crocodylus porosus*) have increased, resulting in an increase in human-crocodile conflicts (Brien et al., 2017; Fukuda, Manolis, & Appel, 2014). An increase in abundance or distribution of a native species may result from one or more factors

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including conservation actions that remove threats (e.g., hunting or predation), human-induced changes in ecosystems and landscapes, and introduction of the species to areas outside of its native range (e.g., Gauthier, Giroux, Reed, Béchet, & Bélanger, 2005; Lunney et al., 2007; Waller & Alverson, 1997).

When a native species becomes abundant and causes conflicts, wildlife managers have the difficult task of developing socially acceptable management strategies (Dubois et al., 2017; Garrott et al., 1993). Management decisions often depend on the iconic nature of the species. For example, culling alligators (*Alligator mississippiensis*) in Florida was considered appropriate, whereas proposals to cull African elephants and white-tailed deer were strongly opposed (Hart, Jewell, & Holt, 1981). Similar dilemmas face management of the koala (*Phascolarctos cinereus*) in Australia. Although populations are declining in the northern part of its range (New South Wales, the Australian Capital Territory and Queensland), in southern states (Victoria and South Australia), koalas can be locally overabundant and have significant impacts on native ecosystems (McAlpine et al., 2015).

1.1 | The koala: Northern versus southern populations

The koala is one of Australia's most iconic endemic species, ranking in the top three wildlife species that international tourists wish to see, and generating billions of dollars in tourism revenue (Hundloe & Hamilton, 1997). Its natural range extends from north-eastern Queensland to south-east South Australia (Natural Resources Management Ministerial Council 2009). The koala is a specialist folivore that subsists on *Eucalyptus* foliage. Its distribution is determined by the presence of *Eucalyptus* species that are high in available nitrogen and moisture, and low in plant secondary metabolites (Cork & Sanson, 1990; Moore & Foley, 2005). Drought and heat waves also are limiting factors (Adams-Hosking, Grantham, Rhodes, McAlpine, & Moss, 2011; Briscoe, Kearney, Taylor, & Wintle, 2016). Koalas are relatively solitary animals that primarily interact during the spring/summer breeding season (Ellis et al., 2015; Watchorn & Whisson, 2019), and generally occur at densities of less than one koala per hectare (Melzer, Carrick, Menkhorst, Lunney, & St. John, 2000).

Hunting and habitat clearance in the late 1800s decimated koala populations throughout their range. It has been estimated that by 1930, only a few hundred remained in New South Wales, up to ten thousand remained in Queensland, and less than a thousand koalas remained on the Victorian mainland (Lewis, 1954;

Menkhorst, 2008; Phillips, 1990). In the late 1920s, each state introduced legislation to stop hunting and to protect koalas. Although this initially halted declines and allowed populations to recover, threats associated with habitat loss and fragmentation, disease, wildfire, changing climates, vehicle collisions and dog attacks have persisted (Natural Resource Management Ministerial Council, 2009). As a result, koala populations have declined in the last two decades by an estimated 53% and 26% in Queensland and New South Wales respectively (Adams-Hosking et al., 2016). A similar decline in 'southern koalas' has not been documented (Adams-Hosking et al., 2016). In 2012, koala experts estimated koala numbers at 79,000 (range 33,000–153,000) in Queensland, 36,000 (range 14,000–73,000) in New South Wales and the Australian Capital Territory, 183,000 (range 77,000–237,000) in Victoria, and 33,000 (range 19,000–51,000) in South Australia (Adams-Hosking et al., 2016). In 2015, only 'northern koalas' were listed as vulnerable under National legislation (Department of the Environment & Energy, 2015).

Continued declines in koala populations are predicted due to climate change resulting in a greater incidence of drought and heat waves (Briscoe et al., 2016). Distribution modeling suggests that by 2070, the koala's range will contract toward the coast, and that most regions of high habitat suitability will be in the south (Briscoe et al., 2016). An increase in atmospheric CO₂ levels also will impact habitat quality by reducing the nutritional quality of *Eucalyptus* foliage (Johnson, De Gabriel, & Moore, 2009). The conservation significance of southern koalas therefore is likely to increase (McAlpine et al., 2015). Although southern koalas are thought to be secure, their true status is unknown due to limited monitoring and field studies (Ashman, Watchorn, & Whisson, 2019; McAlpine et al., 2015). Declines may be occurring in some areas, but issues associated with high-density populations receive the most attention (McAlpine et al., 2015).

Southern koalas have long been the subject of intensive management (Menkhorst, 2008). In Victoria, koalas from island populations established in the late 19th and early 20th century were used to reestablish populations on the mainland where hunting had brought about their near-extinction, and to establish koalas in areas outside their historic range (e.g., Kangaroo Island, South Australia) (Menkhorst, 2008; Wedrowicz, Wright, Schlagloth, Santamaria, & Cahir, 2017). Between 1923 and 2006, over 12,000 koalas were translocated from French and Phillip Islands to the mainland (Menkhorst, 2008). In South Australia, koalas from Kangaroo Island were translocated to other parts of the state including the Eyre Peninsula, Riverlands, southeast SA, and the Adelaide Hills (Robertson, 1978). Although this resulted in the recovery of southern koala populations and

expansion of their range, most populations now have low genetic diversity, resulting from the island source populations being founded by just a few individuals (Cristescu et al., 2009; Houlden et al., 1999; Houlden, England, Taylor, Greville, & Sherwin, 1996).

The iconic nature of the koala combined with its variable conservation status and management needs across its range, creates challenges for policy makers and wildlife managers (Natural Resources Management Ministerial Council 2009; Shumway, Lunney, Seabrook, & McAlpine, 2015). On one hand, the koala is portrayed as a species that will be extinct by 2050 (Australian Koala Foundation, 2020); yet this is countered by reports of koala “overabundance” from the southern states, with calls to cull, sterilize, or translocate koalas to reduce high-density populations (Natural Resources Committee, South Australia, 2019; Possingham et al., 1996; South Australian Government, 2019). In some cases, high-density populations have caused complete and widespread canopy defoliation resulting in mass starvation of koalas (Menkhorst, 2008; Whisson, Dixon, Taylor, & Melzer, 2016). Although koalas in southern states are not listed as “vulnerable” under National legislation, nor listed in any special conservation category under state legislation, their management is considered differently to other common native wildlife. Whereas permits are issued to cull ‘common’ native fauna (e.g., kangaroos) that are causing damage to natural environments or property, the same is not done for koalas. South Australian and Victorian state governments abide by national policy to reject culling of “overabundant” koalas (Australian and New Zealand Environment and Conservation Council, 1998; DELWP, 2004; South Australian Government, 2016). Management of overabundant koala populations therefore relies on translocation and fertility control measures that are expensive and may have poor welfare outcomes for koalas (Duka & Masters, 2005; Whisson et al., 2016; Whisson, Holland, & Carlyon, 2012). Furthermore, implementing such measures over large spatial scales where there may be thousands of koalas is logistically difficult and economically not feasible. As a result, these measures only may be effective in a few situations (e.g., islands) where management areas are small and there is limited potential for immigration (Massei & Cowan, 2014).

2 | WHERE DOES KOALA “OVERABUNDANCE” OCCUR?

We use the term “overabundant” here to describe a koala population that occurs at a density that results in defoliation of preferred food trees. If unmanaged, this can lead

to widespread tree death, nutritional stress in the koala population, and even death of koalas due to starvation (e.g., Martin, 1985a, 1985b, 1985c; Whisson et al., 2016; Figure 1). Overabundance can occur where there are only two koalas per hectare (Menkhorst, 2008), but higher densities are typical. For example, at Cape Otway, Whisson et al. (2016) recorded 23 koalas per hectare immediately prior to mass starvation of koalas and a population crash. Koala overabundance has been documented in the scientific literature for 16 locations in Victoria and South Australia (Figure 2, Table 1). There only has been one report of overabundance outside of the koala’s southern range, and that was reported for a forest remnant in northern New South Wales (Frith, 1979).

Martin (1985b) suggested that fluctuations in koala populations (and thus occasional ‘overabundance’) in preferred habitats may always have occurred. However, only two cases of overabundance have been documented for natural (i.e., nonreintroduced) populations (Walkerville and Wilson’s Promontory). Kershaw (1934) reported that koalas were “numerous” in several areas of Wilson’s Promontory c1905 and in “one or two other localities favored by koalas” despite “periodical raids of skin-hunters”. In fact, translocation of koalas and culls were implemented on Wilson’s Promontory c1910 to reduce populations and over browsing of trees (Kershaw, 1934). Most cases of overabundance have occurred in locations where koala populations have been reestablished via translocations (Table 1). For some of these, overabundance has been resolved either through management (e.g., Quail Island, Snake Island, Sandy Point) or as a result of koala overbrowsing itself causing both a crash in koala numbers and a reduction in habitat quality for koalas (e.g., Kennett River/Grey River; Menkhorst, 2008). However, at many sites, koala overabundance is a continuing concern.

3 | CAUSES OF OVERABUNDANCE

The reason why overabundance occurs only in the southern part of the koala’s range is not clear and may be due to a complexity of climate and site-specific factors, or possibly the low genetic diversity of most southern koala populations. Fecundity rates for many southern koala populations (32 to 81% McLean, 2003) are within the range for northern koalas (e.g., 33 to 85% recorded by Thompson, 2006). At some sites where overabundance occurs, fecundity can be low due to disease associated with *Chlamydia pecorum* (e.g., 38.8% fecundity for the population in Budj Bim National Park [McLean, 2003]). Overabundance also can occur where koalas face considerable threats. For example, the koala population in the Adelaide Hills and Mt Lofty Ranges, a highly urbanized



FIGURE 1 Koala overabundance at Cape Otway in November 2013. (a) Koalas converged on trees that had not been completely defoliated, and (b) individuals became nutritionally stressed and starved to death

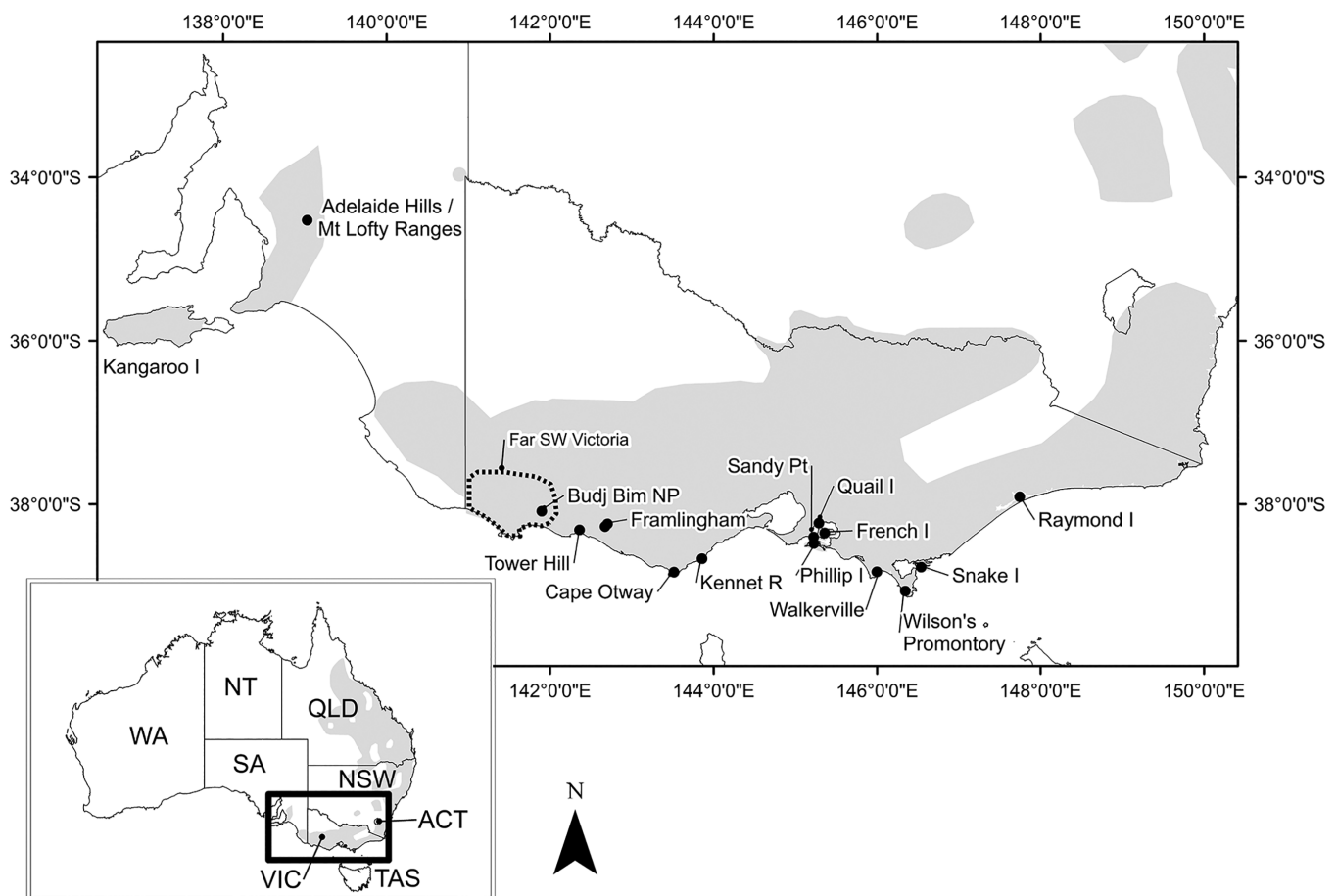


FIGURE 2 Locations of koala overabundance in Victoria and South Australia. The light grey shading shows the distribution of koalas in Australia (Woinarski & Burbidge, 2016)

region, was recently estimated at around 150,000 individuals with densities of up to 13 koalas per hectare recorded in some areas (Sequeira, Roetman, Daniels, Baker, & Bradshaw, 2014; South Australian Government,

2019). In addition to high mortality due to dog attacks and vehicular collisions, this population is impacted by a high incidence of calcium oxalate nephrosis, a condition that results in kidney failure (Speight et al., 2013).

TABLE 1 Sites where koala overabundance and over browsing have been documented (see Figure 2)

Location	<i>Eucalyptus</i> species at site	Forest cover within 10 km	Year(s) and number of koalas introduced	Dates of "outbreaks"	References
Raymond Island (765 ha)	<i>E. viminalis pryoriana</i>	N/A	1953:42 koalas	1985 – Present	Mitchell, Bilney, & Martin, 1988
Snake Island (3,452 ha)	<i>E. viminalis pryoriana</i>	N/A	1945:133 koalas 1955, 1963, 1977: Unknown	1990–2012	McLean, 2003
Wilsons promontory	<i>E. viminalis</i>	75%	N/A - natural	1905–1910	Barrett, 1937 Kershaw, 1915, 1934
Walkerville	<i>E. ovata</i>	13%	N/A - natural	c1980	Martin, 1981, 1985a, 1985b, 1985c
Phillip Island (10,000 ha)	<i>E. viminalis</i>	N/A	1870–1923: Unknown	1941–1978	Lewis, 1954 Gliddon, 1958 Menkhorst, 2008 Wedrowicz et al., 2017
French Island (17,392 ha)	<i>E. viminalis</i>	N/A	c1898: 3 koalas	1923 – Present	Lewis, 1934 Lewis, 1954 McNally, 1960
Quail Island (530 ha)	<i>E. viminalis</i>	N/A	1930–1933: 165 koalas	1944–1945	Braithwaite, Lumsden, & Dixon, 1980
Sandy point (Mornington peninsula)	<i>E. viminalis</i>	17%	1972:20 koalas	1985	Martin, 1989 Backhouse & Crouch, 1991
Kennett river & grey river	<i>E. viminalis</i> <i>E. cypellocarpa</i>	90%	1958, 1977 and 1982:294 koalas	c2000	Menkhorst, 2008
Cape Otway	<i>E. viminalis</i>	71%	1981:75 koalas	2013 – Present	Whisson et al., 2016 Menkhorst, Ramsey, O'Brien, Hynes, & Whisson, 2019
Framlingham forest & Hopkins river	<i>E. viminalis</i> <i>E. ovata</i> <i>E. camaldulensis</i>	5%	1970:37 koalas	1987–1999 2016–2018	Wallis, 2013
Tower Hill game reserve	<i>E. viminalis</i>	1%	1979; 17 koalas	1996–2003	Menkhorst, 2008 Middleton, Walters, Menkhorst, & Wright, 2003
Budj Bim NP, stones reserve & Kutonitj indigenous protected area	<i>E. viminalis</i>	27%	1973:30 koalas 1982:46 koalas	1999 – Present	McLean, 2003 DELWP, 2017
Far SW Victoria	<i>E. viminalis</i> <i>E. ovata</i>	Variable	See Budj Bim NP	c2013 - present	Ashman, Rendall, Symonds, & Whisson, 2020
Kangaroo Island (440,500 ha)	<i>E. viminalis cygnetensis</i> <i>E. ovata</i>	Flinders chase: 94% Cygnet R: 31%	1923:18 koalas	c1965 – Present	Philpott, 1965 Eberhard, 1972 Robertson, 1978 Masters, Duka, Berris, & Moss, 2004
Adelaide hills & Mt lofty ranges	<i>E. viminalis</i>	61%	1959–1969: Unknown	c2016 – Present	SA Government, 2016

Lack of dispersal opportunity has been touted as the primary cause of overabundance (Australian Koala Foundation, 2000) and this may be true on offshore islands or in habitat 'islands' surrounded by cleared landscapes on the mainland (Menkhorst, 2008). However, island populations also occur in the north and have not become overabundant (e.g., McGregor, Kerr, & Krockenberger, 2013). Furthermore, overabundance can occur at sites surrounded by other suitable koala habitat (e.g., Cape Otway, Kennett River, far south-west Victoria, and Flinders Chase on Kangaroo Island, Table 1). In far south-west Victoria, koala overabundance in remnant woodlands and in roadside vegetation has resulted from the establishment of commercial blue gum (*E. globulus*) plantations (Ashman et al., 2020). Blue gum is highly preferred by koalas and population densities of up to 4.3 koalas per hectare have been documented in plantations (Ashman et al., 2020). When plantations are harvested, koalas must disperse, thus exacerbating overabundance issues in native vegetation.

One factor in common across sites of overabundance is the presence of *E. viminalis* (manna gum) and/or *E. ovata* (swamp gum) (Menkhorst, 2008). These species contain high levels of available nitrogen and leaf moisture, and low levels of anti-herbivory compounds, thus making them ideal koala food trees (Moore & Foley, 2005). In woodlands comprising a high proportion of these species, koalas have small home ranges (less than two hectares; Mitchell, 1990; Whisson et al., 2016). Furthermore, koalas in these habitats exhibit high site fidelity and appear reluctant to move to alternate habitat types even when trees become completely defoliated (Whisson et al., 2016). Recent research into the koala's microbiome suggests that this may be due to koalas becoming highly specialized on a single food tree such that they may have limited ability to switch their diet to another food tree species (Blyton et al., 2019; Brice et al., 2019).

Another factor that may contribute to overabundance is low genetic diversity resulting in behavioral changes in koalas. Except for one population in South Gippsland, southern koalas have extremely low genetic diversity resulting from the near-extinction bottleneck in the 1920s (Cristescu et al., 2009; Houlden et al., 1996). Although a reduction in genetic diversity typically leads to reduced reproductive success in a species (Crnokrak & Roff, 1999; Seymour et al., 2001), this has not been the case for southern koalas (McLean & Handasyde, 2006; Whisson & Carlyon, 2010). However, low genetic diversity also may result in individuals being less aggressive. This has been observed in house mice (Barnard & Fitzsimons, 1989; Eklund, 1996), salmon (Tiira et al., 2003) and ants (Tsutsui, Suarez, Holway, & Case, 2000) but remains

untested with koalas. If true for koalas, individuals may better tolerate being near conspecifics, permitting higher densities than typically occur in other parts of the koala's range.

4 | CONSEQUENCES OF OVERABUNDANCE

Overabundance has negative consequences both for koalas and the ecosystem. Defoliation of trees may result in nutritional stress of koalas and in severe cases, mass starvation (Whisson et al., 2016). Impacts to ecosystems range from the defoliation or death of some preferred trees through to a drastic change in the ecosystem resulting from widespread tree death (Menkhorst, 2008). Such impacts have been greatest in "Damp-sands herb-rich woodland", a vegetation association that already is listed as vulnerable (under state legislation) across most of Victoria (Menkhorst, 2008). The flow-on effects of tree defoliation are poorly understood but likely to be highly negative. Whisson, Orlowski, and Weston (2018) found that bird species diversity and richness declined with increasing canopy defoliation. Defoliation also may lead to changes in subcanopy vegetation due to increased light infiltration and changes in microhabitats (Valladares, Laanisto, Niinemets, & Zavala, 2016).

Koala overabundance also impacts on policy decisions, and allocation of resources for conservation. The relative abundance of southern koalas long hindered recognition of northern koalas as vulnerable under Commonwealth legislation (Shumway et al., 2015). Even within the southern states, there is little or no recognition of pervasive threats and declining populations in some areas; and limited resources are allocated to the monitoring or management of declining populations or to conserving the genetically diverse population in South Gippsland (Wedrowicz et al., 2017; Wedrowicz, Mosse, Wright, & Hogan, 2018).

5 | MANAGEMENT OF OVERABUNDANT KOALAS

Managing koala overabundance is challenging because of the koala's iconic nature and the limited and costly management tools available. Culling is not endorsed by Commonwealth or State governments and management actions are limited to translocation, fertility control, exclusion methods, and habitat management (Natural Resource Management Ministerial Council, 2009). At a local scale, koalas may be excluded from single or small groups of trees with tree guards or a koala proof fence

(for example fence design, see Queensland Department of Transport and Main Roads, 2019). Habitat management to reduce the potential for an area to support high-density koala populations also may be effective. Au et al. (2019) showed that koala abundance at a site is related to the nutritional quality (available nitrogen in canopy foliage) of forests. Consequently, revegetating over-browsed sites with less palatable tree species may result in sustainable populations.

Translocation and fertility control can be implemented by government departments (DELWP, 2004; South Australian Government, 2016). Of these, translocation can immediately reduce koala densities at a site; however, the viability of translocation relies on the availability of suitable sites to which koalas can be translocated. In Victoria, sites must contain *Eucalyptus* species that are preferred by koalas, occur at ≤ 700 m elevation, be at least 1,000 ha and at least 1 km from a major road or railway (Menkhorst et al., 2019). Furthermore, for any species, translocation is inherently risky, carrying the risks of spreading disease, causing overabundance in the recipient site, and high animal welfare costs (see Massei, Qu, Gurney, & Cowan, 2010 for review). For koalas, variable survival has been recorded, with success depending on the health of individuals, their treatment prior to translocation (e.g., sterilization method), and the habitat and weather conditions at the release site (see Menkhorst, 2017 for review). In contrast to translocation, fertility control is slow acting, taking between 5 and 10 years for a positive habitat response (Todd, Forsyth, & Choquenot, 2008). Although surgical sterilization of males and females was used in early programs (e.g., Kangaroo Island; Duka & Masters, 2005), treatment of female koalas with levonorgestrel implants is now the standard approach (Hynes, Handasyde, Shaw, & Renfree, 2010; Menkhorst et al., 2019; Middleton et al., 2003; Todd et al., 2008).

There are relatively few cases of koala overabundance being resolved using these methods. Exceptions are Quail Island where in 1945, the entire population of 1,308 koalas was translocated to the mainland; Sandy Point (1,522 koalas translocated), and Snake Island where a combination of translocation (2,607 koalas as of 2006) and fertility control reduced the population to a sustainable level (Menkhorst, 2008). In most cases, ongoing management is required due to the large geographic scale and size of the koala population, and logistical constraints that limit the proportion of the total population that can be sterilized; and because of immigration of koalas into treated areas (Todd et al., 2008). Long-term (>10 years) management programs include those on Raymond Island, Budj Bim National Park, and Kangaroo Island. The Budj Bim NP and Kangaroo Island programs have involved the sterilization and translocation of

thousands of koalas (Duka & Masters, 2005; Natural Resources Kangaroo Island, 2019; Todd et al., 2008). Although both of these programs were successful in the first decade of their implementation (Molsher, 2017; Todd et al., 2008), establishment of commercial blue gum plantations in the landscape surrounding treated areas is now placing the long-term effectiveness of those programs in doubt. On Kangaroo Island, commercial blue gum plantations were first established in the 1990s. In 2015, they covered 13,198 ha and were estimated to support $23,360 \pm 3,330$ koalas (Molsher, 2017). An increase in the koala population in native vegetation from $14,270 \pm 759$ in 2010 to $25,146 \pm 2,646$ in 2015 was mostly attributed to immigration of koalas from blue gum plantations (Molsher, 2017). Similarly, Budj Bim NP in far south west Victoria lies within a region where over 80,000 ha of blue gum plantations have been established and have facilitated a considerable wide-scale increase in the koala population (Ashman et al., 2020; Ashman & Watchorn, 2019). Consequently, constant immigration of Budj Bim NP by unsterilized koalas from plantations is likely.

Reactive management in response to public outcry is typical for most cases of koala overabundance and government management actions tend to focus on addressing koala welfare. For example, at Cape Otway, a “welfare intervention” involving the euthanasia of approximately 700 starving koalas was implemented in November 2013 after widespread tree defoliation already had occurred and large numbers of koalas already had starved to death (Whisson et al., 2016). A longer-term management strategy to prevent a repeat of the situation was not implemented until March 2015, coinciding with world-wide negative media attention (DELWP, 2019a). At the same time, the Victorian Government initiated much-needed research into “habitat triggers for management” to predict when problems were likely to occur (Ramsey, Tolsma, & Brown, 2017). However, the effectiveness of this approach relies both on annual monitoring at sites where overabundance is likely and the ability to respond quickly when thresholds for management are “triggered”. Unfortunately, neither of these conditions were met for Framlingham where management was undertaken in response to a crisis (i.e., starving koalas and widespread tree defoliation and death) in October 2018. In a one-week program, 194 koalas were captured, with 168 of those translocated (females sterilized with levonorgestrel implants) to two state forests approximately 120 km north west of Framlingham (DELWP, 2019b).

There are no easy solutions for managing koala overabundance. Many advocate culling as an answer but considering the koala’s iconic status and the high level of

public outrage expressed when culling has been suggested (Bagust, 2010), it seems unlikely that this method would ever receive government endorsement. If management continues to rely on translocation and fertility control, decisions on where and when to apply these tools should be based on an evidence-based and transparent decision-making framework (Dicks, Walsh, & Sutherland, 2014; Dubois et al., 2017). For koalas, this means predicting where and when overabundance will occur, its costs (animal welfare, ecosystem, human dimensions), and evaluating both the cost and potential efficacy of management actions for each location. With this approach, decisions to not implement fertility control and translocation may be warranted in many situations. In such cases, the welfare of koalas and condition of habitat should be monitored, and actions taken to alleviate koala suffering (e.g., euthanasia of koalas) and to restore damaged habitats.

6 | THE FUTURE OF SOUTHERN KOALAS

With approximately 65% of Australia's total koala population in southern Australia, and population declines occurring throughout the koala's northern range, maintaining healthy populations of southern koalas is becoming increasingly important for conservation of the species. Although southern koalas currently are considered secure, there is limited understanding of their distribution and abundance (McAlpine et al., 2015). Like northern koalas, they especially are threatened by continued habitat loss, fragmentation and degradation; an increasing frequency of droughts and wildfire as a result of warmer and drier climates; and declining nutritional value of *Eucalyptus* foliage with increasing atmospheric CO₂ (McAlpine et al., 2015).

Habitat loss and fragmentation limit both the distribution and long-term viability of koala populations in a landscape (Januchowski et al., 2008; McAlpine et al., 2006). Victoria and South Australia have suffered high rates of deforestation such that forests now cover approximately 34% and 9% of land in each state respectively (Bradshaw, 2012). Remaining forests tend to be highly fragmented, disturbed or ecologically compromised (Bradshaw, 2012; Gill & Williams, 1996; Norton, 1996). In highly fragmented landscapes where koalas may spend more time on the ground moving between habitat patches, the risk of predation and vehicular collisions are heightened, and energy budgets may be compromised (McAlpine et al., 2006). Wildfires have the potential to decimate entire populations of koalas, and impact on habitat quality. On Kangaroo Island, a fire that started in December 2019 burnt 210,000 ha (almost 50% of the

island) including 95% of national park land and a large proportion of koala habitat supporting thousands of koalas (Department for Environment and Water, 2020). At the same time in Victoria, a fire in Budj Bim NP burnt approximately 6,369 ha and over 50% of koala habitat.

In addition to these threats, most populations of southern koalas are inherently at risk of collapse due to their low genetic diversity (Wedrowicz et al., 2018). Such was the case with the Tasmanian devil (*Sarcophilus harrisii*) that also had a history of genetic bottlenecks resulting in low genetic diversity (Siddle et al., 2007). Although abundant prior to 1996, Tasmanian devil populations now have decreased by between 50% and 90% due to the emergence of the highly contagious, devil facial tumor disease (Siddle et al., 2007). Only one southern koala population (in South Gippsland, Victoria) has a relatively high level of genetic diversity which could provide it with a greater chance of survival compared to reintroduced populations (Houlden et al., 1999; Wedrowicz et al., 2018). However, despite the conservation significance of this population, there is limited understanding of the population's extent (abundance and distribution) or threats to its persistence (Wedrowicz et al., 2018).

A comprehensive management strategy for southern koalas is needed. Such a strategy must not just focus on issues of overabundance but aim to address the diversity of issues that impact on koala conservation, and to improve our understanding of the ecology of the species in its southern range. Compared to northern states, there has been relatively little research on southern koalas, and a stronger research focus on tools for managing overabundance (Ashman et al., 2019). An improved understanding of koala distribution, abundance and population fluctuations, current and future threats, population health and genetic diversity, and gene flow between populations is needed to inform effective conservation actions. Furthermore, management should be considered at the landscape-scale and include both the rehabilitation of degraded habitats, and reforestation to increase habitat area and connectivity. Given the propensity for southern koalas to become overabundant in some habitat types, habitat management actions will need to be carefully planned to create habitats that can sustain koala populations, but that do not result in overabundance. Reforestation is not only important for koala conservation but will improve biodiversity and help mitigate the effects of climate change (Paul et al., 2016).

For a management strategy to be effective in delivering on-ground conservation outcomes for koalas, it also must include a process for implementation, and funding to support actions (McAlpine et al., 2015). Implementation of a strategy is often challenging, requiring extensive engagement and collaboration with stakeholders, and

integration with other land management and conservation programs (McAlpine et al., 2015). However, such challenges should not be used as a reason for inaction. Securing the future for southern koalas should be considered a priority.

CONFLICT OF INTERESTS

D.A.W. provides advice on koala management to the Victorian Department of Environment, Land, Water and Planning.

AUTHORS' CONTRIBUTIONS

Both authors were involved in the conceptual development of the manuscript. D.A.W. led the writing of the manuscript. K.R.A. provided feedback on drafts and approved the final version of the manuscript.

ETHICS STATEMENT

The authors are unaware of any ethical issues regarding this work. The manuscript expresses the views of the authors.

DATA AVAILABILITY STATEMENT

The authors confirm that the data supporting the findings of this study are available within the article.

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