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Threats to koala populations in south-eastern Australia and the impacts of forestry activities on koalas and their habitat

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Centre for Environmental MANAGEMENT

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Introduction

This report was commissioned by the National Association of Forest Industries to review the threats to Australia's koala populations and to investigate the potential impact of forestry operations on koala habitat.

Often, sustainable timber harvesting practices are confused with general land clearing activities, despite the modern, ecologically sustainable, principles which the forest industry operates. Many individuals, communities and environmental groups have concerns regarding the persistence of koalas in timber production forests. Without scientifically rigorous facts about koala ecology and behaviour, and a true understanding of the threatening processes facing koalas in areas of timber production, it is difficult to determine the impacts.

Consequently, an investigation into the documented threats to koalas and how these impact on the long term sustainability of koalas in eastern Australia was undertaken. The activities and policies of the New South Wales and Victorian governments and private timber production industries, in regard to koalas, were also reviewed. With the threatening processes facing koalas in perspective with these activities and procedures, an overview of the benefits and possible harm to koala populations is also discussed.

Koala Background

Past to present

Overview

Koalas occur in the eucalypt forests of eastern and southern, mainland Australia (Martin and Handasyde 1999; Melzer *et al.* 2000; Van Dyck and Strahan 2008) and their current distribution is indicated in Figure 1.

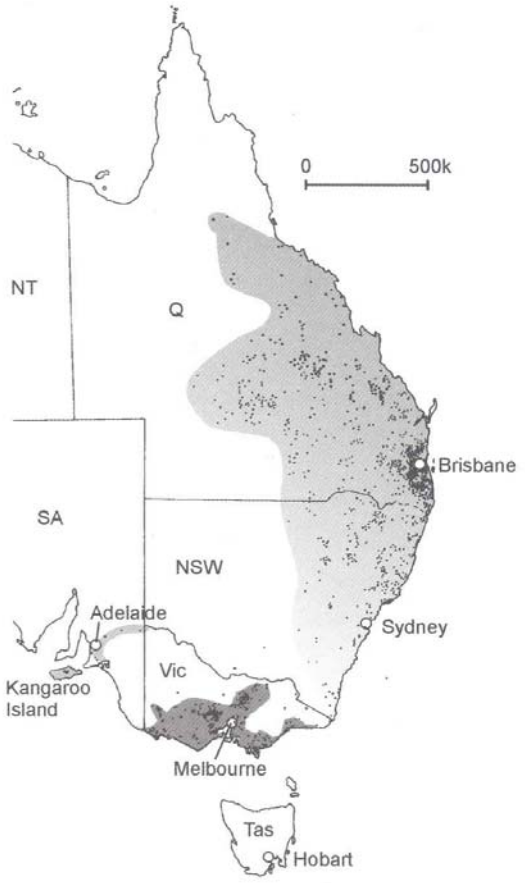

Figure 1 Koala distribution map, copied from Martin and Handasyde (2008) - shading is representative of density and each dot indicates a sighting

During the 20th Century, extended periods of hunting by European fur traders, disease epidemics and increased urban and pastoral pressures have resulted in a reduction of koala distribution and abundance across the koala's entire range (DECC 2008; Melzer *et al.* 2000; Penn *et al.* 2000). The current size of local, regional and state koala populations is unclear because it is very difficult to

assess the number of individuals in a population for each different region. Additionally, many populations are in remote and difficult to access areas. For this reason very little work has been carried out to estimate regional distributions and abundance. Generalisations of distribution and abundance can be made without true population numbers being assessed.

New South Wales

Detailed historical information regarding koalas in the Bega valley of southern New South Wales (Lunney and Leary 1988) and other areas of southern Australia (Melzer *et al.* 2000) demonstrates the presence of abundant koalas in and around the local districts with anecdotal records of koalas in the township of Bega, with one or two in every tree (Lunney and Leary 1988). This was the case for most of the late 1800's for all of southern Australia (Melzer *et al.* 2000). It is not known what caused the influx in numbers at this time, but the removal of aboriginal pressures, either from direct hunting or their intensive fire regimes is thought to be the main cause (Lunney and Leary 1988; Melzer *et al.* 2000).

It was between 1905 and 1909 that koalas almost disappeared from the Bega region with very few sightings in the valley or the surrounding forests. A disease outbreak, combined with fire, both intensified by habitat clearing and fragmentation, was believed to be the cause of the eventual decline ((Troughton 1973) in (Lunney and Leary 1988), (Melzer *et al.* 2000)). However, it is more likely that escalating land clearing between the mid 1860's until 1910 was a major cause of the decline by intensifying the effects of other pressures (Lunney and Leary 1988). It was during this period that farming intensified and by 1910 there was little vegetation remaining in the valleys. Between 1893 and 1921 over 30% of New South Wales was partly or completely cleared, some 25.7 million ha of forest (Lunney and Leary 1988).

Forestry industries also expanded during this period with much more timber being harvested for construction and sleepers, before regulation of the industry and the establishment of the *Forestry Commission* in New South Wales in 1916 (Lunney and Leary 1988). After this, much of the remaining vegetation was declared State Forests. This story can be applied to most regions along eastern New South Wales (Lunney and Leary 1988; Reed and Lunney 1990).

Currently in southern New South Wales there is considerable inconsistencies in the assessment of koala population size and density, and as such it is difficult determine, with certainty, the number of koalas that are currently occupying any given location (Allen *et al.* 2010). Regardless of these

inconsistent monitoring procedures, assessments and best available estimates have determined koalas are low in number and have a very scattered and fragmented distribution with three pockets persisting: i.e. far south coast, 21 to 42 individuals; north eastern Monaro, 80 to 320 individuals; and southern highlands with 160 to 640 individuals (Allen *et al.* 2010).

In northern New South Wales koala numbers are much higher than in the south, but again are difficult to estimate. Their patchy distribution persists on the eastern side of the Great Dividing Range and along creeks and rivers on the western plains (Lunney *et al.* 1997; Reed and Lunney 1990; Reed *et al.* 1990a).

Victoria

Research in Victoria demonstrates paralleled patterns of koala declines as those documented in the Bega region (Lunney and Leary 1988; Martin 1985a; b; c; Martin and Handasyde 1999). In Victoria, the fur industry collapsed by 1910, due to a scarceness of koalas (Melzer *et al.* 2000), and by the mid 1930's koalas numbers in Victoria were estimated to be lower than 1000 individuals (Martin and Handasyde 1999; Martin and Lee 1984; Melzer *et al.* 2000). Concern about local extinctions across Victoria, lead to programs which introduced koalas onto off shore Islands. These islands are now supporting isolated, inbred and unstable populations (Martin and Handasyde 1999; McLean 2003). Mainland Victoria also has a very disjointed distribution with similar genetic inbreeding and stability problems (Martin and Handasyde 1999; McLean 2003), with many koala populations being expanded through the relocation of overabundant koalas from island to main land sites (Martin and Handasyde 1999).

South Australia

In South Australia the koala was extinct by 1930 (Martin and Handasyde 1999; Melzer *et al.* 2000; Phillips 1990), before reintroductions from Victoria resulted in isolated populations on islands and the main land which are now also unstable in number, genetically inbred and require extensive management (Melzer *et al.* 2000).

Queensland

There was a similar pattern in Queensland as in the southern states, however, there was relatively less clearing in the early 1900's with most land clearing occurring later between 1967 and 1985 when significant koala range reductions have been noted (Melzer *et al.* 2000). The hunting of koalas, particularly for the fur trade, at the turn of the century, was an influence on the koala populations and the naturally wide spread distributed Queensland koalas reduced (Gordon *et al.* 1990; Melzer *et al.* 2000). Today the koala is widespread across most of eastern Queensland in low densities, with locally abundant populations in the south east, central and south west. Introduced and naturally occurring offshore island populations of koalas also persist in Queensland.

Habitat Requirements

Koalas are folivorous, arboreal marsupials (Martin and Handasyde 1999; Van Dyck and Strahan 2008), and it is their dependence on trees that dictates their habitat requirements. Across their entire range, over 70 different species of eucalypt and a further 30 non-eucalypt species have been identified as part of the koala's diet (Hindell *et al.* 1985; Hindell and Lee 1988; Hindell and Lee 1991; Martin and Handasyde 1999). However, only 18 species of eucalypt are considered primary fodder (Table 1) and only one or two fodder species are preferred in any one area (Hindell *et al.* 1985; Hindell and Lee 1987; 1988; Hindell and Lee 1991; Kavanagh *et al.* 2007; Matthews *et al.* 2007; Phillips and Callaghan 2000; Phillips *et al.* 2000).

Koalas are highly specialised to take advantage of the low nutrient eucalypt forests that dominate most of Australia (Martin and Handasyde 1999). They eat between 200 and 500 g of leaves per day by nipping them from the branch and chewing them to a fine pulp. Their chewing cuts and shears the leaves, and tears the cell walls, releasing as much absorbable energy as possible (Cork and Sanson 1990; Cork and Hume 1983).

Koalas get most of their water from leaves and thus require browse with at least 50% leaf moisture (Clifton 2010). To do this they inhabit areas with relatively high soil moisture and therefore prefer habitat in close proximity to riparian zones and wetter eucalypt forests. Other authors suggest that they also inhabit areas with high levels of soil nutrients (Gordon *et al.* 1988; Jurskis and Potter 1997; Melzer *et al.* 2000; Munks *et al.* 1996).

Table 1 Koala fodder tree species from the genera Eucalyptus
P = Primary fodder species; ✓ = Less frequently eaten

Eucalyptus spp.	Queensland	New South Wales	Victoria	South Australia
E. camaldulensis	P	✓	P	P
E. coolabah	✓			
E. crebra	✓			
E. fibrosa	✓			
E. globulus			P	
E. grandis		✓		
E. leucoxylon				P
E. microcorys	P	P		
E. obliqua			✓	
E. ovata		✓	P	
E. pilularis		P		
E. populnea	✓			
E. prioriana			P	
E. propinqua	P	P		
E. punctata		P		
E. radiata			✓	
E. regnans			✓	
E. saligna		P		
E. tereticornis	P	P	✓	
E. tessellaris	✓			
E. viminalis		✓	P	P

Several, more recent studies, of tree species preferences show that trees used by koalas for fodder differ from those used for resting. This is evident across northern NSW and throughout Queensland (Ellis *et al.* 1999; Kavanagh *et al.* 2007; Lunney *et al.* 2007; Pfeiffer *et al.* 2005; Tucker 2008). In the Pilliga Forests of northern NSW koalas frequently occupied the white cypress pine (*Callitris glaucophylla*), a non-fodder species with relatively denser crowns than eucalypts. The incidence of Callitris use was higher in the hotter, summer months (22% and 41% of observations in winter and summer respectively). Similarly, in hot humid sites in Queensland, higher proportions of koala observations during the day are noted in shady, densely canopied, non-fodder tree species, particularly in the summer months (Clifton 2010; Pfeiffer *et al.* 2005; Tucker 2008).

There is also a difference in tree species and structure requirements for koalas of different ages or development stage. Sub-adult koalas have been shown to utilise, and disperse through, less ideal habitat than that occupied by their mothers (Dique *et al.* 2003a; Ramsay 1999; Tucker *et al.* 2008). A koala's use of habitat can also be influenced by season. Several cases of koalas dispersing or migrating into less ideal habitat in wet and cooler seasons have been shown, however, they retreated to more favourable habitat (usually in riparian areas) during less favourable (dryer)

conditions (Gordon *et al.* 1988; Melzer and Lamb 1994). Therefore, there is a complexity to the habitat required to maintain all the individuals within a koala population and their ability to use and tolerance habitat of varying degrees in favourable conditions.

Ranging space

Due to the variety of methods used for home range estimation it is difficult to compare those reported by different authors. Generally, however, the home ranges of male koalas are larger than that of females (Table 2) (Martin and Handasyde 1999; Van Dyck and Strahan 2008). In addition, koalas in Victoria generally have smaller home ranges than those in Queensland (Table 2) (Martin and Handasyde 1999).

In Victoria, koala home range clusters tend to correlate with patches of large scattered trees, but in Queensland, the home ranges are too large to be associated with such clusters (Melzer and Houston 1997). The size of the home range also reflects the difference in population density of koalas between southern states and Queensland. For example, Mitchell and Martin's (1991) research on French Island (Victoria) reported a density of 3.9 to 8.9 koalas per hectare, with average home ranges of 1.18 ha and 1.7 ha for female and male koalas respectively. In this environment the koala density and the home range size reflects the number of "preferred" trees within the habitat, particularly when comparing studies from the Brisbane Ranges and urban areas (Ballarat) of Victoria. In contrast, forests at Lismore support koalas with home ranges of 2.18 ha and 12 ha for female and males respectively, with koala densities at 5.6 per hectare. This increases further north into central Queensland, where Melzer (1994) reported a density of 0.02 to 0.4 koalas per hectare with an average home range of 39.2 ha for females and 86.5 ha for males. This can again reflect the density of preferred fodder species and forest densities across their distribution.

Table 2 Comparison of published home range areas using various methods and koala densities

HM - Harmonic Mean; MCP - Minimum Convex Polygon; MCCP - Minimum Concave Polygon; Cen - Centre of activity; K - Kernel

Sub-species	Location	Analysis method	Mean female area (ha)	Mean male area (ha)	Koala density (no. per ha)
P.c. victor (Victoria)	Brisbane Ranges[1]	90% HM	2.08	3.14	
	French Island[2]	90% HM	1.18	1.70	3.9-8.9
	Phillip Island[3]	MCCP	0.15	0.26	
		Cen	0.35	1.07	
		HM	2.08	3.14	0.7-1.7
		HM	2.6	3.7	2.5
	Ballarat[4]	MCP	15.2	14.4	
P.c. cinereus (New South Wales	Eden[5]	MCP	316.5	149.0	0.006
		90% HM	132.5	83.3	
	Pilliga[6]	95% K	10.6*	18.9*	
		MCP	11.6*	22.8*	
	Lismore (NE NSW)[7]	MCP	2.18	12.76	5.6
	Nowendoc[8]	MCP	9.2		0.5
	Greater Sydney[9]	90% HM	12.40*	46.57*	
P.c. adustus (Queensland)	Springsure[10]	MCP	37.6	79.5	0.02-0.4
		95% HM	39.2	86.5	
	SEQ[11]	MCP	5.55*	11.55*	0.57-0.61
	Sheldon[12]	Cen	13.75	19.67	
	Mutdapilly[13]	70% HM	3.5	8.0	
		95% K	15.0	34.4	
		70% K	5.0	12.5	
	Point Halloran[14]	95% MCP	3.6	2.8	1.9-2.5
		95% Cen	5.6	4.3	
		95% HM	3.3	3.1	
	Blair Athol[15]	95% HM	101.4	135.6	
	St Bees Island[16]	95%MCP	2.78		0.84

1 (Hindell *et al.* 1985); 2 (Mitchell 1990); 3 (Sharpe 1980), (Hindell 1984), (Bednarik 1996) sighted in (Thompson 2006); 4 (Hull 1985) sighted in (Thompson 2006) 5 (Jurskis and Potter 1997); 6 (Kavanagh *et al.* 2007); 7 (Faulks 1990; 1991); 8 (Ramsay 1999); 9 (Ward 2002); 10 (Melzer and Lamb 1994); 11 (Thompson 2006); 12 (Tun 1993) sighted in Melzer 1994; 13 (White 1999); 14 (Hasegawa 1995); 15 (Ellis *et al.* 2002); 16 (Tucker 2008)

* Average calculated

Current government legislation

The koala is an iconic species both nationally and internationally. It has also been used as a flagship species for the preservation of forest and for other forest species. But, where does the conservation of this species stand?

At the level of federal government, the koala is not listed in any legislation, however a current senate inquiry into "the status, health and sustainability of Australia's koala population" will report on the 1st June 2011 and this may influence future federal legislation. Within and across each state, the status and level of protection varies (Table 3). As a native species the koala is protected by law and can not be intentionally harmed. New South Wales and South East Queensland offer the most protection for the koala (vulnerable), both areas with action and/or recovery plans and strategies to preserve and maintain the koala and its habitat.

Table 3 The conservation status of the koala across eastern Australia

Government	Legislation	Status
Federal	Environment Protection and Biodiversity Conservation Act 1999	Not listed
New South Wales	Threatened Species Conservation Act 1995	Vulnerable (two populations listed as endangered)
	National Parks and Wildlife Act 1979	Protected
Victoria	Wildlife Act 1975	Protected
	Flora and Fauna Guarantee Act 1988	Not listed
South Australia	National Parks and Wildlife Act 1972	Protected (was Rare, but de-listed in 2008)
Queensland	Queensland Conservation Act 1992	*Vulnerable* in South East Queensland *Least concern* elsewhere in Queensland
ACT	Nature Conservation Act 1980	Not listed

There is no legislation in states where the koala doesn't occur naturally (Tasmania, Western Australia and Northern Territory).

The koala has also been internationally recognised by The International Union for Conservation of Nature where it is listed as "potentially vulnerable" and the United States Endangered Species Act (for the US Fish and Wildlife Service) where it is listed as "endangered".

Key Threats to Koalas

Habitat Loss & Degradation

The historical decline in koala distribution in NSW can be attributed to land clearing for agricultural and urban development, particularly in areas of high soil fertility (Crowther *et al.* 2009). Today, habitat loss remains the most significant threat to koalas throughout their entire distribution (Crowther *et al.* 2009; Lunney *et al.* 2000; McAlpine *et al.* 2006; Melzer *et al.* 2000; Reed and Lunney 1990). This was also reiterated by all the researchers interviewed for this review (see acknowledgements for details of interviewees).

Historically vegetation clearing for farming and other activities has reduced the wooded area of NSW to just 34% of the state (DAFF 2007). Consequently, habitat loss is considered to be the key cause of declining koala populations (Crowther *et al.* 2009; Lunney *et al.* 2007; Reed and Lunney 1990).

Koalas are totally dependent on a small number of tree species which are found on richer soils associated with the river valleys and flood plains. Interoperations made by Reed and Lunney (1990) from an expansive review of historical literature suggest that koalas were once widespread in NSW with an unfragmented, blanketed distribution. As such, in events such as fires and droughts koalas could individually seek refuge in unaffected areas (usually areas with high soil moisture associated with river systems) and these areas also acted as a source for recolonising effected areas after catastrophic events. With the massive clearing effort up until the 1920's the best habitat (fertile valleys and riparian areas) was not only extensively ring-barked, but it left remaining habitat pockets very fragmented and on the poorer, drier hills and ranges. This fragmentation has made the koala susceptible to natural pressures such as wildfires and drought as well as increased the opportunities for disease to spread in localised, and sometimes, overcrowded pockets (Reed and Lunney 1990).

Urbanization on the east coast continues to be the greatest threat to remaining populations of koalas in these areas, and are threatened in areas where urban development is permitted to clear native eucalypt forests (Crowther *et al.* 2009).

In Queensland broadacre clearing for farming was removing 500,000 ha of eucalypt woodland per year (Martin and Handasyde 1999), until recent changes to legislation that is beginning to preserve some woodlands. In South East Queensland urban expansion is rapidly declining the koala populations by removing habitat and exaggerating other pressures from vehicle strikes, dog attacks and disease (Dique 2004).

Degradation can occur through: some logging regimes; thinning of timber during property development; the destruction of mid-storey shelter trees; and the introduction of weed species (Natural Resource Management Ministerial Council 2009). One of the major threats to koalas in the Pilliga forests is infected injuries from the introduced Tiger Pear cactus, *Opuntia aurantiaca* (Kavanagh *et al.* 2007). While in Victoria koalas are affected by Blackberry and other invasive species which limit koala movement through the landscape.

Disease

Chlamydia is the most prevalent koala disease. It is caused by *Chlamydia pecorum* and *C. pneumoniae* (Girjes *et al.* 1988; Ward 2011). Koalas with *C. pecorum* generally show overt signs of infection while those with *C. pneumoniae* have less severe symptoms; however a koala can have both strains (Girjes *et al.* 1993). An individual koala can be infected with the disease and show no clinical symptoms (Ward 2011), however, once symptoms manifest koalas will exhibit one or more of four conditions, including:

- keratoconjunctivitis which may cause blindness - leading to reduced mobility and feeding capacity and can increase the risk of predation or harm to the animal;
- pneumonia and upper respiratory infections;
- urinary tract infections - causes discomfort to the animal and an increased chance of dehydration as the animal has a reduced capacity to maintain water levels, untreated it can lead to kidney failure. This condition is often reported as 'wet tail' or 'dirty bottom';
- reproductive tract infections - which, particularly in females, can cause infertility and affect the reproductive capacity of the population.

Reproductive tract infections (the most prevalent of the conditions) have been shown to lower the fecundity rates of populations. An example of this: a Chlamydia free populations in Victoria, on French and Phillip Islands has an average fecundity rate of 68.59 % ± 2.76 and 70.67 % ± 6.01 respectively (Every 1986; Martin 1981; McLean 2003) while fecundity rates of Chlamydia infected mainland Victorian koala populations are significantly lower (ranging 9 % to 42 %) and this was attributed to the effects of the disease on reproduction (McLean 2003).

Chlamydia is not considered a threat to overall population survival (Gordon *et al.* 1990; Reed and Lunney 1990), however, stress from other pressures can trigger overt Chlamydiosis (Ellis 1997). Lower fecundity rates and disease outbreaks will have long term effects on a koala population's persistence.

Koala Retrovirus (KoRV) has also been isolated from koalas in Queensland and New South Wales and although there is some evidence that the presence of KoRV increases the severity of Chlamydial disease (Hanger and Loader 2011) there is no evidence that this is a threatening process to overall koala populations. Koalas are also susceptible to a suite of other viruses, infections and conditions, none of which pose a great threat to population survival.

Predation (natural and feral)

Natural predators pose a threat to individual koalas on the ground and in the trees. Foxes (Ramsay 1999) and dingos (Martin and Handasyde 1999) have been reported to prey on koalas: particularly small individuals, juveniles or sub-adults. Raptors and owls have also been observed to kill, or attempt to kill young or smaller individuals (Barnard 1925; Hambling and Pavey 2008; Marchant and Higgins 1993; Melzer *et al.* 2003).

Domestic and/or feral dogs constitute a key threatening process for koalas. This is particularly prevalent in urbanised areas of NSW and Southeast Queensland (Dique *et al.* 2004; Lunney *et al.* 2007). Modelling done by Lunney et al. (2007) show that fires and fragmentation mask the true effects of dog attacks and suggest that immediate action is needed to reduce the number of koalas killed by feral and roaming domestic dogs as they have a significant effect on population viability. The long term viability of the Port Stephens population in particular is dependent on reducing mortality (Lunney *et al.* 2007; Reed and Lunney 1990).

Collisions

With the loss of habitat, particularly associated with urban development, koalas are being drawn to remnant pockets of vegetation and many of these are in road verges, increasing the opportunity for a road accident. Vehicle accidents are one of the biggest threats to individual koalas in and around urban areas (Dique *et al.* 2003b; Nattrass and Fiedler 1996; Thompson 2006). In southeast Queensland alone, during 2009 and 2010, the Moggil Koala Hospital and Australia Zoo's Wildlife

Hospital reported 154 admissions resulting from vehicle accidents, of which only 48 were able to be released (Pine Rivers Koala Care Association Inc. 2010).

Motor vehicle accidents are also prevalent in northern New South Wales. Vehicle strike is the second highest reason for admission of koalas to the Koala Hospital at Port Macquarie, NSW (Koala Hospital - Port Macquarie 2010), with an average of 39 koalas (198 in total) admitted over the last five years (Koala Hospital, Port Macquarie, pers. comm.). Just north of Port Macquarie, 227 koalas have been taken into care after vehicle accidents by the Friends of the Koala Inc. in Lismore (Friends of the Koala 2009).

Natural Events

Drought

Koalas in areas of high temperatures develop adaptive behaviours to minimise their water loss and metabolic rates to mitigate the effects of weather extremes on their bodies (Clifton 2010; Ellis *et al.* 2010). In times of high day time temperatures koala will show behaviours of using non-fodder tree species to gain an advantage (Kavanagh *et al.* 2007; Pfeiffer *et al.* 2005; Tucker *et al.* 2008). Their selection of tree in this situation has been shown to offer a thermal advantage by way of providing a microclimate to buffer the effects of climatic conditions (Clifton *et al.* 2007; Ellis *et al.* 2010).

Where droughts are severe there is well documented evidence of the devastating effects on koala populations with Gordon et al. (1988) reporting a 63% reduction in the population numbers during a drought in southern Queensland in the early 1980's. In this case the only animals that survived the severe conditions were those in habitat close to permanent water holes. The defoliation of drought stressed trees resulted in the malnutrition and dehydration of koalas away from the better quality habitat. In years to follow with good seasons the population did recover and recolonise the area.

This emphasises the importance of refuges of prime habitat to provide a retreat in poor conditions and to allow for the reestablishment of the population after the event. Martin and Handasyde (1999) believe that this retreat and expansion over time with poor and good conditions has a naturally occurring and continuous effect on the western edge of the koalas distribution.

Wildfire

Population viability modelling based on koalas in the Port Stephens area has demonstrated that fire and dog attacks are the two greatest risks to koalas (Lunney *et al.* 2007). The impact of fire on an entire population is magnified as it becomes more fragmented and thus more susceptible to the effects and with no recruitment possibilities. An example of this is the slow decline in koala populations in the Port Stephens area, where habitat loss and fragmentation are worsening the effects of fires and dogs on koala populations. This is one of the remaining strongholds for koalas on the north coast of New South Wales (Lunney *et al.* 2007; Reed and Lunney 1990).

Lunney's model surprisingly showed that a reduction in major fires (when accompanied by smaller fires) had little effect on the predicted demise of the population, however his model didn't take into account the spatial patterns of the fires or the temporal effects of building fuel loads between fire events. It also showed that total elimination of fire and predation lead to predictions of rapid positive population growth, potentially leading to localised overpopulation (and the accompanying overbrowsing and defoliation of trees).

Work in the Pilliga forests (of northern New South Wales), have also identified wildfire as one of the major threats to the koala population in this area (Kavanagh *et al.* 2007). The most recent and destructive wildfires in southern Australia, the Black Saturday fires of 2009, severely burnt much of the Victorian landscape. The eucalypt plantation forests of the Strzelecki Ranges managed by Hancock Victoria Plantations (HVP) were affected in these fires. These Ranges support approximately 50% of the HVP koala habitat plantation forests and 50% of these were burnt. The Black Saturday fires claimed substantial numbers of koalas but it is difficult to assess the true number effected (Steve Wentworth, HVP, pers. comm.).

There is a long history of fire in Australian forests with Aborigines and Europeans alike, and koalas have persisted despite this regime. A low intensity fire may affect some individuals but recruitment and reestablishment of the population can easily follow. In a more intense and widespread fire there is a higher proportion of the koala population effected, the opportunity for recruitment is reduced and the effect on the population is more severe. After fire a tree will soon develop epicormic growth and this is sufficient to maintain koalas. Within a few weeks after the 1993 fires in Port Stephens, koalas were successfully reintroduced into burnt habitat (Martin and Handasyde 1999).

Eucalypt dieback

Dieback is a very general term that refers to the gradual dying of trees due to many factors, which may include one or more of the following: land degradation, leaching of nutrients, rising water levels, salination, erosion and weather conditions. However, in southern Australia, areas of cooler and wetter environments have battled a root-rot fungus from the genera *Phytophthora*. *Phytophthora* spp. has been catastrophic on the flora of south-west Western Australia and is a concern in South Australia, Tasmania and Victoria.

There are several species of *Phytophthora* present in native vegetation in the south-west of Western Australia, with the most widespread and destructive species, *Phytophthora cinnamomi*, thought to have been introduced soon after European settlement. Of the 9 000 native species in this area, up to 2 000 are susceptible to dieback disease (DEC 2011). It is wide spread in coastal NSW forests (ECCW 2008), and easily spread by any movement of the soil (from machinery/vehicles, native and feral animals and foot traffic, etc.). There are many koala fodder species listed by the NSW Department of Environment, Climate Change & Water that may be threatened by this pathogen (ECCW 2008).

Although this disease has no direct effect on koalas, it has the potential to significantly alter the habitat structure and composition of forests (Garkaklis *et al.* 2004). Substantial changes to forest structure have been well documented in Western Australia and the Brisbane Ranges, Victoria (Garkaklis *et al.* 2004). Koalas have a significant proportion of their habitat area which is susceptible to *Phytophthora* dieback (Garkaklis *et al.* 2004).

Climate change

Climate change predictions, from CSIRO & BoM (2007), that will affect eastern Australia include:

- An increase of temperate by 1^{o}C by 2030 - but with this there will be an increase in temperature extremes, with “substantially more days over 35^{o}C”.
- A decrease in annual rainfall, but an increase in intensity of rain events (including cyclones), as well as an increase in evaporation rates.
- A higher frequency of droughts along with an increase in “high-fire-danger” weather (particularly in the south-east).
- Increase in atmospheric CO_2 levels.

An increase in atmospheric CO_2 and the resulting effects of "CO_2 fertilisation" promotes faster plant growth which reduces protein levels and increases levels of tannins (SSC 2009). This reduces the overall nutritional quality of Eucalypts and impacts on all species that forage their leaves. For koalas, where Eucalypts contribute to almost all their diet, these reduced nutritional values may lead to malnutrition and starvation (SSC 2009) however there are no published data about the true effects.

The biggest issue with a changing climate is that it exaggerates the effects of other natural disasters, for example an increased frequency and length of droughts and wildfires, ass well as changes to other weather conditions, such as temperature, rainfall and humidity. These conditions affect the koala itself and its habitat. It is predicted that slow changes in the species composition and extent of koala habitat will be seen (Adams-Hosking *et al.* 2011, Natural Resource Management Ministerial Council 2009).

Current policies and strategies for forestry

New South Wales

In New South Wales forestry operations are required to comply with three legislative acts: the *Protection of the Environment Operations Act 1997*, the *Threatened Species Conservation Act 1995*, and the *Fisheries Management Act 1994*. In response to these requirements the government licences' forestry activities through Integrated Forestry Operations Approvals (IFOA) which have been developed for four operational units of forestry management: the Upper North East Region, the Lower North East Region, Eden and the Southern Region (Figure 2). In all these agreements every species of conservation significance that does/or may occur in the region is outlined with specific management protocols for assessment and on ground responses to the species presence before and during forestry activities.

A multi-catchment survey in NSW supports this localised, catchment approach to the management of koalas, showing that a broad (multi-catchment) approach is not sufficient (Crowther *et al.* 2009) and a more effective koala management approach should be developed at a catchment scale rather than at a broader region or state level.

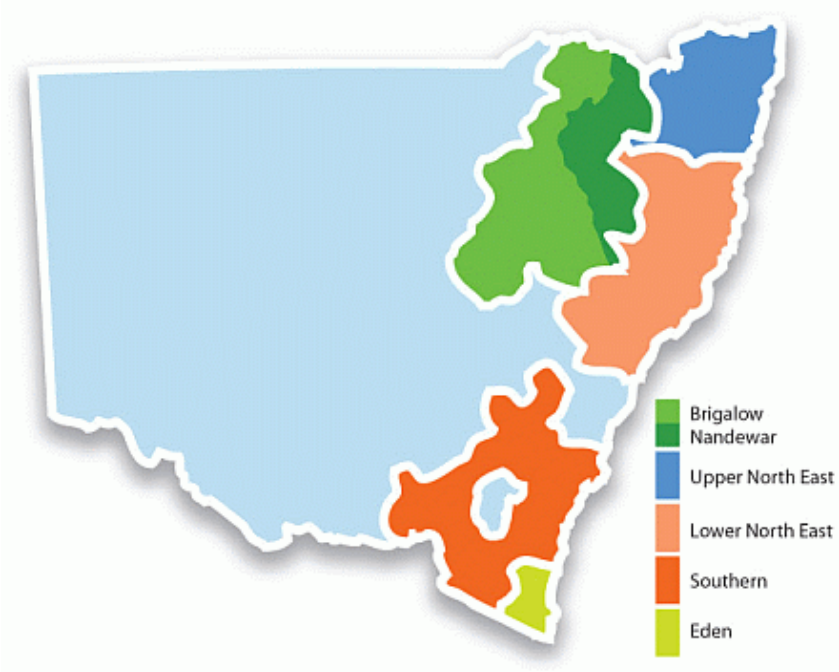

Figure 2 **Forestry management areas of New South Wales (taken from: http://www.environment.nsw.gov.au/forestagreements/index.htm)**

One or more methods of determining the presence of koalas is employed, depending on the evidence or likelihood of koalas being present and the management region. These include:

Transect survey and Quadrats method - in core koala habitat in the Southern Region and if a koala has been detected within 2km of the compartment since 1980 - transects of 50 to 100m intervals uniformly positioned across the harvest area, along the transects at intervals of 25 to 50m, four randomly placed quadrats (50 x 50cm, within 10m of the transect) are assessed for koala scats. Additionally, quadrat areas are also assessed for tree scratches and predator scats to indicate any presence of koalas.

Transect survey - in intermediate koala habitat in the Southern Region - transects of 50 to 100m intervals uniformly positioned across the harvest area and are traversed to determine the presence of koala scratches and/or scats. If evidence is found, it is confirmed by undertaking a quadrat assessment as above.

Traverse survey with quadrats - in marginal koala habitat in the Southern Region - random areas of the forest are traversed so that at least 6km of forest is assessed in four person hours per 200ha of habitat. During the traverse, quadrats are assessed at approximately 50m interval's (methods as above).

Tree inspections - in preferred koala habitat in the Upper and Lower Northern Regions - trained personnel inspect trees (>30cm dbhob) at 10m interval's and search at least 1m from the base of each tree for evidence of scats.

If any of these surveys determine a presence of koalas, an asterisk survey must then be undertaken. This involves designating the tree with koala evidence as "centre tree 1" and running four, 100m long transects at the cardinal compass points, along which all trees within 15m are inspected for evidence of/or koalas. If evidence is found it is confirmed by the presence of scats using four to eight quadrat searches per crown. If scats or a koala is found in this format, and the tree is more than 20m from the pervious, the next tree is considered as "centre tree 2" and the process of transects and a search is repeated, and so on. This continues until no further evidence of koalas are found in the cardinal compass searches. The interest area is then searched further by establishing up to four more (where not overlapping) transects from the "centre trees" at intermediate directions (NE, NW, SE, SW).

Extensive data of tree sizes and densities and nearest neighbours for each "centre tree" is collected and reported in the pre-logging reports and are used to make assessments of logging activities.

Where koalas or evidence of koalas has been established, the following exclusions to logging activities must be adhered:

- Where 1 or 2 “centre trees” are found, a logging exclusion of 50m radius around the points is taken up.
- Where 3 or more “centre trees” are found in an asterisk search the same 50m radius exclusion zone is implemented as well as any areas that lie between these.

Any exclusion zones retained (as above) must be connected with other retained areas within the forestry compartment by a corridor (40m minimum width) which links with a second (or higher) order stream exclusion zone, covers representative habitat of mid slope and ridge top habitats, and incorporates koala browse species.

Where koala evidence within the logging compartment has been found under an asterisk survey, a total of 150ha of suitable koala habitat must be retained within 1.5km of the “centre trees”, made up of exclusion zones and corridors or supplemented with other areas if necessary. Suitable habitat is defined specifically in the documentation and includes sufficient fodder species and areas of similar habitat as that identified in the asterisk surveys.

These exclusion zones are then protected from any disturbance or interference throughout the duration of logging activities and protected from post logging burning.

Victoria

In Victoria the issues are the opposite of that elsewhere, in that koalas are over populating in some areas and management issues associated with Victorian koalas include: conserving habitat and managing over-browsing (DSE 2004). Victorian commercial harvesting of native timber predominately occurs in Eastern Victoria. The main koala populations which may be impacted occur in the eucalypt plantation forests of the Strzelecki Ranges and native forests in central and western Victoria. In these locations Special Protection Zones (where harvesting is excluded) and habitat prescriptions, minimise the effects on koalas (DSE 2004).

In HVP plantations, a Koala Management Plan outlines company policies to protect koalas on their lands (HVP 2011). According to this plan, HVP has many management objectives to preserve koalas and their habitat (HVP 2010). Some of these initiatives include:

- Identify koala habitat and improve corridor links between priority habitat areas and restore priority forests;
- Temporary retention of refuge trees in priority areas after harvesting;
- Improve koala habitat by removing weeds (e.g. blackberry), and participation in corporative weed and pest control programs;
- Replace plantation pines in road reserves, non-viable pockets and plantations in close proximity to riparian corridors with indigenous species;
- Retention of all *Eucalyptus viminalis* (primary fodder species) plantations for koala habitat; and
- Preservation of eucalypt plantation trees in close proximity to corridors and waterways.

The company has very recently, proactively, implemented their koala management plan which has involved the recent training of most operational staff to search and identify koalas and their markings and scats, as well as the commissioning of a "koala habitat atlas" (through the Australian Koala Foundation) that they are in the process of incorporating into their zoning of priority areas.

While logging, if a koala is found in the coupe, activity will cease around the animal and it will be left to make its way out of the area overnight, logging does not recommence until the animal has moved on (Steve Wentworth, HVP, pers. comm.). To facilitate this, the planning process will examine potential corridors and escape routes from coupes and HVP actively maintain and manage native buffers for weeds and species composition which also aid the koala's movement away from logging areas.

Forestry Management

Profile of forestry activities and koala occupancy

Forested areas across Australia cover close to 150 million ha or 19% of the land area (DAFF 2010). Of these, almost 12 million ha are tenured as timber production forests, with Victoria having by far the greatest proportion of the state tenured as such (Table 4). The most common land tenure in both NSW and Queensland is private or lease hold land. The timber production industry was valued at $23 billion in 2008 (DAFF 2010), contributing 0.7% to the National GDP.

The focus of this investigation is south eastern Australia, which encompasses Victoria and New South Wales. Each of these states has very different legalisation, forest activities and management, so a brief background of each will be discussed.

Table 4 Area ('000 ha) of forested land in each tenure type across Australia (from the Australian Government Department of Agriculture, Fisheries and Forestry, Bureau of Rural Sciences (DAFF 2007))

	Timber Production	Nature Conservation	Other Crown Land	Private Land	Leasehold Land	Unresolved Tenure	Total
QLD	3,884 8%	3,225 7%	1,682 4%	9,182 20%	28,199 61%	54 0.1%	46,228
NSW	1,797 7%	4,899 18%	1,801 7%	6,985 26%	9,144 34%	2,117 8%	26,742
Vic	3,308 43%	3,006 39%	175 2%	1,183 15%	43 1%	1 0.01%	7,716
ACT	2	108	0	0	11	0	121
NT	0	46	332	16,694	17,804	3	34,879
SA	5	3,933	373	852	5,227	399	10,789
Tas	1,212	926	98	900	0	0	3,137
WA	1,612	4,364	13,206	1,502	14,025	90	34,800
Australia	11,819	20,506	17,669	37,299	74,454	2,664	164,411

- Timber production forests: publicly-owned forests set aside for timber production, including state forest and timber reserves, in which timber production and mining are permitted together with a range of other commercial and non-commercial activities.
- Nature conservation: publicly-owned forests reserved for conservation, including national parks and flora reserves.
- Other crown land: forests on crown (public) land not covered by the previous categories. This grouping includes such tenures as Aboriginal reserves, defence land, mining reserves and sundry others
- Private forests - forests owned privately
- Leasehold land: publicly-owned forests on land leased from the crown

New South Wales

There are 600 parks and reserves in NSW which cover more than 7% of the state, and 700 state forests. Over the whole of NSW, 34% or 27¼ million ha is forested, of this 16.4% is native forests on public and state land, while 19.1% is plantation forests (Sustain Ability International 2011).

Forests NSW is a government business within the NSW Department of Primary Industries who manage 2.4million ha of native and planted (pine and native species) forests on NSW. Of these approx 3% of native forests are harvested annually (Forests NSW 2008).

Victoria

In Victoria there are 360,000ha of timber plantation and 7.9million ha of native forest, of which only 740,000 ha are viable for logging (VAFI 2011). Around 5,500ha of native forest are harvested annually, with 3.6million ha of native forest in conservation reserves (VAFI 2010).

The commercially logged, State forest in Victoria have few resident koala populations as most of the koalas range is outside of the main commercially harvested native forests. Although there is no specific state legislation for managing Koalas in Victoria, VicForests manages areas where koala are present by excluding approximately 100ha of forest from harvesting where there are resident koala populations (M. Ryan, Forest Scientist, VicForests, pers. comm.).

As one of Australia's largest timber plantation companies, Hancock Victorian Plantations (HVP), manages 254,000ha of land in Victoria, of which 50,000ha is native vegetation managed for conservation. HVP, or its predecessors, have been developing plantations since the 1930's and harvesting timber since the 1950's, by planting timber production forests on previously cleared farming lands.

Over recent years they have donated or exchanged more than 4,500ha of land, mainly in the Strzelecki Ranges, for the creation of national parks and conservation reserves (HVP 2011). The clear felling of mosaic coupes, harvest between 3 to 4% of HVP forests annually in a rotation of 25 to 30 years (HVP 2010). Most coupes are 40 to 50ha but can range from 5 to 100ha in size.

Forests managed by HVP are mainly plantations of *Pinus radiata* (Radiata Pine), *Eucalyptus globulus* (Southern Blue Gum) and *E. regnans* (Mountain Ash) (Steve Wentworth, HVP, pers. comm.). In the future, HVP plans to phase out plantations of *Eucalyptus globulus*, to newly introduced *E. nitens* (Shining Gum). *Eucalyptus globulus* is a primary fodder species for koalas in this area, *E. regnans* is

considered a secondary fodder species, if there is also a primary fodder species present. HVP is currently investigating the koala's utilisation of *E. nitens*.

The Strzelecki koala is of particular conservation importance, as it represents the original koalas of Victoria before extinctions elsewhere and the genetic bottlenecking produced by translocations to (and later, from) islands (HVP 2010).

Forestry specific koala research

The direct research into the effects forestry activities on koalas is very limited. A small number of researchers have investigated the issue over a limited geographical area. From the research, there is evidence from New South Wales that suggests koalas can persist in forests disturbed by logging (Jurskis 1996; Kavanagh *et al.* 1995; Kavanagh *et al.* 2007; Smith 2004). These studies, from the Pilliga Forests, Eden State Forest and Pine Creek State Forest, monitored koala populations before during and after logging and found that logging had no short or medium term effect on the populations.

Kavanagh et al. (2007) found no effects on population biology from logging at the Pilliga Forests, there was no difference in population survival or fecundity rates or mortality between logged and undisturbed areas of the forest. In this study the clear felling of coupes applied forestry protocols, where cypress pine was harvested, leaving 30 metre wide strips on each side of creek lines and the retention of trees centred around 'high use' locations, determined by the presence of >50 faecal pellets.

Kavanagh et al. (2007) identified the importance of a minimum number of eucalypt trees per hectare for koala habitat and suggested a minimum threshold of 20 eucalypt trees larger than 20 cm diameter at breast height (DBH) per hectare to maintain habitat quality. Similarly, in the Eden State Forest, research recommended the retention of koala habitat to include "browse tree species in sizes greater than 30cm DBH" (Jurskis, 1997).

Studies done at Pine Creek State Forest (6400ha in north-east NSW) showed a variation in koala density among different forest structures and harvesting history. Koala preferred structurally complex (uneven ages, with old growth elements, and high species diversity) forests. Habitat preferences favoured areas with larger trees (40-80 DBH) (Smith 2004). More recent studies in Pine Creek by Radford (unpublished) have found that logged forests continued to support koala populations in the area (R. Kavanagh, pers. comm.) however caution is required due to the retrospective nature of the study, with no pre-logging comparisons. The radio tracked koalas were found to use a range of forest structures and a variety of species richness (R. Kavanagh, pers. comm.), with this research yet to be published.

Reports from Forests and Rangeland Ecosystems Research at the NSW Industry and Investment also show that koalas will use relatively young eucalypt plantation forests (6 to 10 years). On occasions satellite tracked animals crossed paddocks or crops to reach young plantation vegetation, however,

when the plantation was close to or adjoining remnant vegetation the koalas utilised the eucalypts regularly (Kavanagh *et al.* 2010). This shows that koalas are adaptable and will use areas and fodder in regrowth or plantation forest coups.

There is evidence from south eastern New South Wales that the State Forests in the Eden region contain the core of the remaining koalas of the region (Crowther *et al.* 2009). However, these koalas have not been investigated fully and little is known about the impact of forestry activities on their survival.

Discussion

With the long term sustainability of forest industries being dependent on the maintenance of multiple-use timber production forests, koalas have the opportunity to simultaneously utilise and take advantage of these habitats. Some of the now forested areas in Victoria which are important Koala habitat were planted for timber production (between 1930 and 1950) after being completely cleared for farming or broadacre logging. In NSW the regulated timber industry ceased land clearing on vast estates after extensive areas were completely cleared for agriculture and livestock. In many of these areas koalas may have become locally extinct without the habitat provided by the industry.

The nature of the forestry industry being business based, also allows for the upkeep and maintenance of the lands, through the control of weed and animal pests, maintaining fire breaks and managing traffic. This active management is not always possible in National Parks and Reserves and can be difficult on private and leasehold lands. Forestry management maintains the forest integrity and structure as well as pests. For example, the management of feral pests (particularly dogs) has a direct carry on effect for koala populations.

The most obvious threat to individual koalas from the forestry industry is harm to individuals during the process of clear felling. This has been noted in Hancock Victorian Plantation (HVP) forests with recent incidences of koalas occupying trees being felled and also of collisions with harvesting equipment. In the majority of cases the animal is released on site, while koalas with severe injuries are transported to care at a nearby facility operated by the Southern Ash Wildlife Shelter. There are no similar instances from NSW, where pre logging surveys and mitigation policies are in place.

The destruction of koala habitat by timber harvesting can be a threatening process in any forest. The very limited research to date shows no overall effects on koala populations from timber harvesting activities in forests, due to logged forests being regenerated or the establishment of plantations (of Eucalypts) which restores habitat. This, as well as the current procedures to preserve koala use areas and provide buffers and corridors to un-harvested areas in NSW and the preservation of riparian and corridors in Victoria, provides opportunities for koalas to exist with the logging activities. This is not the case of clearing on private or lease hold land, for urban development, agriculture and livestock, as the land use permanently changes and there is no regeneration of forest/habitat, which is a much more significant loss for koalas.

Forestry activities can open the forest to other threats by providing transport corridors for the introduction of disease and access track for pests (particularly wild dogs and dingoes). In Victoria

nurseries for plantation plants are operated and treated for *Phytophthora* spp. to limit the spread and effect of this disease (Steve Wentworth, HVP, pers. comm.). All the forestry agencies have active pest management policies for the control of wild dogs from these forests, which limit the extent of impact these will have on the koala population.

The assessment of koala habitat areas (according to the IFOAs) in the various regions of NSW State Forests is quite intensive and is constantly under review. The continual refinement of these techniques to the best possible methodology will enhance the strategy and allow it to develop around new techniques and koala behavioural ecology for each specific region.

The mosaic nature of coupe logging and the rotational periods for coupes being 25 to 30 years in most areas provides an opportunity for koalas to avoid impact areas and persist in adjacent forests. This, along with the evidence of koalas utilising relatively young (5 to 10 year old) regrowth, and preferring multi age and complex forest structures provides support for the continued sustainability of koalas in timber production forests.

One issue of roost and fodder tree preferences being locally specific (Hindell *et al.* 1985; Hindell and Lee 1987; 1988; Hindell and Lee 1991; Kavanagh *et al.* 2007; Matthews *et al.* 2007; Phillips and Callaghan 2000; Phillips *et al.* 2000), suggests that the 'primary food species' of koalas at each logging site be retained in the same mix in regeneration or plantation forests (Kavanagh *et al.* 2007; Phillips and Callaghan 2000; Phillips *et al.* 2000; Smith 2004). However, to do this a full understanding of the koala's behaviour and preferences in each site or area needs to be ascertained through further investigations and research programs, and then, most importantly, this information must feed into the management and policies of timber production forests.

Lower elevations and high soil fertility were the two key parameters indicating koala presence in NSW, however urban and rural developments also favour these areas (Crowther *et al.* 2009). Reserves and conservation areas in NSW tend to be on higher elevations and infertile areas so are not effective in the preservation of koala populations (Crowther *et al.* 2009). Therefore the timber production forests create suitable habitat in areas suitable for koala populations (on areas of high soil nutrients and lower altitudes).

Koalas persist in areas of private or lease hold land as well as within national parks or forestry estates (Reed and Lunney 1990), suggesting that the future persistence of koalas across Australia needs to have an integrated approach regardless of land tenure. It is insufficient to manage koalas

in a single tenure, such as within a forestry area. A coordinated and regional approach is necessary to ensure the future sustainability of koala populations.

Conclusion

Due to the history of development in Australia and the allocation of some remaining forested areas to timber production, by default, the forestry industry has inherited the fauna that occupies them. As custodians of these lands and forests, the forestry industry has developed policies and strategies to reduce their impact on the environment and specifically koalas and other significant fauna. These strategies and management plans along with operational and logging protocols need to be continuously updated and amended to take into consideration all new research and accepted techniques for monitoring and managing koalas in harvested forests.

Considering all the threats facing the koala populations, particularly in areas around urban development, the sustainability of timber production forests, and their proactive, and evolving management, has the opportunity to contribute to the future security of koalas on their lands through management actions and strategies that support continued koala research and conservation efforts. There is the potential that further research could demonstrate opportunities for the forestry industry to have a positive effect on the sustainability of koala habitat and the long term perseverance of koalas within forestry estates.

Acknowledgements

We acknowledge and thank all the forestry and research experts we talked to during this review.

Consultations regarding forestry practices were made with:

- Kevin Petty, Planning Manager, Southern Region, NSW Forestry;
- Michael Ryan, Forest Scientist, VicForests; and
- Steve Wentworth, HVP Victoria.

Expert opinions from koala researches were given by:

- Rod Kavanagh, Senior Principal Research Scientist, Forest and Rangeland Ecosystems, NSW Department of Primary Industries;
- Dr Dan Lunney (Senior Principal Research Scientist) and Ms Elly Stalenberg (Koala Survey Project Officer), Biodiversity Conservation Science Section, Department of Environment, Climate Change and Water, Hurstville NSW ;
- Dr Delma Clifton, Centre for Environmental Management, CQUniversity;
- Koala Hospital, The Koala Preservation Society NSW Inc., Port Macquarie, NSW; and
- Contact was also made with the South Gippsland Land Care Network.

References

Adams-Hosking C., Grantham, H. S., Rhodes J. R., McAlpine C. & Moss P. T. (2011) Modelling climate-change-induced shifts in the distribution of the koala. *Wildl. Res.* **38** 122-130

Allen C. D., Saxon M. & McDougall K. (2010) Koala survey in central forests of the Bermagui - Mumbulla: 2007–09: An interim report. Sydney South

Barnard C. (1925) A review of the bird life on Coomooboolaroo Station, Duringa District, Queensland, during the past 50 years. *The EMU* **24** 252-65.

Bednarik R. G. F. (1996) Habitat use by koalas at the Koala Conservation Centre, Phillip Island. University of Melbourne, Melbourne.

Clifton I. D. (2010) High koala mortality associated with low browse moisture in tropical environments. *Aust. Mammal.* **32 (2)**, 157-9.

Clifton I. D., Ellis W. A. H., Melzer A. & Tucker G. (2007) Water turnover and the northern range of the koala (*Phascolarctos cinereus*). *Aust. Mammal.* **29** 85-8.

Cork S. & Sanson G. D. (1990) Digestion and nutrition in the koala: a review. In: *Biology of the koala* (eds A. K. Lee, K. A. Handasyde and G. D. Sanson). Surrey Beatty and Sons, NSW.

Cork S. J. & Hume I. D. (1983) Microbial digestion in the koala (*Phascolarctos cinereus*, Marsupialia), an arboreal folivore. *J. Comp. Physiol., B* **152** 131-5.

Crowther M. S., McAlpine C. A., Lunney D., Shannon I. & Bryant J. V. (2009) Using broad-scale, community survey data to compare species conservation strategies across regions: A case study of the Koala in a set of adjacent 'catchments'. *Ecol. Manage. Restor.* **10 (Suppl. 1)**.

CSIRO & BoM. (2007) Climate change in Australia: technical report 2007. CSIRO.

DAFF. (2007) The tenure of Australian native forests. Department of Agriculture, Fisheries and Forestry. [on-line] http://www.daff.gov.au/brs/forest-veg/nfi/forest-info/tenure

DAFF. (2010) Australia's forests at a glance 2010 - Data to 2009. Department of Agriculture, Fisheries and Foresrty, Commonwealth of Australia, Canberra.

DEC. (2011) Managing dieback. Department of Environment and Conservation. [on-line] http://www.dec.wa.gov.au/content/view/213/2051/

DECC. (2008) Recovery plan for the koala (*Phascolarctos cinereus*). Department of Environment and Climate Change NSW, Sydney.

Dique D., Preece H., Thompson J. & de Villiers D. (2004) Determining the distribution and abundance of a regional koala population in south-east Queensland for conservation management. *Wildl. Res.* **31** 109-17.

Dique D., Thompson J., Preece H., de Villiers D. & Carrick F. (2003a) Dispersal patterns in a regional koala population in south-east Queensland. *Wildl. Res.* **30** 281-90.

Dique D., Thompson J., Preece H., Penfold G., de Villiers D. & Leslie R. (2003b) Koala mortality on roads in south-east Queensland: the koala speed-zone trial. *Wildl. Res.* **30** 419-26.

Dique D. S. (2004) The distribution, abundance and dynamics of a regional koala population in south-east Queensland. In: *School of Life Sciences* p. 189. University of Queensland, Brisbane.

DSE. (2004) Victoria's Koala Management Strategy. (ed P. Menkhorst). Victorian Government Department of Sustainability and Environment, Melbourne.

ECCW. (2008) Infection of native plants by *Phytophthora cinnamomi* - key threatening process listing. [on-line] http://www.environment.nsw.gov.au/determinations/PhytophthoraKTPListing.htm

Ellis W. (1997) Stressors, prevalence of disease and cortisol concentrations in koalas (*Phascolarctos cinereus*). In: *Department of Zoology and Entomology*. University of Queensland, Brisbane.

Ellis W., Melzer A., Clifton I. D. & Carrick F. (2010) Climate change and the koala *Phascolarctos conereus*: water and energy. *Aust. Zool.* **35 (2)**, 369-77.

Ellis W. A. H., Carrick F. N., Lundgren P., Veary A. & Cohen B. (1999) The use of faecal cuticle examination to determine the dietary composition of koalas. *Aust. Zool.* **31 (1)**, 127-33.

Ellis W. A. H., Hale P. T. & Carrick F. N. (2002) Breading dynamics of koalas in open woodlands. *Wildl. Res.* **29** 19-25.

Every K. R. (1986) Evaluation of a decline in population of the koala, *Phascolarctos cinereus* (Goldfuss) in Ventnor Reserve, Phillip I., Vic., by means of a triple-count technique. *Aust. Wildl. Res.* **13** 517-25.

Faulks J. (1990) The ranging behaviour of koalas. University of New England, New South Wales.

Faulks J. (1991) A preliminary investigation of the distribution of koalas and their potential habitat in the Tweed Shire, and implications for management. *Aust. Zool.* **27** 1-13.

Forests NSW. (2008) Timber harvesting in native state forests. New South Wales Department of Primary Industries. [on-line] http://www.dpi.nsw.gov.au/forests/publications/timber-harvesting-native-state-forests

Friends of the Koala. (2009) Firends of the Koala - Conservine koala and their habitat in the Northern Rivers of NSW. [on-line] http://www.friendsofthekoala.org/fok/

Garkaklis M. J., Calver M. C., Wilson B. & Hardy G. (2004) Habitat alteration caused by an introduced plant disease, *Phytophthora cinnamomi*: a potential threat to the conservation of Australian forest fauna. In: *Conservation of Australia's forest fauna (second edition)* (ed D. Lunney) pp. 899-913. Royal Zoological Society of New South Wales, Mosman, NSW.

Girjes A. A., Hugall A. F., Graham D. M., McCaul T. F. & Lavin M. F. (1993) Comparison of type I and type II *Chlamydia psittaci* strains infecting koalas (*Phascolarctos cinereus*). *Vet. Microbiol.* **37** 65-83.

Girjes A. A., Hugall A. F., Timms P. & Lavin M. F. (1988) Two distinct forms of *Chlamydia psittaci* associated with disease and infertility in *Phascolarctos cinereus* (koala). *Infect. Immun.* **56** 1897-900.

Gordon G., Brown A. S. & Pulsford T. (1988) A koala (*Phascolarctos cinereus* Goldfuss) population crash during drought and heatwave conditions in south-western Queensland. *Aust. J. Ecol.* **13** 451-61.

Gordon G. & Hrdina F. (2005) Koala and possum populations in Queensland during the harvest period, 1906-1936. *Aust. Zool.* **33 (1)**, 69-99.

Gordon G., McGreevy D. G. & Lawrie B. C. (1990) Koala populations in Queensland: major limiting factors. In: *Biology of the Koala* (eds A. K. Lee, K. A. Handasyde and G. D. Sanson) pp. 85-95. Surrey Beatty and Sons Pty Limited.

Hambling B. & Pavey C. (2008) Predation on koalas by breeding Powerful Owls. *Australian Field Ornithology* **25 (3)**, 140-4.

Hanger J. & Loader L. (2011) Infectious disease in koalas: Implications for conservation. Australian Wildlife Hospital, A program of Australia Zoo Wildlife Warriors Worldwide Ltd.

Hasegawa M. (1995) Habitat utilisation by koalas (*Phascolarctos cinereus*) at Point Halloran, Queensland. University of Queensland, Brisbane.

Hindell M. A. (1984) The feeding ecology of the koala, Phascolarctos cinereus, in a mixed Eucalyptus forest. In: *Department of Zoology*. Monash University, Melbourne.

Hindell M. A., Handasyde K. A. & Lee A. K. (1985) Tree species selection by free-ranging koala populations in Victoria. *Aust. Wildl. Res.* **12** 137-44.

Hindell M. A. & Lee A. K. (1987) Habitat use and tree preferences of koalas in a mixed eucalypt forest. *Aust. Wildl. Res.* **14** 349-60.

Hindell M. A. & Lee A. K. (1988) Tree use by individual koalas in a natural forest. *Aust. Wildl. Res.* **15** 1-7.

Hindell M. A. & Lee A. K. (1991) Tree preferences of the koala. In: *Biology of the Koala* (eds A. K. Lee, K. A. Handasyde and G. D. Sanson) pp. 117-21. Surrey Beatty & Sons Pty Limited, NSW.

Hull G. (1985) The utilisation of residential areas by the koala, Phascolarctos cinereus Goldfuss, in Ballarat, Victoria. In: *Department of Applied Biology*. Ballarat Council for Adult Education, Ballarat.

HVP. (2010) The Strzelecki Koala. HVP Plantations. [on-line] www.hvp.com.au

HVP. (2011) Hancock Victorian Plantations - environment and conservation. Melbourne. [on-line] http://www.hvp.com.au/index.php

Jurskis V. (1996) Habitat assessment, tree preferences, environmental and history - where's the connection? In: *Australian Koala Foundation Conference on the Status of the Koala in 1996* pp. 31-40.

Jurskis V. & Potter M. (1997) Koala surveys, ecology and conservation at Eden. Forest Research and Development Division, State Forest of New South Wales.

Kavanagh R., Debus S., Tweedie T. & Webster R. (1995) Distribution of Nocturnal Forest Birds and Mammals in North-Eastern New South Wales: Relationships With Environmental Variables and Management History. *Wildl. Res.* **22 (3)**, 359-77.

Kavanagh R., Law B., Lemckert F., Stanton M., Chidel M., Brassil T., Towerton A. & Penman T. (2010) Conservation value of eucalypt plantations established for wood production and multiple environmental benefits in agricultural landscapes: Final report for NAP/NHT2 Eucalypt Plantations project SLA 0013 R3 NAP. NSW Industry and Investment (formerly NSW Department of Primary Industries), Forest and Rangeland Ecosystems Research Program, Forest Science Centre, West Pennant Hills.

Kavanagh R., Stanton M. & Brassil T. (2007) Koalas continue to occupy their previous home-ranges after selective logging in *Callitris-Eucalyptus* forest. *Wildl. Res.* **34** 94-107.

Koala Hospital - Port Macquarie N. (2010) Koala Hospital - Port Macquarie, NSW - The facts about koalas. Port Macquarie. [on-line] http://www.koalahospital.org.au/the-facts

Lunney D., Esson C., Moon C., Ellis M. & Matthews A. (1997) A community based survey of the koala, *Phascolarctos cinereus*, in the Eden Region of southeastern New South Wales. *Wildl. Res.* **24** 111-28.

Lunney D., Gresser S., O'Neill L. E., Matthews A. & Rhodes J. (2007) The Impact of Fire and Dogs on Koalas at Port Stephens, New South Wales, Using Population Viability Analysis. *Pac. Conserv. Biol.* **13 (3)**, [189]-201.

Lunney D. & Leary T. (1988) The impact on native mammals of land-use changes and exotic species in the Bega district, New South Wales, since settlement. *Aust. J. Ecol.* **13** 67-92.

Lunney D., Matthews A., Moon C. & Ferrier S. (2000) Incorporating habitat mapping into practical koala conservation on private lands. *Conserv. Biol.* **14 (3)**, 669-80.

Marchant S. & Higgins P. (1993) *Handbook of Australian, New Zealand and Antarctic Birds. Volume 2 Raptors to Lapwings*. Oxford University Press, Melbourne.

Martin R. W. (1981) Age-specific fertility in three populations of the koala, *Phascolarctos cinereus* Goldfuss, in Victoria. *Aust. Wildl. Res.* **8** 275-83.

Martin R. W. (1985a) Overbrowsing, and decline of a population of the koala, *Phascolarctos cinereus*, in Victoria I. Food preference and food tree defoliation. *Aust. Wildl. Res.* **12** 355-65.

Martin R. W. (1985b) Overbrowsing, and decline of a population of the koala, *Phascolarctos cinereus*, in Victoria II. Population condition. *Aust. Wildl. Res.* **12** 367-75.

Martin R. W. (1985c) Overbrowsing, and decline of a population of the koala, *Phascolarctos cinereus*, in Victoria III. Population dynamics. *Aust. Wildl. Res.* **12** 377-85.

Martin R. W. & Handasyde K. A. (1999) *The koala. Natural history, conservation and management*. UNSW Press.

Martin R. W. & Lee A. (1984) The koala, *Phascolarctos cinereus*, the largest marsupial folivore. In: *Possums and Gliders* (eds A. P. Smith and I. D. Hume) pp. 463-7. Surrey Beatly & Sons Pty Limited, Sydney.

Masters P., Duka T., Berris S. & Moss G. (2004) Koalas on Kangaroo Island: from introduction to pest status in less than a century. *Wildl. Res.* **31** 267-72.

Matthews A., Lunney D., Gresser S. & Maitz W. (2007) Tree use by koalas (*Phascolarctos cinereus*) after fire in remnant coastal forest. *Wildl. Res.* **34** 84-93.

McAlpine C. A., Bowen M. E., Callaghan J. G., Lunney D., Rhodes J. R., Mitchell D. L., Pullar D. V. & Poszingham H. P. (2006) Testing alternative models for the conservation of koalas in fragmented rural-urban landscapes. *Austral Ecol.* **31 (4)**, 529-44.

McLean N. (2003) Ecology and management of overabundant koala (*Phascolarctos cinereus*) populations. In: *Department of Zoology* p. 332. The University of Melbourne, Melbourne.

Melzer A., Carrick F., Menkhorst P., Lunney D. & John B. S. (2000) Overview, critical assessment, and conservation implications of koala distribution and abundance. *Conserv. Biol.* **14 (3)**, 619-28.

Melzer A. & Houston W. (1997) A review of literature of the koala for State Forests of New South Wales. p. 94. Koala Research Centre, Central Queensland University, Rockhampton.

Melzer A. & Lamb D. (1994) Low density populations of the koala (*Phascolarctos cinereus*) in Central Queensland. *Proc. R. Soc. Queensl.* **104** 89-93.

Melzer A., Tucker G., Hodgon J. & Elliott B. (2003) A note on predation on koalas *Phascolarctos cinereus* by raptors, including wedge-tailed eagles *Aquila audax*, in Queensland. *Qld Nat.* **41** 1-3.

Mitchell P. & Martin R. (1991) The structure and dynamics of koala populations - French Island in perspective. In: *Biology of the koala* (eds A. K. Lee, K. A. Handasyde and G. D. Sanson) pp. 97-108. Surrey Beatty & Sons Pty Limited, NSW.

Mitchell P. J. (1990) The home ranges and social activity of koalas - a quantitative analysis. In: *Biology of the koala* (eds A. K. Lee, K. A. Handasyde and G. D. Sanson). Surrey Beatty & Sons Pty Limited.

Munks S. A., Corkrey R. & Foley W. J. (1996) Characteristics of arboreal marsupial habitat in the semi-arid woodlands of Northern Queensland. *Wildl. Res.* **23** 185-95.

Nattrass A. E. O. & Fiedler K. B. (1996) Koala rescue - the perception and the reality. In: *Koalas: Research for Management - proceedings of the Brisbane koala symposium* (ed G. Gorden) pp. 129-36. World Koala Research Inc., Brisbane.

Natural Resource Management Ministerial Council. (2009) National Koala Conservation and Management Strategy 2009-2014. Department of the Environment, Water, Heritage and the Arts, Canberra.

Penn A. M., Sherwin W. B., Gordon G., Lunney D., Melzer A. & Lacy R. C. (2000) Demographic Forecasting in Koala Conservation. *Conserv. Biol.* **14 (3)**, 629-38.

Pfeiffer A., Melzer A., Tucker G., Clifton D. & Ellis W. (2005) Tree use by koalas (*Phascolarctos cinereus*) on St Bees Island, Queensland - Report of a pilot study. *Proc. R. Soc. Queensl.* **112** 47-51.

Phillips B. (1990) *Koalas: the little Australians we'd all hate to lose*. Australian Government Publishing Service, Canberra, ACT.

Phillips S. & Callaghan J. (2000) Tree species preferences of koalas (*Phascolarctos cinereus*) in the Campbelltown area south-west of Sydney, New South Wales. *Wildl. Res.* **27 (5)**, 509-16.

Phillips S., Callaghan J. & Thompson V. (2000) The tree species preferences of koalas (*Phascolarctos cinereus*) inhabiting forest and woodland communities on Quaternary deposits in the Port Stephens area, New South Wales. *Wildl. Res.* **27 (1)**, 1-10.

Pine Rivers Koala Care Association Inc. (2010) Koala Statistics. Department of Environment and Resource Management and Australian Wildlife Hospital. [on-line] http://www.prkoalacare.com.au/statistics.html

Ramsay S. (1999) The ecology and dispersal patterns of juvenile koalas, *Phascolarctos cinereus*, in fragmented habitat. In: *School of Biological Sciences* p. 234. University of Sydney, Sydney.

Reed P. & Lunney D. (1990) Habitat loss: the key problem for the long-term survival of koalas in New South Wales. In: *Koala summit: managing koalas in New South Wales* (eds D. Lunney, C. A. Urquhart and P. Reed) pp. 9-31. New South Wales National Parks and Wildlife Service (Hurstville), Sydney.

Reed P., Lunney D. & Walker P. (1990a) Survey of the koala *Phascolarctos cinereus* (Goldfuss) in New South Wales (1986-87), with an ecological interpretation of its distribution. In: *Biology of the Koala* (eds A. K. Lee, K. A. Handasyde and G. D. Sanson). Surrey Beatty & Sons, Norton.

SSC (Species Survival Commission) (2009) Koalas and climate change, Hungry for CO2 cuts. The International Union for Conservation of Nature and Natural Resources (IUCN) Red List of Threatened Species. [on-line] http://cmsdata.iucn.org/downloads/fact_sheet_red_list_koala_v2.pdf

Sharpe L. L. (1980) Behaviour of the koala, *Phascolarctos cinereus* (Goldfuss). Monash University, Melbourne.

Smith A. P. (2004) Koala conservation and habitat requirements in a timber production forest in north-eastern New South Wales. In: *Conservation of Australia's Forest Fauna* (ed D. Lunney) pp. 591-611. Royal Zoological Society of New South Wales, Mosman.

Sullivan B. J., Baxter G. S., Lisle A. T., Phal L. & Norris W. M. (2004) Low-denisty koala (*Phascolarctos cinereus*) populations in the mulgalands of south-west Queensland. IV. Abundance and conservation status. *Wildl. Res.* **31** 19-29.

Sustain Ability International. (2011) NSW Maps & Facts - Australia's Forests. Sustain Ability International. [on-line] http://www.australianforests.org.au/australiasforests/maps-facts-nsw.htm

Thompson J. (2006) The comparative ecology and population dynamics of koalas in the Koala Coast Region of south east Queensland. p. 300. The University of Queensland, Brisbane.

Troughton E. (1973) *Furred animals of Australia - 9th Edition*. Angus & Robertson Ltd., Sydney.

Tucker G. (2008) Ecology, behaviour and growth of sub-adult koalas (*Phascolarctos cinereus*) on St Bees Island, Central Queensland. p. 264. CQUniversity, Rockhampton.

Tucker G., Melzer A. & Ellis W. (2008) The development of habitat selection by subadult koalas. *Aust. J. Zool.* **55 (5)**, 285-9.

Tun U. N. (1993) Re-establishment of rehabilitated koalas in the wild and their use of habitat in Sheldon, Redland Shire, southeast Queensland with particular reference to dietary selection. University of Queensland, Brisbane.

VAFI. (2010) Victorian Association of Forest Industries: Sustainability Report 2010. Victorian Association of Forest Industries, Victoria.

VAFI. (2011) Forestry in Victoria: Key Issues and Facts. Victorian Association of Forest Industries, Melbourne.

Van Dyck S. & Strahan R. (2008) *The Mammals of Australia*. New Holland, Chatswood, Australia.

Ward M. (2011) Chlamydia professional - Comprehensive, evidence based, authoritative. University of Southampton, England. [on-line] http://www.chlamydiae.com/

Ward S. J. (2002) Koalas and the community: a study of low density populations in southern Sydney. p. 215. University of Western Sydney, Sydney.

White N. A. (1999) Ecology of the koala (*Phascolarctos cinereus*) in rural south-east Queensland, Australia. *Wildl. Res.* **26 (6)**, 731-44.