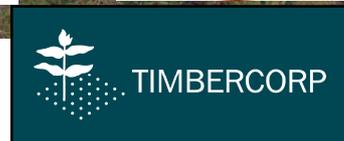




Use of Blue Gum Plantations by Koalas

(a report to stakeholders in the plantation industry by the Australian Koala Foundation)

June 2008



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Executive Summary

Aims

The Australian Koala Foundation (AKF) initiated the idea and was supported by stakeholders in the plantation industry, (see inside cover for full list) to assess the use of Blue Gum (*Eucalyptus globulus* sp.) plantations by the Koala (*Phascolarctos cinereus*). Little is currently known about the Koala's use of Blue Gum plantations and research aimed at expanding this knowledge is an important first step in developing effective management practices for koalas in these plantations. The primary aim of this study was to quantify the extent to which koalas use Blue Gum plantations and whether their use depends upon plantation characteristics; in particular plantation age and size. A secondary aim was to determine whether use of Blue Gum trees within plantations varies with distance away from native forest and tree size. The findings of this study will provide important information upon which to base recommendations for the selection of sites and design of new plantations and harvesting regimes for the long-term management of koalas in plantations at a landscape scale.

Methods

A review of published scientific research on plantations, koalas, and their use of habitat provided a framework for desktop analysis of data from 1045 plantations that were supplied by five stakeholders. A variety of software programs was used to select a sub sample of appropriate sites to be surveyed. Subsequently, Koala faecal pellet surveys of Blue Gum plantations and adjacent native forest were conducted in two phases during 2005/06 using the AKF's Spot Assessment Technique (SAT). A statistical analysis was then conducted to determine the Koala's use of Blue Gum plantations in relation to use of adjacent native forest, plantation age/size, tree size and distance from native forest.

Results

The key findings of the study were:

- 1) No koala activity was found in Blue Gum plantations when there was no koala activity in adjacent native forest.
- 2) When koala activity was detected in adjacent native forest, it was almost always greater in the native forest than in the Blue Gum plantation.
- 3) Plantation age, size and average dbh (diameter at breast height) of trees were weak predictors of the use of Blue Gum plantations relative to adjacent native forest.
- 4) Within plantations, koalas were more likely to use large blue gums close to native forest than small blue gums far from native forest.

Key Recommendations

A full list of recommendations for plantation management, further research priorities, and other tasks is made at the end of this report. However, the key recommendations are listed below:

- Dissemination of findings to all stakeholders through the publication of a paper in a scientific journal as well as in an industry magazine and via public forums such as industry field days.
- Explore the possibility of pre-establishment and pre-harvest desktop-surveys to determine the likelihood of koala occurrence in plantations and for the need for pre-harvest Koala surveys to protect individual koalas in plantations with high Koala activity levels. This would need to be linked with the development of protocols and realistic, practical management strategies as part of further research.

- Further data analysis (and possibly data gathering) resulting in a process that would also contribute to the development of a predictive model for Koala use of native vegetation as well as Blue Gum plantations.
- Undertake a radio-tracking program to establish Koala home range behaviour in both Blue Gum plantations and neighbouring Koala habitat.
- Investigate the importance of retained remnant trees within a plantation design, of incorporating Koala corridors in a plantation layout and the potential for maximising plantation edge with native forest and/or staggered planting / harvesting regimes when practical and financially viable.
- Investigate use of Blue Gum plantations by koalas near a known Koala isolate eg. Mt Eccles.
- Investigate a Koala-friendly eco-certification program to raise awareness of the plantation industry's commitment to Koala conservation.

1 Project Aims

The Australian Koala Foundation (AKF) initiated the idea and was supported by stakeholders in the plantation industry (see inside cover for full list) to assess the use of Blue Gum (*Eucalyptus globulus* sp.) plantations by the Koala (*Phascolarctos cinereus*). Little is currently known about the Koala's use of Blue Gum plantations and research aimed at expanding this knowledge is an important first step in developing effective management practices for koalas in these plantations. The key aims of this project were:

- 1) To quantify the extent to which koalas use Blue Gum plantations and whether their use depends upon plantation characteristics; in particular plantation age and size.
- 2) To determine whether koala's use of Blue Gum trees within plantations varies with distance away from native forest and tree size.

The findings of this study will provide important information upon which to base recommendations for the selection of sites and design of new plantations and harvesting regimes for the long-term management of koalas in plantations at a landscape scale.

2 Background

2.1 Koala Biology and Ecology

Koalas are the largest arboreal marsupial occurring over a wide but fragmented geographical range in Eastern and South-eastern Australia. Koalas feed mainly on the leaves of trees from a small number of species of the genus *Eucalyptus* (Hindell *et al* 1985), which provide a high fibre, low-protein diet (Ellis *et al* 1995). Numerous studies have suggested that koalas need to feed frequently, cannot store excess energy as fat, and rely on a low metabolic rate and behavioural traits such as sleeping and resting to conserve energy (Cork *et al* 2000). Koalas usually feed for two to four hours per day predominately in the early evening, and will eat most leaves within reach, often stripping all leaves on younger branches (Hindell *et al* 1985). It is likely that koalas observed in a particular tree in the daytime will also feed on that tree during the night, although they may subsequently move to a different tree to continue feeding (Hindell *et al* 1985). Ellis (1995) suggested that in drier climates koalas also feed in the morning to obtain extra moisture from dew-laden leaves. There is evidence that koalas move into wetter areas such as drainage lines in times of drought; these animals subsequently have higher survival rates compared to koalas unable to relocate to these areas because of occupancy by dominant resident koalas (Gordon *et al* 1988).

Koalas are sexually dimorphic with males larger than females (McLean and Handasyde 2006) and are significantly larger in Victoria than Queensland, with a weight range of from 6.5-11.8 kg (males) and 5.1-7.9 kg (females).

Females first breed at about two years of age when body weight reaches ~6 kg (McLean and Handasyde 2006), and thereafter usually raise one young per year. Males become fully mature approximately a year after females (Gall 1980). Sex ratios in Koala colonies are unbalanced; the species is polygamous with a dominant “alpha” male mating with

several females (Gall 1980). However, DNA profiling has been used to throw some doubt on the accepted paradigm of the “socially stable breeding aggregation”, Ellis *et al* (2002b) found that resident (i.e. alpha) and transient males sired about equal numbers of offspring. Male koalas may live up to about 10 years in the wild, with females living to about 12 years (Augustine 1998).

Between 20-36 months of age, young koalas disperse from their natal home ranges (about 20% of the total population, a significant proportion of which are males) (Dique *et al* 2003a). Dispersal occurs just prior to and during the early part of the breeding season, which in Victoria lasts from October to March with a peak from November to January (McLean and Handasyde 2006), similar to southeast Queensland (Dique *et al* 2003a). Dispersal distances vary from 0.3 to 10.6 km with an average of 3.5 km (Gall 1980, Dique *et al* 2003a).

Koala breeding dynamics are known to be affected by the bacterial disease *Chlamydia* which may infect the reproductive tract of females, reducing the breeding rate to two years out of three in affected populations (McLean and Handasyde 2006). In Victoria most Koala populations carry *Chlamydia* with the exception of koalas at Framlingham and French Island (McLean and Handasyde 2006). While fecundity of individual females may be affected by *Chlamydia*, the disease does not seem to have an effect on the persistence of specific Koala populations (Augustine 1998), however other researchers suggest that, where other limiting factors such as drought and habitat loss operate, the presence of *Chlamydia* increases population stress (Weigler *et al* 1988, Phillips 2000).

2.2 Koala Tree Use

Koalas generally favour habitats on soils with higher fertility and moisture availability (Lunney *et al* 2000). Near Campbelltown in NSW koalas show a distinct preference for Grey Gum (*E. punctata*) and Blue-leaved Stringybark (*E. agglomerata*) when these species grow on shale-derived soils rather than on sandstone-derived soils (Phillips and Callaghan 2000). Soil fertility requirements have been quantified for some arboreal mammals living in eucalypts, for example the Greater Glider, (*Petauroides volans*), is

found where soils have phosphorus levels of 200-1400 ppm, and in one survey no arboreal animals were observed where soil phosphorus levels were below 50 ppm (Braithwaite 1996). Analysis of leaves offered to captive koalas showed that preferred browse contained a range of 0.08-0.42% phosphorus and 0.30-2.06% potassium (Ullrey 1981). Higher foliar nutrient appears to be the major determinant of arboreal species richness and density in the Eden area of NSW (Braithwaite *et al* 1983). Foliar levels of nitrogen, potassium, and phosphorous were highly correlated, and highly correlated with levels of potassium and phosphorous in the soil (Braithwaite *et al* 1983). Younger foliage contains more nitrogen than mature foliage, and certain preferred tree species provide younger foliage for prolonged periods (Hindell *et al* 1985). Younger foliage also contains less fibre and more moisture and sugars with a resultant increase in digestibility (Moore *et al* 2004b). During drought conditions trees will produce less new foliage and, as the leaves age, nitrogen content of foliage is reduced and may impose severe restrictions on the ability of koalas to satisfy their nutritional needs (deGrabriele 1981). Captive koalas appear to reject foliage when crude protein levels (highly correlated with nitrogen content) fall below about 10% for four species found in northern Victoria, River Red Gum (*E. camaldulensis*), Yellow Gum (*E. leucoxylon*), Red Ironbark (*E. sideroxylon*) and Red Box (*E. polyanthemos* subspecies *vestita*) (Ullrey 1981). It was concluded that, because of the great range in the level of leaf constituents both within and between species, dietary requirements over the long-term could be best met by offering a wide assortment of food choices (Ullrey 1981). The crude protein threshold of 10% was confirmed in wild koalas by Ellis (1995).

Many Blue Gum plantations are established on previously fertilised agricultural land and therefore phosphorus and nitrogen levels will vary depending on the previous management of the paddock. There is a possibility for certain elements to be available to koalas via the foliage of *Eucalyptus* trees at a different rate to what is available in the leaves of trees in the surrounding native forest. However, it is not within the scope of this research to investigate this possibility.

Published studies on koalas' preference for eucalypts in certain areas have sometimes focussed on the role of nutrients as food attractants contrasted with the role of toxic chemicals as feeding deterrents (Cork *et al* 2000). It is thought that where eucalypts grow in nutrient-rich areas, more of the tree energy and nutrient budgets can be directed

towards production of extra foliage rather than the production of “anti-foodants” such as terpenes and some phenolic compounds which discourage consumption of foliage by arboreal mammals (Lawler *et al* 1998). Individual trees of the same species may have highly variable levels of anti-foodant compounds, koalas actively avoid eating leaves from these individuals even though they might be preferred food trees (Lawler *et al* 1998). Koalas fed Yellow Box (*E. melliodora*) reduced their intake by half when the concentration of the phenolic compound sideroxydonal was increased to 45 mg/g (Moore *et al* 2005). In an earlier study, koalas used larger trees with lower levels of anti-foodants (Moore *et al* 2004a) and it seems that even adjacent trees may have differing levels of anti-foodants (Moore *et al* 2004b).

Munks *et al* (1996) in a study in semi-arid north Queensland (mean annual rainfall 492 mm) found a significant positive relationship between leaf water concentration and the occurrence of koalas. This particular study also found that Koala faecal pellet counts were at least an order of magnitude (i.e. 10 times) higher in close proximity to watercourses (Munks *et al* 1996). Additionally, faecal pellet counts increased as species richness and total basal area increased independent of watercourse proximity (Munks *et al* 1996). A mixture of old and fresh pellets was found near watercourses, whereas only older pellets were found on slopes and rises away from watercourses, suggesting that use of these areas was in summer months by dispersing sub-adult males (Munks *et al* 1996). Munks *et al* (1996) observed that these sub-optimal habitats were important to prevent overcrowding of optimal habitats and enable normal dispersal and recruitment social behaviour mechanisms to operate.

In the arid Queensland mulgalands, koalas use a variety of habitats including riverine, floodplain, plains and residual hills. Riverine environments had the highest percentage of trees with faecal pellets under them (47.6%), the dry residual hills had the second-highest percentage (28.6%), floodplains and plains had fewer pellets (9.5% and 14.3% of trees respectively) (Sullivan *et al* 2003).

In Victoria, koalas are widespread at low densities (<1 per ha) in lowland and foothill forests where rainfall exceeds about 500 mm (DSE 2004a). Studies in the Brisbane Ranges of Victoria found that within their home ranges koalas repeatedly favour some

trees and actively avoid others, including trees of the same species (Hindell and Lee 1987). Individual koalas may exhibit a marked preference for certain species compared to nearby koalas with the same choice of species, especially when that species is in low abundance (Hindell *et al* 1985). In the drier Blair Athol area of central Queensland (mean annual rainfall 670 mm) a radio-tracking study found that koalas were mostly only observed using single day-time roosting trees once (1098/1551 occasions), and with a very small proportion of trees (30/1551) used by more than one koala, a finding supported by some other studies (Ellis *et al* 2002). Trees used for roosting were observed to correspond to food trees on 68% of occasions, with the study concluding that day-time roosting trees were not necessarily a good indicator of food tree preferences, especially in areas with different vegetation communities and tree species available within a koala's home range (Ellis *et al* 2002). These findings appeared to differ from Victorian studies where multiple tree use was more common in areas with much higher Koala density (Ellis 2002a). Ellis (2002a) concluded that, over time, koalas would use most of the trees available within their home range, and that assertions about the use of specific trees for social behaviour had little support.

In the same area of central Queensland, Ellis (1995) found a distinct variation in seasonal tree use, with winter food trees providing more energy, and summer food trees providing more moisture, a finding backed by laboratory analysis of collected leaves. Seasonal tree use is also prevalent in Victoria, with koalas feeding on Swamp Gum (*E. ovata*) in winter and Messmate (*E. obliqua*) in summer when this species had abundant new growth (Martin 1985). In south-east Queensland, female access to (*E. tereticornis*) appeared to be an important requirement during the breeding season, at other times of the year they preferred Narrow-leaved Ironbark (*E. crebra*), in part due to males denying access to Forest Red Gum (White 1999). Male dominance of preferred food trees also occurs on the North Coast of NSW (AKF unpub. data). It appears that occupation of preferred food trees by male koalas is an important dynamic in the configuration of breeding Koala populations.

Koalas demonstrate a preference for larger trees (Phillips and Callaghan 2000, Lunney *et al* 2000, Santamaria *et al* 2005), this preference could be due to a number of factors including a larger crown (West *et al* 1991) with subsequently increased food and shelter

resources. Preference for larger trees is independent of sex and season (Hindell and Lee 1987, White 1999, Santamaria *et al* 2005) and in some cases koalas exhibit a seasonal preference for certain tree species within their home range, in other cases they show no such preference (Hindell and Lee 1987). Koalas tend to be sedentary, with the exception of juvenile males dispersing from their maternal range. It would therefore be advantageous for koalas to locate their home ranges in areas containing trees used preferentially in different seasons (Hindell and Lee 1987).

2.3 Koala Home Range Size

Radio tracking of collared koalas is the favoured method of establishing home-ranging behaviour of koalas (White 1999, Ellis *et al* 2002, Dique *et al* 2004, AKF unpub. data).

Determination of the size of Koala home ranges is problematic owing to the patchy nature of habitat use and unsymmetrical shape of home ranges (Hindell and Lee 1988). However, harmonic mean analysis overcomes these issues by defining the main centres of activity within a home range (Hindell and Lee 1988). Hindell and Lee (1988) calculated average home ranges for 10 radio-tracked koalas in the Brisbane Ranges (70 km west of Melbourne) of 3.14 +/- 1.01 ha and 2.08 +/- 0.86 ha for male and female koalas respectively. Male koala home ranges tended to have more than one centre of activity and an irregular shape, whereas female home ranges tended to be circular with a single centre of activity (Hindell and Lee 1988). Home range size may change between breeding and non-breeding seasons with the proportion of overlap between male-female home ranges tending to increase, and male-male overlap tending to decrease (Ellis *et al* 2002). The shape of male koala home ranges may be due to the largely polygamous nature of koala breeding units, an alpha male will attempt to encompass the home range of several females whose home ranges overlap only slightly, however, this hypothesis was untested by comparing the centres of activity between males and females (Hindell and Lee 1988). In a similar study by AKF on the NSW North Coast, 10 koalas (4 males and 6 females) were radio-tracked with home ranges also calculated using harmonic means (AKF unpub. data). For females, home ranges varied between 1.8 and 16.3 ha for females, and 10.8 and 42.8 ha for males, with the highest figure belonging to the group's alpha male who occupied a home range

with a high percentage of open farmland, and the lowest belonging to a female in very high-quality habitat (AKF unpub. data). Figure 1 shows the arrangement of koala home ranges ascertained in this study. Dividing the total area occupied by koalas by the sum of the home ranges occupied by individual koalas gives a rough approximation of 20% overlap between home ranges. The koala home ranges shown in Figure 1 include at least some habitat on either alluvial soils or coastal-sand-flat soils with a high water table and higher nutrient availability.

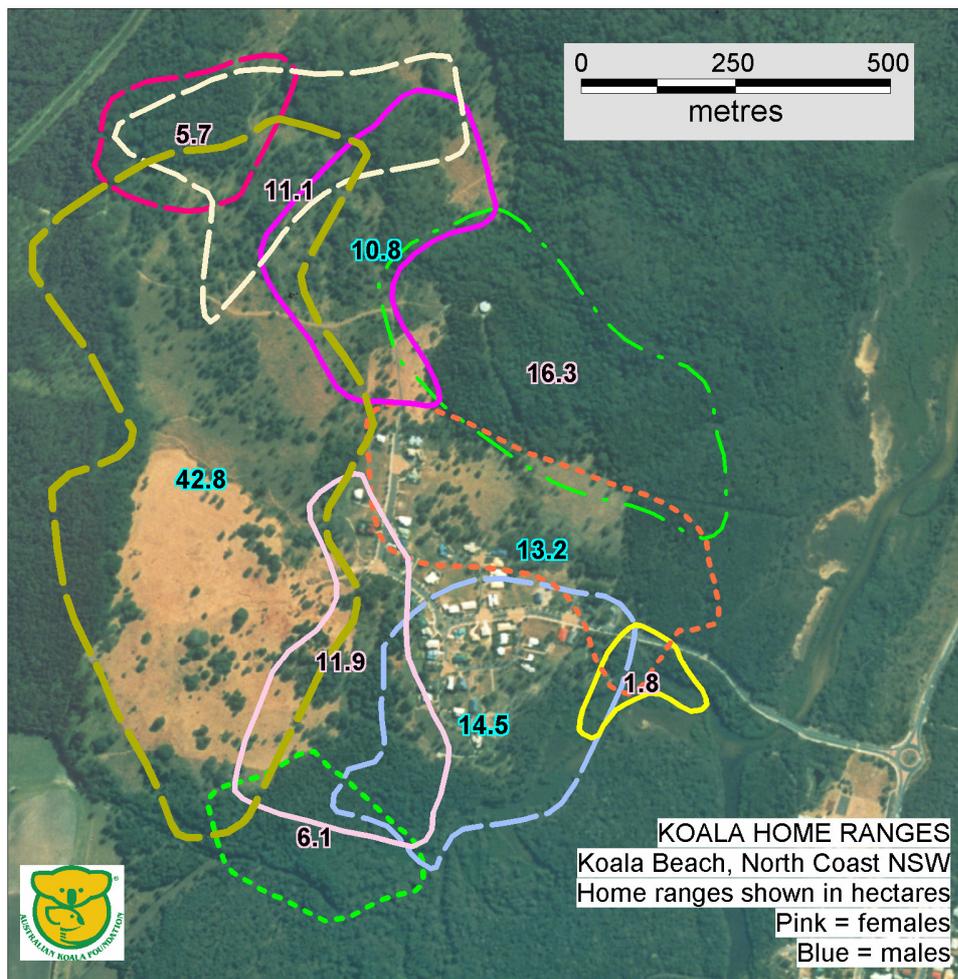


Figure 1: Koala home ranges on the North Coast of NSW (AKF unpub. data).

In the Blair Athol area koalas had well-defined home ranges averaging 135 ha in size for males and 101 ha for females, however the smallest home range was 5.4 ha and the largest 296 ha (both males) (Ellis *et al* 2002). In higher-rainfall south-east Queensland, mean densities varied from 0.02 to 1.26 koalas/ha (Dique *et al* 2004). In rural south-east

Queensland, home ranges varied from 5.3 to 91.4 ha, with approximately 25% overlap (White 1999).

Sullivan (2004) developed a “faecal standing crop” method whereby koala densities were calculated based on number of pellets counted and average daily deposition rate. This method compared favourably to a direct visual count method that estimated koala densities at 0.32-0.45 koalas/ha in riverine habitats in the Queensland Mulgalands (Sullivan 2004).

Other studies have found large variation in the density of koalas (a converse measure of home range size), for example as high as 8.6-8.9 koalas/ha in habitat fragments and as low as 0.7-1.6/ha elsewhere in Victoria (Meltzer *et al* 2000). In NSW, densities were measured at 0.006/ha at Eden and 4-8/ha in north-east NSW, and in Queensland from 0.01/ha in central Queensland to 1-3/ha in south-east Queensland (Meltzer *et al* 2000). A pioneering study at Tucki Tucki Reserve on the North Coast of NSW found a density of nearly 7 koalas/ha in high-quality habitat with about 30 trees for each koala available, but only about 1 koala/ha in adjacent similar-quality habitat (Gall 1980). On French Island koalas had from 18 to 40 trees available in each home range (Mitchell 1990a).

Line transect sampling has been used in Pine Rivers Shire in south-east Queensland to directly estimate koala numbers, with 84 koalas counted over 134 lines with a total transect distance of 64 km (Dique *et al*, 2003b). Pine Rivers Shire, just north of Brisbane, has a relatively high koala density with an estimated 4584 koalas within 77,000 hectares, including about 5,000 ha which is highly urbanised in the eastern part of the Shire (Dique *et al* 2003b). In contrast, in scattered, low-density koala populations such as the Mulgalands of south-west Queensland, koalas are few and difficult to detect, direct transect counts often yield little data (Sullivan *et al* 2002). As a result, few studies have produced reliable estimates of Koala abundance in low-density Koala populations (Cork *et al* 2000).

Table 1 summarises home range information from published papers. Koala densities from other sources have been converted to home range equivalents using 20% overlap between home ranges (Table 2). The great disparity in home range size is likely due to a

combination of factors including variation in soil fertility, rainfall, historical disturbance (drought, fire, past hunting), habitat fragmentation, and the methodologies employed in each study. On French Island home ranges tended to be bigger with increasing tree density, an indication that koalas prefer bigger trees further apart than smaller trees closer together (Mitchell 1990a).

Table 1: Koala home range sizes from previous research. For White (1999) no distinction was made between male and female maximum/minimum home range size.

State	Area	Male			Female			Overlap %	Source
		Minimum	Maximum	Mean	Minimum	Maximum	Mean		
VIC	Brisbane Ranges	2.13	4.14	3.14	1.22	2.08	2.94		Hindell and Lee 1988
VIC	French Island			1.7			1.18		Mitchell 1990
NSW	Tweed Coast	10.78	42.78	20.3	1.84	16.28	8.82	20	AKF unpub. Data
QLD	Blair Athol	5.4	296	135			101		Ellis <i>et al</i> 2002
QLD	south-east	(5.3)	(91.4)	34.4	(5.3)	(91.4)	15	25	White 1999

Table 2: Density estimates from previous research. Densities are converted to home range sizes, allowing for a 20% overlap between home ranges (White 1999 and AKF unpub. data).

State	Location	koalas/ha		Home range (20% overlap)		Source
		Min	Max	Min	Max	
VIC	fragmented	8.6	8.9	0.1	0.09	Meltzer <i>et al</i> 2000
VIC	other	0.7	1.6	1.14	0.5	Meltzer <i>et al</i> 2000
NSW	Eden	0.006			133.3	Meltzer <i>et al</i> 2000
NSW	north-east	4	8	0.1	0.2	Meltzer <i>et al</i> 2000
NSW	Tucki Tucki	1	7	0.11	0.8	Gall 1980
QLD	Mulgaland	0.32	.45	1.8	2.5	Sullivan 2004
QLD	south-east	0.02	1.26	0.6	40	Dique <i>et al</i> 2004
QLD	central	0.01			80	Meltzer <i>et al</i> 2000
QLD	south-east	1	3	0.06	0.8	Meltzer <i>et al</i> 2000

Radio tracking also provides data on the distances koalas move over a defined period, White (1999) found that, for radio-tracking records at least 30 days apart, 50% of

movements were between 200 and 500 m, a further 35% were between 500 m and 1 km, and the rest were under 5 km. For records three days apart, 20% were in the range 2 - 5 km (White 1999), indicating that koalas often roam considerable distances from their home ranges before returning (White 1999).

Hindell and Lee (1987) also found that as well as certain large trees being preferentially used, use of these trees was not exclusively by one animal. Larger trees may offer several advantages to koalas, including increased shelter and food availability because of a larger canopy (Hindell and Lee 1987), and greater access to water and nutrients because of a deeper root system (Phillips and Callaghan 2000). A recent study at St Bees Island off the coast of central Queensland found a marked difference in the use of trees, with closed-canopy trees used as shelter during the day, and open-canopy trees, particularly *Eucalyptus tereticornis* (a Red Gum), used for feeding at night (Pfeiffer *et al* 2005). 91.4% of nocturnal koala observations were in *E. tereticornis*, with 20.4% of daytime observations in this species (Pfeiffer *et al* 2005). Koalas exposed to full sun in this humid environment appeared stressed, with laboured breathing evident (Pfeiffer *et al* 2005). Unpublished research by NSW State Forests reports "...dense foliage of white cypress pines and rough-barked apples were frequently used by koalas as daytime resting sites"... "to cope with the extremes of regular high summer temperatures" (DPI 1999)

2.4 Koala Faecal Pellets

Faecal pellet surveys have been used by many Koala researchers (Lunney *et al* 1998, Lunney *et al* 2000, Phillips and Callaghan 2000, Phillips *et al* 2000, Sullivan *et al* 2002). The primary advantage of this type of survey arises from the fact that faecal pellets persist long after a koala has left the area (Lunney *et al* 2000) and are distinctive in shape and size compared to faecal pellets of other animals (McAlpine *et al* 2006b).

As Koala faecal pellets will be a fundamental part of this study, it is useful to know something about the spatial and temporal aspects of faecal pellet deposition. A study of Queensland koalas found that most pellets are deposited between 6 p.m. and midnight when koalas were most active, and rarely when koalas were resting during the day (Ellis

et al 1998). A disproportionately high percentage of pellets are found within one metre of tree trunks(Ellis *et al* 1998). Free-ranging koalas will produce an average of 150 faecal pellets/day (Sullivan *et al* 2004).

Assessing the age of faecal pellets can be achieved by examination of physical changes in the pellet, for example presence or absence of surface patina, colour change from olive-brown to greyish, loss of eucalyptus odour with age, and bleaching of leaf cuticle within the pellet. (Sullivan *et al* 2002). In the arid and semi-arid environments of the Queensland Mulgalands, pellets aged with these criteria were classed as fresh (0-28 days) or old (14-28 days) (Sullivan *et al* 2002). The rate of ageing is primarily affected by rainfall and substrate moisture (White 1995) with breakdown occurring more rapidly in summer than winter (Sullivan *et al* 2002). In more humid coastal climates (Port Stephens, NSW) pellets begin to decay after six weeks and persist for up to six months (Lunney *et al* 1998) or 24 months in the Eden (NSW) area (Jurskis and Potter 1997).

2.5 Landscape Ecology

Landscape structure can be conveniently divided into three fundamental elements: patches, corridors, and the matrix. A patch is a relatively homogenous area of vegetation that differs from its surroundings, patches > 200 m apart can be considered isolated (McAlpine *et al* 2006a). A corridor is a linear strip of habitat different to its surroundings, while the matrix is the most extensive and most connected landscape element in which patches and corridors are embedded, for example cleared land in farming areas (McAlpine *et al* 2006a).

Habitat fragmentation may be defined as the successive subdivision of habitat into smaller, more numerous and more isolated patches (McAlpine *et al* 2006a).

Fragmentation is a major issue for Koala conservation in light of the fact that the low-energy, low-nutrient diet provided by eucalypt leaves provides reduced scope (because of increasing energy cost) for koalas to travel across open ground between habitat fragments (White 1999, DSE 2004a).

Patches can be considered as coarse-grained if the patch is bigger than a koala's home range, and fine-grained if the home range consists of two or more patches (White 1999). Koalas inhabiting home ranges composed of more than one patch must necessarily cross open ground to access patches. In urban areas dogs and cars increase the danger of travel between patches (White 1999). White (1999) found that koalas often use isolated paddock trees and make frequent long-range movements (> 2 km) across open ground, and concluded that koalas were not reliant on continuously-vegetated corridor systems which were absent from the study area (White 1999).

However, recent studies (McAlpine *et al* 2004, Rhodes *et al* 2006) have demonstrated that large patches of habitat with effective connections are essential for the long-term maintenance of Koala populations in three geographically dispersed areas in eastern Australia.

Corridors may be used by resident adult koalas with stable home ranges as well as by dispersing animals. A study on the Strathbogie plateau found densities of koalas to be similar (8-9/ha) in both larger forest patches and in corridors, use of which was independent of the distance to forest patches (Downes *et al* 1997).

Habitat patches are subject to edge effects including weed invasion and wind desiccation. Patch shape is an important consideration: linear patches, including corridors, have a relatively longer edge than circular patches and so are more susceptible to edge effects (McAlpine *et al* 2006a). It has been suggested that larger circular patches some distance apart act as "stepping stones" and, in revegetation projects, it is better to increase the size of these patches rather than attempt to link them with a narrow corridor (McAlpine *et al* 2006a).

Secondary and supplementary habitats provide a crucial role in maintaining Koala populations in several different ways, particularly when they are in close proximity to preferred habitat. These habitats provide a buffer by ensuring that incompatible land use does not occur on land immediately adjacent to preferred habitat and can help protect preferred habitat from edge effects and nutrient impacts (McAlpine *et al* 2006a). Secondary habitats also provide for the extension of significant Koala activity of a

breeding group by providing additional habitat, and habitat for sub-dominant koalas unable to establish home ranges in richer habitat (McAlpine *et al* 2006a). Secondary and supplementary habitats also provide vegetated links between areas of preferred habitat, enabling safer dispersal and recruitment of sub-adult koalas (McAlpine *et al* 2006a).

2.6 Historical Factors

Higher-quality Koala habitat generally occurs on soils mostly cleared for agriculture and pasture, and increasingly for urban development, especially in coastal areas (Lunney *et al* 2000). The loss of better-quality valley habitats supporting high-density Koala populations has meant that remaining koalas persist mainly in poorer-quality hilly habitats with a lower “carrying capacity”, that is, at much lower densities (Lunney and Leary 1988). Remaining habitats are predominately in privately-held forests and are poorly represented in reserves (Braithwaite 1996).

Koalas were previously widespread in Victoria and an intensive hunting industry developed however by 1910 the hunting industry had collapsed due to a shortage of koalas (Meltzer *et al* 2000). At about the same time the large Bega Valley (NSW) Koala population crashed, an event ascribed to increased disease susceptibility as a result of nutritional stress arising from destruction of the better-quality valley habitat (Lunney and Leary (1988). Hunting, combined with drought, clearing, wildfire and disease, meant that koalas had disappeared from most of Victoria, with possibly as few as 1000 animals remaining by 1934 (Melzer *et al* 2000). Some koalas were translocated to Westernport Bay islands in the 1920s, these animals flourished, causing overbrowsing and death of food trees and prompting more translocations to other islands and the mainland (Melzer *et al* 2000).

Victoria and South Australia are the most extensively cleared States within the Koala’s geographic range, with isolated “island” remnants of native forest separated by land cleared for farming. Habitat fragmentation on this scale severely limits Koala dispersal and recruitment, exacerbating over-population effects in some areas and causing local extinctions in others. Since 1923 the Victorian Government has managed Koala populations in these areas with further translocation programs, however it appears that

little unoccupied suitable habitat remains (DSE 2004a). Much of the habitat available for translocation was and is also isolated, thereby in some instances replicating the problem of overpopulation in new locations. Sterilisation and contraception are recent tools employed in translocation programs in Victoria (DSE 2006) and on Kangaroo Island (Duka and Masters 2005).

Koalas are now widespread throughout lowland and coastal Victoria within the 500 mm isohyet and in riparian vegetation in the drier Riverina (Melzer *et al* 2000). It is also likely that, in the absence of effective population-increase control, translocations will continue in Victoria for the foreseeable future (Melzer *et al* 2000).

2.7 Trees and Water Use

Availability of nutrients for leaf growth is determined by the amount of moisture available to facilitate movement of nutrients both within the soil and within the tree. Tree water use, that is, the rate at which trees can extract moisture from the soil, is governed, under particular atmospheric conditions, by the amount of leaf surface area, the extent of the root system, and the amount of moisture in the soil (Landsberg 1999). Ultimately leaf area is governed by the amount of available moisture in the soil, so that, in lower rainfall areas, leaf area index is lower than in the same species growing in higher rainfall areas (Landsberg 1999).

In turn, there are specific relationships relating the leaf surface area to the sapwood area of the tree stem although these relationships vary for different species (Landsberg 1999). Generally, a doubling of stem diameter results in a leaf surface area increase of approximately four times (Landsberg 1999).

Eucalypts have a dimorphic root system, with a widely-spreading lateral root system just under the ground surface, with a deep tap root in younger trees and deep vertical sinker roots in mature trees enabling trees to reach water at deeper levels in dry periods to maintain normal levels of evapotranspiration (Knight 1999). Globally, trees have approximately 35% of root biomass below 30 cm soil depth and with deeper roots in drier environments (Knight 1999). Rooting studies of irrigated *E. camaldulensis* found

that most roots were between 0.4-0.8 m below the surface, with greater development of roots towards the wetter part of the moisture profile (Knight 1999).

Given the same access to water, some *Eucalyptus* species make more efficient use of water and therefore available nutrients than other eucalypts, and there is also considerable variation within each species (Anderson *et al* 2000).

In geologically-old soils, such as are found in Australia, it is likely that nitrogen, phosphorus and other nutrients are primarily derived from recycling of existing nutrients rather than geological weathering of substrate materials, and that water availability is the dominant control over canopy development (Hatton *et al* 1999). This hypothesis explains the finding that there is little difference between *Eucalyptus* species in water-use efficiency of trees with the same leaf area (Hatton *et al* 1999).

2.8 Climate Change

Long-term management of koalas needs to consider impacts from projected climate changes on the environment. In particular, effective management should include strategies to modify and/or buffer any adverse impacts which are projected including higher temperatures, increased dryness, and increased frequency and severity of extreme weather events such as drought and bushfire (DSE 2004b). Climate change projections are based on computer modelling and as such are imperfect, but the models have improved to the extent that it is now prudent to include these projections into land and environmental management.

Illustrating the effects of climate change, a 2°C rise in temperature and 10% decrease in rainfall (in the moderate range of projections) would mean that by 2070 Shepparton will have the same climate that Condobolin in NSW currently has (DSE 2004b).

Koalas are found from northern Queensland and throughout eastern Australia to South Australia with koalas in southern areas tending to be larger than their northern counterparts. With an increase in temperature from climate change, these larger animals are more likely to suffer heat stress resulting from reduced thermoregulation efficiency couple with reduced water intake from drier vegetation. Defoliation of food trees,

reduction in foliar nitrogen and increase in production of polyphenolic compounds are additional possible impacts on koalas (Melzer *et al* 2000).

Many *Eucalyptus* species are restricted in geographic range due to climatic and species competition factors. Climatic variables also influence their chemistry, it has been shown that an increase in atmospheric CO₂ reduces the amount of foliar nitrogen and increases the levels of polyphenols (Moore *et al* 2004b). Forest structure is likely to change too, for example woodland changing to open scrub (Moore *et al* 2004b). Species with wide present-day distributions, for example *E. camaldulensis*, are less likely to be affected by climate change as they have a larger “climatic envelope”. ESOCLIM modelling has been used in combination with herbaria species records and temperature and rainfall records to generate the current climatic envelope for 819 *Eucalyptus* species (Hughes *et al* 1996). An estimated 53% of all species have mean annual temperature ranges spanning less than 3°C, indicating that a projected annual average temperature increase of 3°C by 2030 would completely displace these species from their current temperature envelope, a 5°C rise by 2070 would displace 73% of all *Eucalyptus* species (Hughes *et al* 1996). Similarly, a 20% change in rainfall would displace an estimated 23% of species from the current rainfall envelope (Hughes *et al* 1996).

2.9 Mapping Koala Habitat

The Spot Assessment Technique (SAT) is a plot-based faecal pellet survey methodology developed by the AKF to ascertain Koala food tree preferences within a study area (Phillips and Callaghan, submitted). The survey methodology involves random plot site selection stratified sample the range of edaphic (e.g. geology) and floristic (e.g. *Eucalyptus* species) variables within each study area to the fullest extent possible (Phillips and Callaghan, submitted).

The selected sites are searched for koala faecal pellets under 30 trees, with the species and diameter-at-breast-height (dbh) and presence or absence of pellets for all 30 trees recorded (Phillips and Callaghan, submitted). Data from all SAT sites within a study area is pooled and statistically analysed using various techniques to develop food tree preferences for koalas in the area (Phillips and Callaghan, submitted). The food tree

preferences are then ranked as primary, secondary or supplementary for use in the Koala Habitat Atlas (McAlpine *et al* 2006b). Other data collected include an estimate of pellet age, fire history and site disturbance.

The activity level (percentage of trees with pellets) is calculated. Phillips and Callaghan (submitted) propose three categories of koala activity, with differences in activity level categories dependent on whether the site location is coastal/tablelands with higher rainfall or inland with rainfall <600 mm. Table 3 shows the activity levels proposed by Phillips and Callaghan (submitted).

Table 3: Koala site activity categories for Western areas (Phillips and Callaghan, submitted.)

ACTIVITY CATEGORY	LOW USE	MEDIUM (NORMAL) USE	HIGH USE
Area (density)			
Western areas (med – high)	< 35.84%	≥ 35.84% to ≤ 46.72%	> 46.72%

The Koala Habitat Atlas (KHA) is a technique developed and used by the Australian Koala Foundation (AKF) to map and rank Koala habitat quality and has been in use since 1994. The KHA is primarily based on vegetation community mapping derived from aerial photography, with a Koala habitat ranking for each community based on the proportional abundance of identified primary, secondary and supplementary food trees (McAlpine *et al* 2006b). Primary food trees have a significantly higher proportion of surveyed trees with one or more Koala faecal pellets around the base compared to other tree species, secondary food trees have a significantly higher proportion of faecal pellets than other trees (but less than primary trees) and supplementary food trees have a lower proportion of trees with pellets compared to primary or secondary food trees, but still significantly higher than trees lacking any evidence of use by koalas (McAlpine *et al* 2006b). Additionally, other non-eucalypt trees may be used as supplementary food trees, and both eucalypt and non-eucalypt trees may be used to provide shelter (McAlpine *et al* 2006b). Vegetation communities as delineated on a map can then be ranked according to the proportion of primary, secondary and supplementary food trees in each community, and displayed on a map as a Koala Habitat Atlas (McAlpine *et al* 2006b). The different habitat classes are listed in Table 4.

Table 4: Derivation of Koala habitat classes used in the AKF's Koala Habitat Atlas (McAlpine *et al* 2006b).

Habitat Quality Class	Food Tree Rank and percentage of Overstorey			
	Primary euc. species	Primary & Secondary euc. species	Secondary euc. species	Supplementary euc. species
Preferred	$\geq 30\%$	or $\geq 50\%$	or $\geq 50\%$	Balance
Secondary	10<30%	or 30<50%	or 10<50%	Balance
Supplementary	or <10%	or <30%	or <10%	Balance
Mainly cleared	Scattered trees	Scattered trees	Scattered trees	Scattered trees

The Koala Habitat Atlas methodology, incorporating the Spot Assessment Technique, has been used by the AKF for over 10 projects in Victoria, NSW and Queensland and has been endorsed by lead conservation agencies as a suitable method to identify, map, and rank Koala habitats. (DSE 2004a, NPWS 2003).

The Victorian Koala Management Strategy lists koala food trees for Victoria (DSE 2004a). Amongst some of the preferred forage *Eucalyptus* species are Southern Blue Gum (*E. globulus*) as well as its variants, Manna Gum (*E. viminalis*), Swamp Gum (*E. ovate*) and Red Gum (*E. camaldulensis*), while Messmate Stringybark (*E. obliqua*), Long-leaved Box or Bundy (*E. goniocalyx*), Yellow Gum (*E. leucoxylon*), Red Stringybark (*E. macrorhyncha*), Yellow Box (*E. melliodora*) and Red Box (*E. polyanthemos*) are also known to be eaten (DSE 2004a). However, Hindell and Lee (1987) suspected that use of some tree species such as *E. macrorhyncha* was favoured by individual non-breeding male koalas in summer months with little or no access to better-quality habitat. Limited information is available on the preference for Blue Gum (*E. globulus*) when grown in plantation form but anecdotal evidence suggests that koalas do eat this species. Data for the Ballarat Local Government Area, indicate *that* Blue Gum is likely to be a preferred food tree species (AKF 2006).

2.10 Blue Gum Plantations and Wildlife

Over much of southern Australia, hardwood plantations are expanding and timber production is going to be a major land use in the future (Hardwood Plantations Quantifying conservation and environmental service benefits Hobbs et al 2003) with the Australian Government endorsing the plantation industry's view of trebling their estate by 2020 as it is underlined by the Plantations for Australia 2020 vision' (Australian Government Department of Agriculture Fishery and Forestry 2003). Plantations provide more than half of Australia's timber production (CSIRO page accessed 3-5 2005) and represent 2% of the area used for crop or pasture. While this project focuses on larger plantations, it is important to note that increasing numbers of farmers chose to incorporate farm forestry into their operations. A recent study in southeast Queensland found that mature farm forestry plantations recorded equal levels of plant species diversity as comparable to native forest. With the greenhouse discussion 'hotting' up over recent months, it is important to note that plantations are reported to function as carbon sinks (DPI 2004).

With an increase of plantations in the Australian landscape has come an opportunity to measure impact of plantations as well as their benefits to catchments and biodiversity (Cawsey and Freudenberger 2005). There has been a recent shift to hardwood plantations away from Pine plantations. It is believed that this shift brings with it the environmental benefit of native hardwood plantations providing resources for native wildlife. Research conducted by Rossi (2003) found that wildlife species diversity and abundance was higher in native forests and that progressively decreased from eucalypt plantations through to cleared land. There is the potential for these areas to be used as corridors, for shelter and fodder. The tree species most used in hardwood plantations is Blue Gum (*Eucalyptus globulus*). This is indigenous of Tasmania and South-eastern mainland Australia but due to the rapid growth rate, the quality of the wood and the adaptability to a wide type of soils, it is now widely used by commercial forestry and comprises two thirds of the eucalypt species used for commercial purpose (Strauss 2001).

The importance of Blue Gum plantations in the conservation of native wildlife has been investigated in various documents and studies are still being conducted to establish the value of plantations in comparison to cleared land. Preliminary results (Loyn et al 2004) show that some native wildlife use eucalypt plantations at a higher rate than introduced species. This is in contrast with most pure, large scale Pine plantations that are mainly used by introduced species and only a few native species (Strauss 2001). However, a recent report (Lindenmayer 2004) qualifies this perception somewhat by its detection of 100 native bird species, along with numerous frogs, reptiles and few marsupials inhabiting some Pine-eucalypt mosaic landscapes.

Browsing of seedlings of *Eucalyptus nitens* and *Acacia melanoxylon* amongst others by herbivores (eg *Oryctolagus cuniculus* (European Rabbit), *Trichosorus vulpecular* (Brushtail Possum) and *Thylogale billardierii* (Red-Bellied Pademelon)) have shown to reduce the success of commercial forestry in Tasmania (Bulinski and Mc Arthur 1998, Neilsen and Brown 1997).

However, none of these previous studies have exclusively investigated the use of plantations by the Koala (*Phascolarctos cinereus*). Therefore it is not known if the use of young blue gums as staple food by koalas could impact the success of plantations if these are found to be extensively browsed. On the other hand if plantations are used by koalas as corridors between two isolated forested areas, the harvesting could cause sudden isolation of the Koala population. These are issues that can be investigated once the relationship between Blue Gum plantations and use by koalas is established. The Koala is Australia's largest herbivorous mammal. It feeds mainly on eucalypt leaves but also on other native and sometimes non-native species (eg acacias, tea trees, pines) (Melzer and Houston 2002, Moore and Foley 2000 and Matthews et al. 2007). This species is also known to use blue gums for fodder and or shelter when these are found in native forests. This research will focus on the use of Blue Gum (*Eucalyptus globulus*) plantations by koalas and therefore, the value and importance of these plantations in the conservation of the Koala.

3 Study Area

We obtained data on Blue Gum plantations from across the State of Victoria but, due to commercial confidentiality, we were unable to produce a map showing the exact locations of these sites.

Final study sites were spread over an area reaching from the South Australian border down to Portland in the south-east of the State, across to the Otway Ranges and from Seymour in the North to the Yarra Ranges in the East.

4 Methods

4.1 Selection of Study Sites

The study required the selection of suitable Blue Gum plantations which would provide information, firstly on the age of plantations at which Koala use becomes apparent as measured by the Spot Assessment Technique (SAT) (Phillips & Callaghan 1995), and secondly, to ascertain whether size of plantation has any influence on Koala usage for different plantation ages. Statistical power analyses indicated that three replicate sites in each of three plantation age by three plantation size classes in a factorial experimental design (making a total of 27 sites) would be sufficient to have a reasonably high chance of detecting ecologically important plantation age and size effects on Koala usage, as measured by Koala activity levels, at each site (Rhodes 2005). During actual fieldwork two additional sites were surveyed due to the availability of extra resources at the time. Additionally, it was determined that at sites where Koala activity was detected the most appropriate methods for assessing the effect of distance from native forest on Koala tree use within plantations would be a transect of SAT sites along a gradient between remnant native vegetation and adjoining Blue Gum plantations.

GIS data supplied by five plantation companies (including one PDF image, digitised with an estimated accuracy of +/- 30 metres) were combined into a single map in a GIS, with 1045 initial plantations, or 2502 polygons after disaggregation. Plantation polygons,

DSE's Ecological Vegetation Classes (EVC) mapping and three recent satellite images covering the study area (downloaded from GLCF 2005) were visually checked for position against a cadastral dataset obtained from Land Victoria. Positioning of plantation data and the Landsat data relative to the cadastral dataset was generally better than 25 metres, while EVC mapping demonstrated both greater variability and registration errors generally less than 40 metres. Registration errors between datasets were considered not to have any great bearing on the selection of field sites.

Expert advice (John Callaghan *pers. com.*) indicated that koalas are able to cross 50 metres and more of open ground, accordingly plantations of the same planting year less than 50 m apart were joined together, resulting in a total 661 plantation patches. The earliest planting year in the data was 1976 (2 patches). However, patches planted before 1992 were excluded on the basis that firstly, they were of small size and secondly, because there were insufficient plantations of a similar age. Descriptive statistics for planting years since 1992 (616 patches) are shown in Table 5.

Table 5: Descriptive statistics for the 616 plantation patches.

Plant year	YSP*	No. Patches	min (ha)	max (ha)	av (ha)	Sum (ha)
1992	13	2	2.67	8.75	5.72	11.42
1993	12	2	29.07	33.64	31.36	62.71
1994	11	4	2.02	11.63	6.48	25.94
1995	10	2	17.07	460.39	238.73	477.46
1996	9	24	1.02	29.88	9.07	217.56
1997	8	65	1.67	155.73	22.54	1464.98
1998	7	83	0.32	559.41	50.06	4154.77
1999	6	92	0.14	477.15	92.81	8538.71
2000	5	155	0.08	1664.48	122.35	18963.79
2001	4	121	0.06	2735.22	171.18	20713.34
2002	3	28	0.22	290.10	50.50	1413.99
2003	2	38	0.03	231.99	27.76	1054.75

*YSP = Years since planting (calculated from Winter 2005)

From Table 5, plantings started in earnest in 1997 and reached a peak in the years 2000-2001 both in number and size of patches. Since then, both number of plantings and patch sizes have decreased.

Initial analysis, using DSE's EVC mapping, eliminated plantations with cleared land or with unsuitable (not containing eucalypts) native vegetation adjoining. To be suitable, a patch of native vegetation was required to contain eucalypt forest (with Koala food trees present), be at least 100m wide (to reduce edge effects), and be at least 300m in depth (to allow random sample point generation and sufficient transect length). This process reduced the number of candidate sites to 182 patches.

A major requirement of the sampling design was to eliminate plantations closer than a certain distance threshold to different age classes, avoiding any potential influence arising from differences in habitat use according to age class.

At this stage the remaining sites were allocated age classes. Several different schemes were tried, however, age classes of 3-4 years, 5-6 years, and 7+ years provided the most even spread of potential sites within and between age classes. The 182 plantation patches making up the three age classes were saved into a separate map for further analyses. The polygons were assigned a distance to the nearest plantation of a different age-class, for the desirable purpose of excluding patches less than 5km from a patch of a different age class. This decision follows research indicating a significant influence on Koala activity extending to at least 5km distance (McAlpine *et al* 2004). Distance thresholds were not calculated to the 1-2 year class, as this class is not likely to be used by koalas because of the small size of the trees. An unknown variable is the size and location of plantations not owned by the companies involved in this study, some of this information was obtained from EVC mapping (EVC Classes 929, 930 and 987, representing undefined, damp forest and wet forest plantations respectively). Proximity to any hardwood plantation of unknown age within the 5km distance was sufficient reason to reject a site. Later arrival of data from additional companies was also very useful in this regard (as well as providing additional potential sampling sites). This data was considered to be of great importance, although it meant that the complete site selection analyses process had to be repeated several times. Table 6 shows the reduction in number of potential sites as the different criteria are applied, and at different distances.

Table 6: Number of patches and distance to a plantation in each different age class.

Age Class	all sites	adjacent to EVC						Suitable **
		0km*	1km	2km	3km	4km	5km	
3-4	138	56	46	32	25	21	17	9
5-6	224	88	72	63	57	51	49	36
7-14	161	38	35	34	30	23	25	7
Total	523	182	153	129	112	95	91	52

* indicates the number of candidate patches available at the threshold distance shown between different age classes. ** Suitable is the final tally, eliminating unknown EVC hardwood plantations.

Strict application of these criteria would result in insufficient candidate sites to select 3 replicate sites in each age class, accordingly this requirement was relaxed to approximately 2.5km in some cases where landscape configuration (native vegetation and plantation) was acceptable, for example 3 km of cleared farmland between patches of different age class was judged to be a suitable site.

At the end of this process 52 plantation patches were still in contention as field sites.

The next stage was to identify and eliminate sites situated in disparate landscapes as determined by FRAGSTATS fragmentation software (McGarigal and Marks 1995). For FRAGSTATS analyses, sites with a relaxed threshold distance of 4 km were used to provide a more representative sample of potential sites across the study area.

A 5km buffer was generated around the edge of each plantation. Eucalypt-containing EVCs were combined into one class, clipped to each buffer and converted to grid format (AGD84 Zone 54 or 55). An example is shown in Figure 2, and the location of the buffers (i.e. sites) within Interim Bioregions (Environment Australia 2000) is shown in Figure 3.

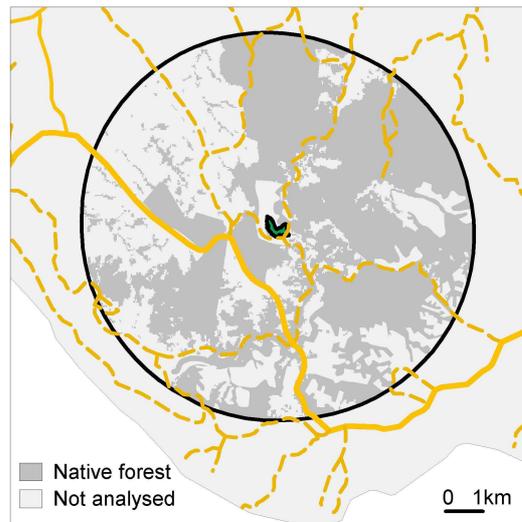


Figure 2: Plantation between Lavers Hill and Port Campbell

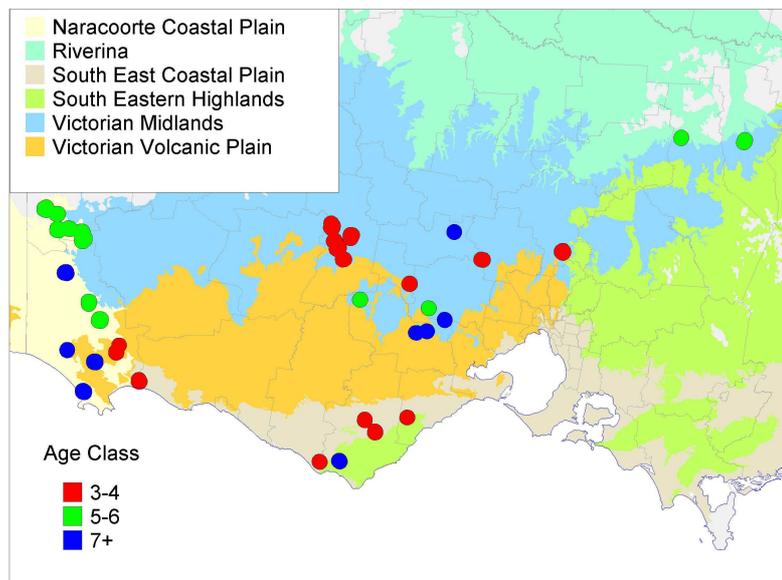


Figure 3: Location of potential sites within Bioregions

Using FRAGSTATS Version 3 (McGarigal and Marks 1995) software, landscape metrics for the native vegetation combined classes were generated within the buffers. A search radius of 16km was used to guarantee that every pixel within each buffer was used in calculations to generate landscape configuration metrics (rather than landscape composition since there is only one class, eucalypts). 51 metrics were generated, and compared in correlation coefficient matrices, one for each age class.

Many metrics are inherently related since they are derived from the same primary metrics- patch type, area, edge, and neighbor type (McGarigal & Marks 1995). Redundant, highly correlated metrics can cause bias towards a particular group of metrics and only one of each set should be used (McGarigal & Marks 1995). While some metrics are inherently correlated, other correlations reflect empirical statistical correlations in the actual landscape (McGarigal & Marks 1995). Booth (1994) suggests correlation coefficients above 0.5 indicate metrics are proxies of each other. In this study, metrics with correlation coefficients above 0.65 were considered redundant, leaving 21 metrics for further analyses.

Fragstats was re-run with the 21 metrics, and sites within each age class were correlated to find the most similar sites. Correlation coefficient matrices for the 3-4 age class are shown in Appendix 1 with correlations above 0.65 shown in bold. These are the most closely matched sites in terms of landscape metrics. Sites 19 and 37 were removed as these were spatially auto-correlated, that is, too close to sites 20 and 35 respectively, but were kept as alternate sites if sites 20 and 35 were unsuitable for other reasons, for example field access.

The 52 potential sites were then split into size classes to yield an approximately equal number for size classes within age classes. The largest area in the 7+ age class was 220 ha, so the upper limit for size was set at 250 ha, which resulted in the elimination of 1 patch in the 3-4 year-old (yo) class and two patches in the 5-6 yo class. Minimum size was set to 10 ha, patches under this limit usually had insufficient size to generate random Spot Assessment points within the patches, however one patch of 4.37 ha was included in the 3-4 yo class to provide a spare site if necessary.

Table 7: Final numbers of sites for each Age/Size Class

	10-30 ha	40-110 ha	130-250 ha	total
3-4 yo	4	5	3	12
5-6 yo	5	4	5	14
7+ yo	5	4	3	12
Total	14	13	11	

Table 7 shows that for most classes there is at least one “spare” site for each category, but not in two age classes in the largest patch category.

With the final round of 38 sites selected, the next step was to generate the random SAT and transect endpoint coordinates. The requirements were that sites had to be at least 50 m from an edge (to minimise edge effects) and no closer than 300 m to each other (to reduce spatial autocorrelation effects). A suitably sized polygon was digitised over the native vegetation adjoining each plantation polygon. Both polygons were then internally buffered 50 metres using MapInfo, this second polygon is termed the “sampling polygon”. The sampling polygons were imported into ArcView, where a software extension allowed the generation of the required number of points at the minimum required distance of 300 m between points. Because of the reduced size and geometry of the sampling polygons, only 24 sites met this minimum distance requirement. The distance threshold was successively relaxed to “capture” the required number of points, for example a 250 m threshold generated sufficient points for five more sampling polygons, 200 m two more polygons, 175 m three polygons, and 150 m and 125 m one polygon each.

Prior to fieldwork, a location and site map were printed to enable navigation to the site and around the site.

4.2.1 Phase one field survey

For each of twenty-nine plantations, three SATs in adjacent native forest and three SATs in blue gums were conducted. Explanatory covariates used were: (1) age of each blue gum plantation, (2) average dbh of trees in each Blue Gum plantation, and (3) size (ha) of each Blue Gum plantation. There were 30 trees in each spot assessment plot.

4.2.2 Phase two field survey

For each of eight plantations between two and six SATs in adjacent native forest and between five and 10 SATs in blue gums, limited by the size and shape of plantation,

were conducted. Explanatory covariates used were: (1) distance of each spot assessment plot in blue gums to nearest native forest, and (2) difference in dbh of each Blue Gum tree from the average dbh of the plantation. There were 30 trees in each spot assessment plot.

4.3 Statistical Methods

Statistical analysis of the data was conducted within a Bayesian framework (Ellison 1996, Wade 2000) using Markov chain Monte Carlo (MCMC) in WinBUGS version 1.4.1 (<http://www.mrc-bsu.cam.ac.uk/bugs/>). Our measure of tree use by koalas was the probability of finding a faecal pellet under a tree (Phillips et al. 2000, Phillips and Callaghan 2000). Using this as measure of use the aims of the analysis was to identify the key factors determining differences in tree use between blue gums and adjacent native forest: (1) at the at the plantation scale (using the phase one data), and (2) within plantations (using the phase two data). Analysis of the phase one data was conducted first and the Bayesian posterior distributions of the model parameters obtained from this analysis were used as prior probability distributions for the model parameters in the phase two data analysis. The process whereby existing information (e.g., data already existing prior to a study or expert opinion) is explicitly incorporated into a statistical analysis of data is one of the key benefits of the Bayesian approach (Wade 2000). It ensures that all available information is incorporated into the analysis in a straightforward way and allows models to be updated as more data is collected.

4.3.1 Phase One Analysis

We fitted a series of models to the phase one data that were all variations of the model

$$m_{ij} \sim \text{Binomial}(p_{ij}, 30)$$

$$n_{ik} \sim \text{Binomial}(q_{ik}, 30)$$

$$\log\left(\frac{p_{ij}}{1-p_{ij}}\right) = \alpha + \gamma_i \quad ,$$

$$\log\left(\frac{q_{ik}}{1-q_{ik}}\right) = \beta'_i \mathbf{X}_i + \gamma_i$$

$$\gamma_1 = 0$$

with the relatively uninformative priors

$$\begin{aligned}\alpha &\sim \text{Normal}(0,0.001) \\ \beta_i &\sim \text{Normal}(0,0.001) \\ \gamma_i &\sim \text{Normal}(0,0.001) \text{ for } i = 2, \dots, 29\end{aligned}$$

where m_{ij} is the number of trees with pellets in native forest adjacent to plantation i in spot assessment plot j ; n_{ik} is the number of blue gums with pellets in plantation i in spot assessment plot k ; α is the intercept parameter for native forest; \mathbf{X}_i is a vector of covariates for plantation i ; β_i is a vector of parameters associated with the covariates \mathbf{X}_i ; and γ_i is a plantation fixed-effect for plantation i . The model specified in Eq. 1 is essentially a generalised linear model with a logit link function and binomial error distribution (McCullagh and Nelder 1989). Preliminary analysis revealed that there was substantial variation in use of both native forest and blue gums between plantations. Therefore a plantation fixed-effect, γ_i , is included to reflect this variation. However, the $\beta_i' \mathbf{X}_i$ terms are also included to allow for the possibility that the use of blue gums was different from the use of adjacent native forest. The assumption here is that differences in the use of native forest and blue gums is explained by the covariates \mathbf{X}_i and the parameters β_i . Therefore using this modelling framework we can identify important factors determining differences in the use of native forest and blue gums by comparing the support from the data for a range of alternative models that differ in the covariates, \mathbf{X}_i , and parameters, β_i , that they contain.

We considered eight alternative models describing difference in use between native forest and blue gums (Table 8). One model assumed that use of blue gums and native forest was the same (model one), one model assumed that the use of blue gums was different from native forest, but that this difference was the same for all plantation (model two), and one model assumed that the use of blue gums was different from native forest, but that this difference was unique for each plantation (model eight). The other six models (models three - seven) assumed that the difference in use of blue gums and native forest was determined by various combinations of the covariates, \mathbf{X}_{ij} , consisting of plantation age, mean plantation diameter-at-breast-height (dbh), and plantation size. These covariates were, *a priori*, considered likely to be important determinants of differences in the use of native forest and blue gums. However, mean dbh and plantation age were highly correlated (Pearson's $\rho = 0.90$) with mean dbh likely to be a

proxy for plantation age. Therefore, to avoid multicollinearity problems (Graham 2003) we did not include mean dbh and plantation age together in the same model, i.e., they were both considered alternative measures of plantation age. Plantation age was measured in years, mean dbh was measured in cm and plantation size was measured in ha, but all covariates were standardised to have a mean of zero and standard deviation of one prior to analysis. The alternative models were compared using deviance information criteria (DIC), whereby, the lower the DIC the more parsimonious the model (Spiegelhalter et al. 2002). DIC is an information-theoretic measure for model selection similar to Akaike's information criterion (AIC, Burnham and Anderson 2002), but for use with Bayesian models. This approach enabled the most parsimonious descriptions of the data, and hence the key determinants of differences in the use of native forest and blue gums, to be determined from the set of candidate models.

Table 8. Alternative models for the phase one data analysis.

Model number	Effects	Description
1	$\beta'_i \mathbf{X}_i = \alpha$	use of blue gums and native forest are the same
2	$\beta'_i \mathbf{X}_i = \delta$	difference in use of blue gums and native forest is the same for all plantations
3	$\beta'_i \mathbf{X}_i = \beta_{dbh} \cdot dbh_i$	difference in use of blue gums and native forest depend on mean plantation dbh
4	$\beta'_i \mathbf{X}_i = \beta_{age} \cdot age_i$	differences in use of blue gums and native forest depend on plantation age
5	$\beta'_i \mathbf{X}_i = \beta_{size} \cdot size_i$	differences in use of blue gums and native forest depend on plantation size
6	$\beta'_i \mathbf{X}_i = \beta_{dbh} \cdot dbh_i + \beta_{size} \cdot size_i$	differences in use of blue gums and native forest depend on mean plantation dbh and plantation size

7	$\beta'_i \mathbf{X}_i = \beta_{age} \cdot age_i + \beta_{size} \cdot size_i$	differences in use of blue gums and native forest depend on plantation age and plantation size
8	$\beta'_i \mathbf{X}_i = \delta_i$ $\delta_1 = 0$	differences in use of blue gums and native forest are unique for each plantation, i.e., there is a separate δ_i parameter for each plantation

Notes: dbh_i = mean dbh of blue gums in plantation i , age_i = age of plantation i , $size_i$ = size of plantation i , all standardised to have a mean of zero and standard deviation of one, and α , δ , β_{dbh} , β_{age} , β_{size} , and δ_i are parameters to be estimated.

4.3.2 Phase Two Analysis

For the analysis of the phase two data we applied model eight used for the phase one analysis, but allowed for variation in use within blue gums dependent upon distance to nearest native forest for each spot assessment plot and the difference between the dbh of each blue gum tree and the mean dbh for the plantation. These covariates were, a priori, considered to be potentially important determinants of variation in blue gum use within plantations. The basic model used was

$$m_{ijk} \sim \text{Bernoulli}(p_{ijk})$$

$$n_{irs} \sim \text{Bernoulli}(q_{irs})$$

$$\log\left(\frac{p_{ijk}}{1 - p_{ijk}}\right) = \alpha + \gamma_i$$

$$\log\left(\frac{q_{irs}}{1 - q_{irs}}\right) = \delta_i + \gamma_i + \beta_{dist,i} \cdot dist_{ir} + \beta_{dbh,i} \cdot dbh_{irs},$$

$$\beta_{dist,i} \sim \text{Normal}(\mu_{dist}, \tau_{dist})$$

$$\beta_{dbh,i} \sim \text{Normal}(\mu_{dbh}, \tau_{dbh})$$

$$\gamma_1 = 0, \delta_1 = 0$$

where m_{ijk} is a dichotomous variable (one or zero) indicating whether a pellet was found under native tree k , in spot assessment plot j , adjacent to plantation i ; n_{irs} is a dichotomous variable (one or zero) indicating whether a pellet was found under blue gums, in spot assessment plot r , in plantation i ; $dist_{ir}$ is the distance from the centre of spot assessment plot r in plantation i to the nearest native forest; and dbh_{irs} is the

difference between the mean dbh of blue gums in plantation i and the dbh of blue gums, in spot assessment plot r , in plantation i . The $\beta_{dist,i}$ and $\beta_{dbh,i}$ are the coefficients for the effect of distance to native forest and dbh for plantation i . Preliminary analysis revealed variation in the distance to native forest and dbh effects between plantations and therefore this variation was characterised by normal random-effects for $\beta_{dist,i}$ and $\beta_{dbh,i}$, with means μ_{dist} and μ_{dbh} , and variances $1/\tau_{dist}$ and $1/\tau_{dbh}$, respectively. Priors for the parameters α , γ_i , and δ_i were normally distributed with means and variances taken from the means and variances of the posterior distributions estimated from the phase one data. In this way, information from the phase one analysis was explicitly included in the phase two analysis as prior information. Other parameters were given relatively uninformative priors

$$\mu_{dist} \sim \text{Normal}(0,0.001)$$

$$\mu_{dbh} \sim \text{Normal}(0,0.001)$$

$$\tau_{dist} \sim \text{Gamma}(0.1,0.1)$$

$$\tau_{dbh} \sim \text{Gamma}(0.1,0.1)$$

The aim of the phase two analysis was then to identify whether the effects of distance to native forest and dbh were different from zero and to estimate the size of these effects. Therefore, we considered four alternative models that differed in the specification of the mean effects of the distance and dbh covariates, μ_{dist} and μ_{dbh} (Table 9). Model one assumed that both effects were zero; model two assumed that the distance effect was non-zero and the dbh effect was zero; model three assumed that the distance effect was zero and the dbh effect was non-zero; and model four assumed that the distance and dbh effects were both non-zero. As in the analysis of the phase one data, these hypotheses were tested by ranking the alternative models based on DIC (Spiegelhalter et al. 2002). Distance to native forest was measured in m and dbh was measured in ha, but were standardised to have a mean of zero and standard deviation of one prior to analysis.

Table 9. Alternative models for the phase two data analysis.

Model number	Effects	Description
1	$\mu_{dist} = 0, \mu_{dbh} = 0$	both distance to native forest and dbh effects are zero
2	$\mu_{dist} = \mu_{dist}, \mu_{dbh} = 0$	distance effect is non-zero and dbh effect is zero
3	$\mu_{dist} = 0, \mu_{dbh} = \mu_{dbh}$	distance effect is zero and dbh effect is non-zero
4	$\mu_{dist} = \mu_{dist}, \mu_{dbh} = \mu_{dbh}$	both distance to native forest and dbh effects are non-zero

Notes: μ_{dist} is the mean effect for distance to native forest and μ_{dbh} is the mean effect for the difference between dbh and the mean dbh of blue gums in the plantation.

5 Results

For all models convergence was achieved within 50,000 MCMC iterations. Convergence was checked using the Gelman and Rubin convergence statistic (Gelman and Rubin 1992) from three MCMC chains using the R package ‘coda’ (R Project for Statistical Computing, <http://www.r-project.org/>). Therefore, for each model, we used a burn-in of 50,000 iterations, followed by a further 50,000 iterations, from which we calculated posterior parameter distributions and DIC values.

5.1 Phase one analysis

Based on DIC values, model eight was by far the most parsimonious description of the data with very little relative support for the models that explained variation in the different use of blue gums and native forest as functions of dbh, age or size (Table 10).

Table 10. Model rankings and DICs for the phase one analysis.

Ranking	Model	DIC
1	model 8 ($\beta'_i \mathbf{X}_i = \delta_i$)	661.24
2	model 2 ($\beta'_i \mathbf{X}_i = \delta$)	775.39
3	model 5 ($\beta'_i \mathbf{X}_i = \beta_{size} \cdot size_i$)	777.02
4	model 4 ($\beta'_i \mathbf{X}_i = \beta_{age} \cdot age_i$)	777.22
5	model 3 ($\beta'_i \mathbf{X}_i = \beta_{dbh} \cdot dbh_i$)	777.23
6	model 7 ($\beta'_i \mathbf{X}_i = \beta_{age} \cdot age_i + \beta_{size} \cdot size_i$)	778.88
7	model 6 ($\beta'_i \mathbf{X}_i = \beta_{dbh} \cdot dbh_i + \beta_{size} \cdot size_i$)	779.13
8	model 1 ($\beta'_i \mathbf{X}_i = \alpha$)	967.46

Model eight assumed that the difference between use of blue gums and adjacent native forest is unique for each plantation. Therefore, this result suggests that dbh, age or size of the plantations are poor predictors of variation in the relative use of blue gums and native forest, at least for the range of the data collected in this study. Although koalas generally did use blue gums when the adjacent native forest was also used, there was strong statistical evidence that the use of blue gums was much lower than that of adjacent native forest. Predictions from the most parsimonious model (model eight) showed that, apart from one plantation, use of blue gums was always lower than the use of adjacent native forest (Fig. 4).

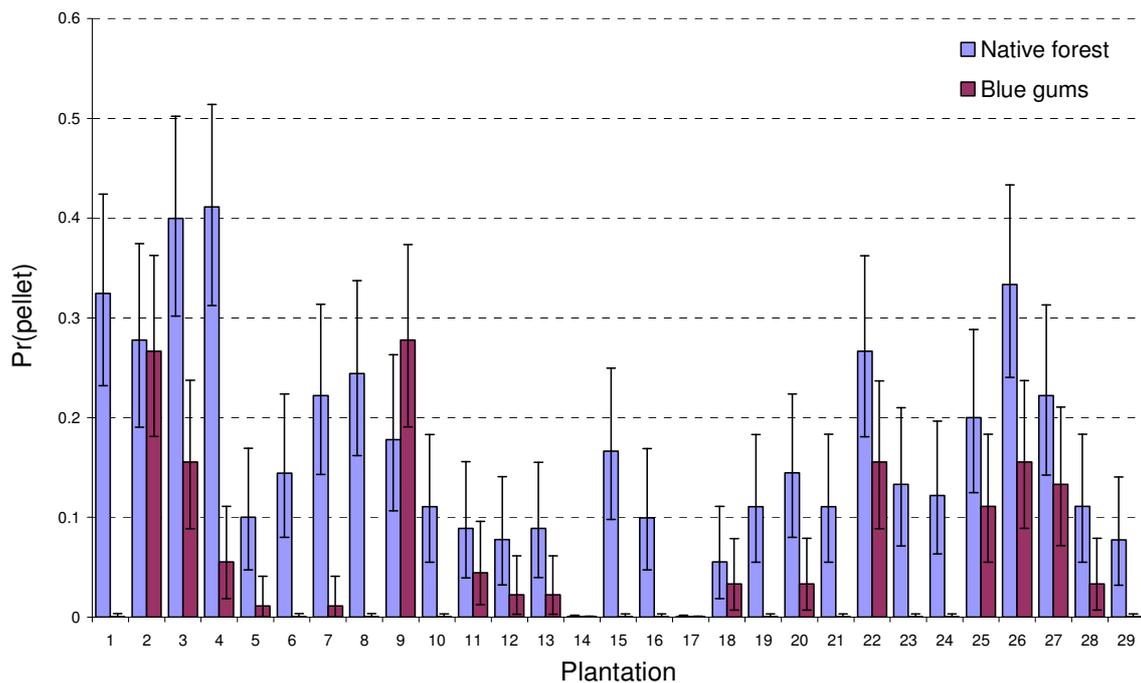


Figure 4. Predicted use of blue gums and adjacent native forest by koalas for the 29 plantations surveyed in the phase one study based on model eight. Means and 95% credible intervals of the posterior distributions are shown.

5.2 Phase two analysis

Based on DIC values, model four was the most parsimonious description of the data (Table 4). In model four distance and dbh effects were both non-zero, which suggests that both distance to native forest and the dbh of blue gums are important determinants of variation in Blue Gum use within plantations. Within plantations, koalas were more likely to use blue gums close to native forest than far from native forest and were more likely to use large blue gums than small blue gums. However, models within 1-2 DIC units of the best model should also be considered as having support from the data relative to the best model (Spiegelhalter et al. 2002). Therefore, models two and three could also be considered parsimonious descriptors of the data relative to model four (Table 11). This means that, although the weight of evidence is that both distance to native forest and dbh are important explanatory factors of Blue Gum use within plantations, the data does not allow us to determine whether one is more important than the other. Finally, variation between plantations in the dbh effect was greater than

variation between plantations in the distance effect ($E\{\tau_{dbh}\} = 2.34$, whereas $E\{\tau_{dist}\} = 7.01$ for model four).

Table 11. Model rankings, DICs and selected posterior parameter estimates (means and 95% credible intervals) for the phase two analysis.

Ranking	Model	DIC	μ_{dist}	μ_{dbh}
1	model 4 ($\mu_{dist} = \mu_{dist}, \mu_{dbh} = \mu_{dbh}$)	1813.37	-0.33 (-0.77, 0.11)	0.98 (0.37, 1.64)
2	model 2 ($\mu_{dist} = \mu_{dist}, \mu_{dbh} = 0$)	1814.36	-0.33 (-0.77, 0.10)	
3	model 3 ($\mu_{dist} = 0, \mu_{dbh} = \mu_{dbh}$)	1815.46		0.98 (0.37, 1.66)
4	model 1 ($\mu_{dist} = 0, \mu_{dbh} = 0$)	1816.41		

6 Discussion and Conclusions

There has been no published research on the use of Blue Gum plantations by koalas. This study has contributed to our knowledge base on the use of Blue Gum plantations and adjacent native vegetation. In Australia research on wildlife use of plantations has mainly been limited to birds and pest species. However, some opportunistic recordings of marsupial species have been made, including the occasional report of a koala.

While the use of Blue Gum as a Koala fodder species has not yet been conclusively determined (the species has been classified as “likely primary” in the Ballarat Koala Habitat Atlas) when it occurs in plantation form, there have been ample reports of Koala sightings in Blue Gum plantations and individual trees. Even if plantation blue gums could only be afforded a secondary habitat status, their occurrence might still facilitate the extension of a koala’s home range by providing additional food and shelter resources, and facilitate dispersal of sub-adults and recruitment of new adults into the population.

Our research clearly showed that koalas do use Blue Gum plantations, but usually only when adjacent native forest is also used by koalas. In addition, in areas where koalas were found to use both the native vegetation and plantation, activity levels were almost always higher within the native vegetation than they were in plantations. It was also shown that within plantations, koalas tended to use trees close to native forest more than trees far from native forest. This suggests that Blue Gum plantations are likely to serve as an extension to existing Koala habitat rather than as Koala habitat in their own right. The general preference for larger trees by koalas is known from a number of earlier studies. Larger trees in general and in this study larger blue gums are easier to climb, provide a greater amount of food and offer shelter at the same time, as well as having young leaves which are often, preferred Koala browse. Anecdotal reports have placed koalas in very young blue gums where they were also reported to cause damage to young growth at the top of a tree. While such observations are undoubtedly true, the majority of our observations and scat evidence placed koalas more often in older (larger) rather than younger (smaller) trees. While our research showed koalas' preference for larger blue gums it does not mean that they won't use smaller ones at all or that small blue gums cannot serve as fodder trees. Koalas are notoriously difficult to spot and generally are easier to see when in young or small trees or in trees where the lack of canopy and bark does not offer much camouflage. It appears that koalas do not frequently use young blue gums and most likely do not impact plantation establishment or plantation success.

While no direct link between plantation size or plantation age and koala use was found, plantation shape may affect Koala use of plantations with consequent management implications when considering new plantations. Since koalas were found to utilise plantation edges adjacent to native forest more than plantation interiors, taking into consideration the constraints faced by plantation managers, it is preferable where possible to have plantations that maximise the edge adjacent to native forest / Koala habitat. More generally we would expect plantations that maximise edge with native forest to be used more by koalas than plantations that have minimal edge with native forest. Therefore, strategically placed plantations that maximise edge with native forest, may increase habitat or habitat connectivity for koalas more effectively than plantations with minimal edge with native forest. The authors acknowledge that such planning for

increased edge effect might not always be achievable due to constraints such as local property conditions, boundaries and land title restrictions.

Another example of an application of this finding would be the inclusion of narrow Blue Gum plantations into shelterbelts on farms in conjunction with a few rows of known Koala habitat tree species. While the blue gums would be harvested, the native vegetation would remain and serve as Koala (and other wildlife) habitat until a new Blue Gum plantation belt would be mature advanced enough to support koalas. Such plantation design would be well suited along water courses and some wider tracks on farms.

However, this preliminary study only provides some evidence of this and clearly more research is needed. This may include a more detailed analysis of the existing phase one data to investigate distance to native forest effects in conjunction with plantation size and age effects. Further analysis of the existing data and the collection of new data on Koala use of native vegetation near plantations would also help to develop a predictive model of Koala use of native forest and plantations. If a predictive model could be developed that included site and landscape scale variables, then this would allow predictions of which plantations are most likely to contain koalas. This would provide valuable information for the strategic management of existing and future plantations.

There is little doubt in the authors' minds that some Blue Gum plantations are being used as an extension of existing Koala habitat and possibly as corridors. Koala management in Victoria, over the past 80 odd years, has resulted in the creation of a number of isolated "island like" forests on the mainland where koalas were translocated into. These areas often experience unnatural population increases due to the lack of dispersal opportunities for young koalas. Strategically placed Blue Gum plantations whose design incorporates native vegetation buffers and which are planted / harvested in a rotational system, could potentially assist with the dispersion of koalas from such isolated forests like Mt Eccles. This is especially so as Blue Gum plantations are now covering wide areas of the Koala's original range. The species appears to be palatable to koalas, the rainfall requirements allow it to be grown widely and plantations are therefore continually expanding across the state. Recently, there has been a push for larger scale re-vegetation projects with an aim of linking habitats and creating corridors.

With financial support for the inclusion of native vegetation buffers within Blue Gum plantations, Koala corridors could fast become a reality.

In light of the current climate change debate and speculations on carbon trading schemes, using Blue Gum plantations, with or without native vegetation buffers or corridors, as an incentive or a means to plant more trees, should be seen as an opportunity to minimise any potential impacts from increased temperatures on the all so prevalent stresses to existing Koala habitat.

At this point in time there is no conclusive evidence to suggest that koalas permanently inhabit Blue Gum plantations. Radio-tracking of individual koalas is the only definitive way to assess Koala home-ranges and use of habitat. Radio-tracking studies would therefore be of particular interest to determine how individual koalas use particular plantations. Differences in usage by koalas of different sexes and ages, as well as seasonal differences should also be examined.

Finally, our findings suggest that koalas will be present in some plantations once they are harvested. Therefore, at the very least, this suggests that harvesting prescriptions should be developed which consider the welfare of koalas in plantations where there is a high likelihood of their occurrence. This could be in form of pre-planting desktop surveys to establish the likelihood of koalas occurring at the site when the plantation matures and / or Koala scat surveys or line transect surveys before harvesting to establish where koalas are most likely encountered during harvesting. There is most definitely the need to have in place some management guidelines that deal with circumstances where koalas are encountered during the actual harvesting process.

7 Summary of Recommendations

Research

- Further analysis of phase one and phase two data (with a potential need to obtain more SAT data) to investigate distance to native forests in combination with plantation age and size effects. This process would also contribute to the

development of a predictive model for Koala use of native vegetation as well as Blue Gum plantations.

- Undertake a radio-tracking program to establish Koala home range behaviour in both Blue Gum plantations and neighbouring Koala habitat.
- Undertake a comparative study of available nutrients and toxins in the leaves of plantation blue gums and those occurring elsewhere.
- Investigate the health and genetic status of a Koala population in and near a Blue Gum plantation with high Koala activity levels.
- Investigate use of Blue Gum plantations by koalas near a known Koala isolate eg. Mt Eccles.

Management

- Dissemination of findings to all stakeholders through the publication of a paper in a scientific journal as well as in an industry magazine and via public forums such as industry field days.
- Explore the possibility of pre-establishment and pre-harvest desktop-surveys to determine the likelihood of Koala occurrence in plantations.
- Explore the need for pre-harvest Koala surveys to protect individual koalas in plantations with high Koala activity levels. Both of the above points would need to be linked with the development of protocols and realistic, practical management strategies as part of further research.
- Investigate the importance of retained remnant trees within a plantation design, of incorporating Koala corridors in a plantation layout and the potential for maximising plantation edge with native forest and/or staggered planting / harvesting regimes when practical and financially viable.
- Investigate a Koala-friendly eco-certification program to raise awareness of the plantation industry's commitment to Koala conservation.

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