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The tree species preferences of koalas (*Phascolarctos cinereus*) inhabiting forest and woodland communities on Quaternary deposits in the Port Stephens area, New South Wales

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Abstract. An assessment of the tree species preferences of koalas inhabiting forest and woodland communities growing on Quaternary deposits in the Port Stephens area, New South Wales, was undertaken between November 1994 and March 1996. Using a plot-based methodology, 3847 trees were sampled, comprising 15 *Eucalyptus* species and 17 species of non-eucalypt. Evidence of tree use by koalas, specifically the presence of koala faecal pellets, was recorded from beneath 10 *Eucalyptus* species and 9 species of non-eucalypt. Tree species preferences were determined by analyses of log-likelihood ratios derived from data based on the presence/absence of koala faecal pellets, rather than on gross counts. This approach confirmed significant variation in the levels of utilisation amongst and between different tree species, and that two in particular – swamp mahogany (*E. robusta*) and drooping red gum (*E. parramattensis*) – were most preferred. Increases in the levels of use of other tree species were also positively associated with the presence of *E. robusta* and/or *E. parramattensis*. Levels of utilisation of *E. robusta* and *E. parramattensis* did not alter significantly in response to changes in their respective densities, suggesting that the relative abundance of both was important in terms of understanding the carrying capacity of vegetation communities utilised by koalas. The results have established the success with which an enumerative approach to the interpretation of faecal pellet data can be utilised to clarify the tree species preferences of koalas. Application of the approach for habitat assessment and mapping purposes is also discussed.

Introduction

The koala (*Phascolarctos cinereus*) is an obligate folivore that feeds primarily on the genus *Eucalyptus* (Martin and Lee 1984). Throughout their range in eastern Australia, koalas have been reported as utilising a wide variety of eucalypt and non-eucalypt species, aspects of which have been discussed by various authors (Hindell *et al.* 1985; Lee and Martin 1988; White and Kunst 1990; Hindell and Lee 1990; Phillips 1990; Melzer 1995; Melzer and Lamb 1996). While some of these accounts tend to portray koalas as opportunistic in terms of their tree species preferences, it has been generally acknowledged that, within a particular area, only a few of the available *Eucalyptus* species will be preferentially utilised while others, including some non-eucalypt genera, appear to be browsed opportunistically or used for other behavioural purposes (Lee and Martin 1988; Lee and Carrick 1989; Phillips 1990; Pahl and Hume 1990; Hindell and Lee 1990). Soil nutrients are also believed to influence the suitability of some food tree species (Cork and Braithwaite 1996).

A common theme in the literature on the management of free-ranging koala populations is a perception that habitat destruction represents the greatest threat to long-term conservation of the species (Lunney *et al.* 1990; Phillips 1990; Gordon 1996). If this is true, then it is clear that habitat must be conserved. Unfortunately, there is little agreement among researchers as to which tree species are most preferred by koalas (Phillips 1990). As a consequence, uncertainty about how best to define koala habitat (Cork *et al.* 1990; Hume 1990; Norton and Lindenmayer 1991; Norton and Neave 1996) and which are the most preferred tree species in a given area (Phillips 1990; Sharp and Phillips 1997) tends to overshadow and undermine the more pressing need to effectively conserve it, an issue that is exacerbated by the absence

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of an approach to habitat assessment that is broadly accepted by the scientific community.

The Port Stephens area was identified as one of the richest koala sites in New South Wales by a 1986–87 survey (Reed *et al.* 1990). Effective long-term management of the area's koala population will be contingent upon a detailed understanding of its habitat requirements. The purpose of this study was to examine habitat utilisation by koalas in that part of the Port Stephens Local Government Area (the LGA) considered to support most of the koala population (Callaghan *et al.* 1994). The study was undertaken with a view to identifying those tree species of most importance to koalas in the area. In doing so, the study also aimed to initiate a substrate-based approach that had broader ramifications for koala conservation by not only contributing further to an understanding of habitat use by the species, but also by providing a means by which the resolution of differences regarding tree preferences and the assessment of koala habitat could be achieved.

Methods

Study area

The Port Stephens LGA covers an area of approximately 97 000 ha and is located some 200 km north of Sydney on the central coast of New South Wales (Fig. 1). A significant proportion of the LGA constitutes a body of Quaternary deposits known as the Tomago Coastal Plain, an area of more than 35 000 ha largely comprising sandbeds of Pleistocene and Holocene origin separated by a low-lying inter-barrier of estuarine flats (Matthei 1995; Murphy 1995). To the north and west, alluvial Quaternary deposits derived from other geological strata also adjoin the sandbeds; however, such areas were excluded from this study due to their differing origins, vegetation types and more complex pedology[1].

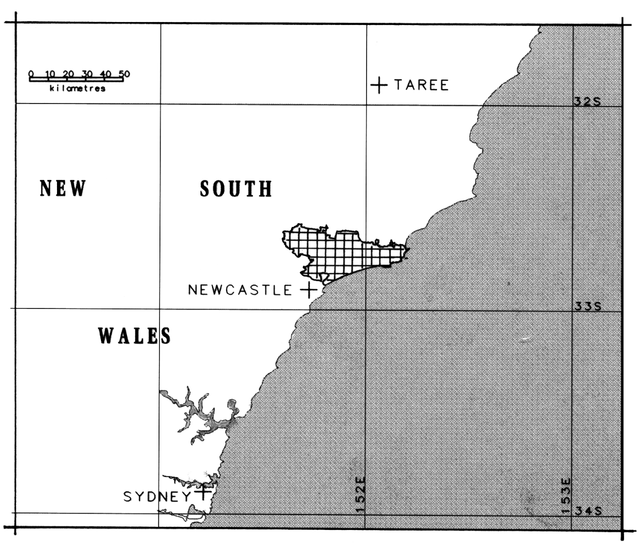

Fig. 1. Location of the Port Stephens Local Government Area (cross-hatched area) on the central coast of New South Wales.

Selection of field sites

Vegetation maps of the Tomago Coastal Plain at a scale of 1 : 25 000 and that had been prepared for the Port Stephens Draft Koala Management Plan (Callaghan *et al.* 1994) were used to assist selection of field sites. The maps identified a mosaic of broad vegetation types from forest and woodland communities variously dominated by smooth-barked apple (*Angophora costata*), swamp oak (*Casuarina glauca*), broad-leafed paperbark (*Melaleuca quinquenervia*), blackbutt (*Eucalyptus pilularis*), scribbly gum (*E. signata*), red bloodwood (*Corymbia gummifera*), swamp mahogany (*E. robusta*) and drooping red gum (*E. parramattensis*), to wetlands and coastal heaths dominated by *Melaleuca* spp., *Leptospermum* spp. and *Banksia* spp.

To minimise the potential for possible edge effects, a 150-m exclusion zone was applied over ecotonal areas and to boundaries of vegetation communities affected by disturbances such as recent fire, urban development or major arterial roads. Field site localities were then chosen by arbitrarily selecting a discrete area of vegetation, the boundaries of which conformed with that delineated on the vegetation map. The selected area was then partitioned using a 50 m × 50 m grid-cell-based numerical overlay. Final site selection was then determined by the first correspondence of a given cell number with one from a series of independently generated random numbers. AMG co-ordinates for the centre of each grid cell so selected were then ascertained and transferred to Magellan 'Trailblazer' GPS units to assist location in the field. At least four independent replicates were initially generated for each of the major vegetation communities. Given that the use of such areas by koalas and the abundance of various tree species within a particular vegetation community could not be predicted with certainty, sampling was also driven by the need to ensure that statistically useful data sets were compiled for each tree species; additional sites were subsequently generated as required.

Assessment of field sites

Once located in the field (to ±50 m), each site was established by using a compass, measuring tape and flagging tape to designate the corners and midpoints of a 40 m × 40 m (0.16 ha) plot oriented along each of the four cardinal compass bearings from a central reference point. Towards the latter part of the study, supplementary field sites in the form of variable radius plots (Phillips and Callaghan 1995) were also employed to gather additional data; this latter approach afforded greater flexibility for the purposes of site selection while utilising the same assessment protocols, and was specifically used to increase sample size and the number of independent replicates for otherwise poorly sampled tree species.

Within each field site, an area on the ground prescribed by a distance of 100 cm from any one point around the base of each tree was carefully inspected for the presence of koala faecal pellets. All koala faecal pellets within the radial search area were recorded, the count initiated with a precursory inspection of the area described above, followed by a more thorough inspection of the substrate that included disturbance of the leaf litter and any ground cover. Where the distribution of faecal pellets fell within overlapping search areas brought about by two or more trees growing in close proximity to each other, the number of pellets within the area of overlap were allocated to each tree accordingly (i.e. without regard for the other). Approximately 2 person-minutes were devoted to the faecal pellet search at each tree. Once counted and recorded, all pellets were replaced at the base of the tree. For purposes of the study a 'tree' was defined as a live woody stem of any plant species (excepting palms, cycads, tree-ferns and grass-trees) that had a diameter at breast height (dbh) of 100 mm or greater.

[1]Quaternary landscape data provided in the related work by Lunney *et al.* (1998) includes the results from sites that were located on these alluvial substrates.

Data analysis

'Active' and 'inactive' sites

In order to describe the extent of habitat use that could be attributed to a given field site, 'activity levels' for each were expressed as the percentage equivalent of the quotient derived by dividing the total number of trees (all species) that had one or more faecal pellets within the prescribed search area by the total number of trees (all species) sampled in the field site. For the purposes of statistical analyses, variation in activity levels was assumed to be normally distributed.

To avoid the potential for biasing results whereby the recorded absence of koala faecal pellets in a given field site was possibly a consequence of factors other than poor koala habitat quality *per se*, completed field sites were categorised as either 'active' or 'inactive' on the basis of whether pellets were present or absent respectively. Only 'active' field sites were considered for analysis in the first instance; data relating to 'inactive' sites were subsequently reviewed in the light of results obtained by the approach detailed below.

Faecal pellet counts

The average number of faecal pellets observed within the prescribed search area beneath each tree was calculated from trees in both 'eucalypt' and 'non-eucalypt' categories. Variances associated with the average score in each category were tested for homogeneity and the appropriate *t*-test used for comparative purposes.

Tree preferences and habitat utilisation

Recent studies have concluded that the use of counts of accumulated faecal pellets for determining tree species preferences is problematical (Melzer *et al.* 1994; Hasegawa 1995; Pahl 1996). Because of this, no further consideration was given to the total number of faecal pellets recorded beneath each tree; rather, they were considered to be either present or absent, thus transforming the association between tree species and their use by koalas into that being measured by a binary variable. For a given tree species 'i', the results from each active field site were pooled to obtain a proportional index (P_i) – hereafter referred to as the 'strike rate' – which was simply derived by dividing the total number of individual trees of species 'i' that had one or more koala faecal pellets recorded beneath them (p_i), by the total number of trees of that species sampled (n_i). Thus, $P_i = p_i / n_i$.

Data sets for each tree species were regarded as most appropriate for analysis purposes when (a) the data set had been obtained from at least 7 independent 'active' sites, and (b) n_iP_i and $n_i(1 - P_i)$ were both at least as large as 5. Data that satisfied these criteria were considered part of a primary data set containing those tree species that were being frequently utilised by koalas and thus most likely to be of some importance in terms of sustaining the population. Log-likelihood ratios were used to examine the extent of variation amongst the strike rates for each tree species in the primary data set. Significant heterogeneity was addressed by a re-arrangement of data sets for each species in order of decreasing strike rate and the resulting hierarchical model was then tested for homogeneity using simultaneous test procedures. Logistic regression was used to investigate the relationship between density (no. of live stems per 0.16 ha) and the number of trees with pellets in each active field site for each species isolated by the above procedure as being most preferred. Density figures for relevant tree species were obtained directly from that recorded in study plots and a likelihood-ratio test was used to examine the significance of each relationship, the results being presented as simplified logit models in each instance.

The extent of variation amongst strike rates for those tree species that failed to satisfy the minimum criteria for inclusion in the primary data set was examined using a Kruskal–Wallis ANOVA. Where significant heterogeneity was indicated, between-species comparisons were undertaken using the U statistic derived from a Wilcoxon two-sample test.

A *post hoc* test of association (G-test of independence) was also undertaken to examine the relationship between the number of trees with pellets in each field site and the presence/absence of those tree species identified as most preferred by koalas in the study area; the phi coefficient (ϕ) was calculated to determine the strength of any association.

Statistical procedures utilised for the study followed procedures detailed by Sokal and Rohlf (1995) and Agresti (1996); BIOMstat 3.2 and SPSS 6.1 software were employed for critical components of the data analyses.

Results

Data were collected from 58 independent field sites (Fig. 2). In total, 3847 trees were assessed, collectively comprising 15 *Eucalyptus* species and 17 species of non-eucalypt. In all, 41 of the field sites contained evidence of utilisation by koalas, with faecal pellets recorded from beneath 10 *Eucalyptus* species and 9 species of non-eucalypt (Table 1). Activity levels (variable radius plots excluded) ranged from 2.9% to 90.3% [mean = 32.41 ± 4% (s.e.)].

Of the 3107 trees present in active sites, 977 had koala faecal pellets recorded within the prescribed search area beneath each tree. The number of faecal pellets recorded beneath individual *Eucalyptus* species ranged from 1 to 388 (mean = 8.89, median = 3, mode = 1, n = 666) while the number of pellets recorded beneath individual tree species of non-eucalypt genera ranged from 1 to 204 (mean = 7.15, median = 2, mode = 1, n = 311). Although a higher number of faecal pellets tended to be found under 'eucalypts' than 'non-eucalypts', the difference was not statistically significant (Levene's Test: $F = 1.487$, $P > 0.05$; $t_{[975]} = -1.19$, $P > 0.05$).

Tree species preferences

Data sets that met the specified criteria for inclusion in the primary data set were obtained for 5 of the 10 *Eucalyptus* species and for 5 non-eucalypt species. Of the eucalypts, the range of strike rates varied from 0.293 for *Eucalyptus signata* to 0.555 for *Eucalyptus robusta*. There was significant heterogeneity amongst strike rates when tested for Goodness of Fit ($G_{adj} = 69.8282 > \chi^2_{0.001[4]} = 18.467$). Using a critical value of $\chi^2_{[4]} = 9.4878$, the results of an unplanned test for homogeneity using simultaneous test procedures subsequently established the presence of two homogenous data sets within the sample (Table 2). Both *E. robusta* and *E. parramattensis* were isolated by this process as the most preferred tree species. There was no significant difference between the strike rates of *E. robusta* and *E. parramattensis* ($G_{adj} = 0.271 < \chi^2_{0.05[1]} = 3.841$). However, that of *E. piperita* was significantly lower when compared with the pooled *E. robusta / E. parramattensis* data sets ($G_{adj} = 8.586 > \chi^2_{0.01[1]} = 6.635$). Regression analyses further established that the proportion of *E. robusta* and *E. parramattensis* that had faecal pellets recorded within the prescribed search area did not alter significantly in response to changes in the number of live stems (*E. robusta*: $G^2(M_O) = 0.567$, $P = 0.451$; *E. par-*

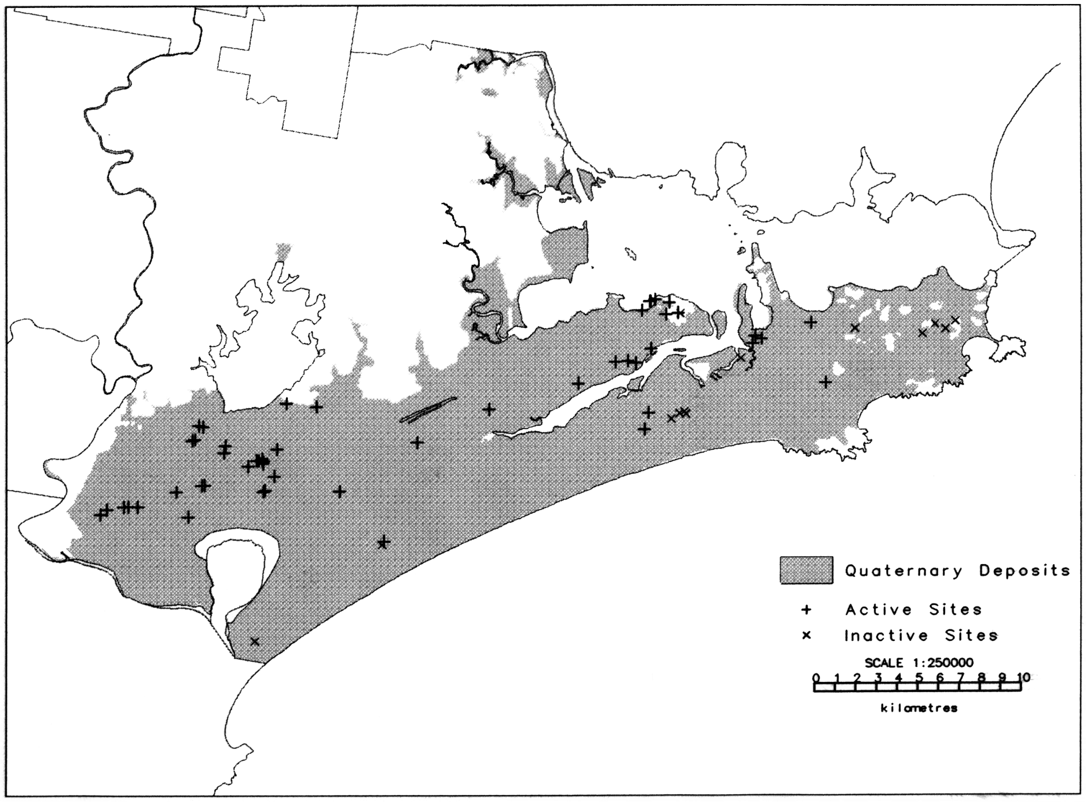

Fig. 2. Distribution of active and inactive field sites.

Table 1. Pooled results derived from 41 sites utilised by koalas in the Port Stephens area

For each tree species, the total sample size (n_i) and the number of independent sites in which it was represented are detailed. Strike rates (P_i) are presented ± s.e.

Species	No. sites	n_i	P_i	Species	No. sites	n_i	P_i
Eucalypts				Non-eucalypts			
E. robusta	14	348	0.555 ± 0.036	*C. gummifera*	16	224	0.308 ± 0.056
E. parramattensis	9	494	0.536 ± 0.031	*M. quinquenervia*	12	718	0.297 ± 0.032
E. piperita	7	171	0.421 ± 0.058	*A. costata*	22	263	0.247 ± 0.053
E. pilularis	8	90	0.356 ± 0.085	*B. serrata*	12	101	0.139 ± 0.092
E. signata	13	351	0.293 ± 0.045	*M. nodosa*	10	175	0.131 ± 0.070
E. eugeniodes	3	26	0.154 ± 0.180	*M. stypheloides*	5	33	0.242 ± 0.152
E. globoidea	3	7	0.286 ± 0.319	*C. glauca*	2	8	0.250 ± 0.306
E. spp.	3	6	0.167 ± 0.368	*M. linearfolia*	1	3	0.600 ± 0.365
E. resinifera	2	10	0.100 ± 0.300	*A. torulosa*	1	36	0.222 ± 0.147
E. botyroides[A]	1	4	1.000	Others (8 spp.)	8	33	
Others (3 spp.)	3	6		Total trees		1594	
Total trees		1513					

[A] species not native to the area.

ramattensis: $G^2(M_O) = 1.414$, $P = 0.235$). Scatterplots associated with the respective regression models are detailed in Figs 3 and 4.

Strike rates of the three other *Eucalyptus* species (*E. eugenioides*, *E. globoidea* and *E.* spp.) that were represented by data sets that did not satisfy the minimum standard for inclusion in the primary data set were also examined. The extent of variation amongst the strike rates for these three species was not significant (Kruskal–Wallis ANOVA: $H = 0.473 < \chi^2_{0.05[2]}$), nor did their respective strike rates (0.154, 0.286 and 0.167) indicate a level of utilisation by koalas that was similar to that recorded for the two most preferred species. Data relating to the remaining *Eucalyptus* species (*E. resinifera* and *E. botyroides*) beneath which faecal pellets were recorded were not considered suitable for analysis purposes.

Table 2. Extent of homogeneity amongst the strike rates (P_i) for the five *Eucalyptus* species most frequently utilised by koalas

The descriptor 'HDS' refers to each of the homogeneous data sets established using simultaneous test procedures. Erob = *E. robusta*, Epar = *E. parramattensis*, Epip = *E. piperita*, Epil = *E. pilularis*, Esig = *E. signata*

Tree spp.	Erob	Epar	Epip	Epil	Esig
P_i	0.555	0.536	0.421	0.356	0.293
HDS1	×	×	×		
HDS2			×	×	×

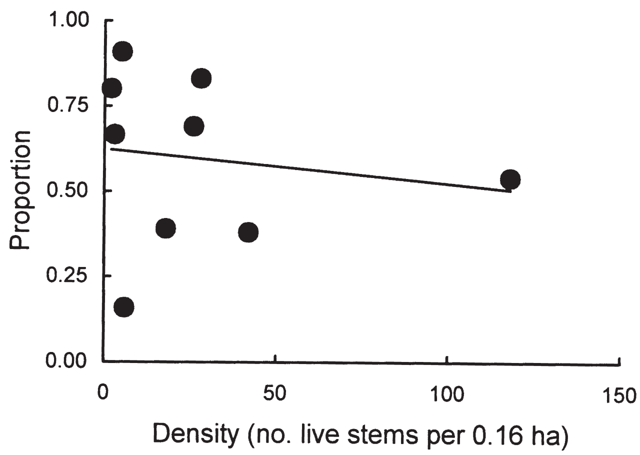

Fig. 3. Scatterplot associated with the simplified logit model for swamp mahogany (*E. robusta*). Regression model describes relationship between the proportion of trees with pellets (P) and the density of live stems per 0.16 ha. Intercept (logit) = 0.349 ± 0.235 (s.e.); regression coefficient. $b = -0.002 \pm 0.003$ (s.e.).

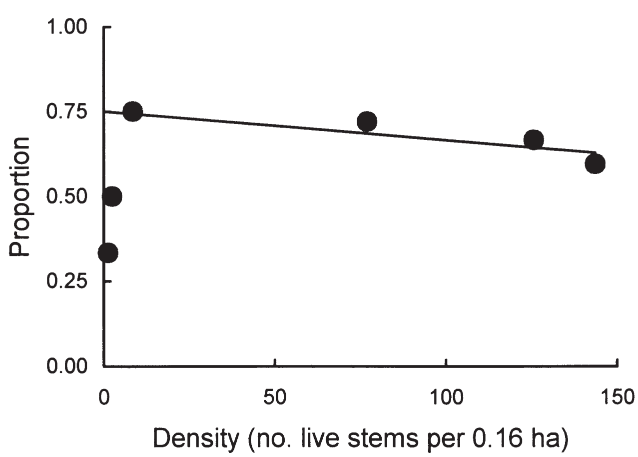

Fig. 4. Scatterplot associated with the simplified logit model for drooping red gum (*E. parramattensis*). Regression model describes relationship between the proportion of trees with pellets (P) and the density of live stems per 0.16 ha. Intercept (logit) = 1.084 ± 0.424 (s.e.), regression coefficient $b = -0.004 \pm 0.003$ (s.e.).

Of the non-eucalypts, the range of strike rates varied from 0.308 for *Corymbia gummifera* to 0.131 for *Melaleuca nodosa* (Table 1). There was significant heterogeneity amongst the strike rates when tested for Goodness of Fit ($G_{adj} = 33.6789 > \chi^2_{0.001[4]} = 18.467$). Using a critical value of $\chi^2_{[4]} = 9.488$, an unplanned test for homogeneity using simultaneous test procedures (all replicates) resulted in the identification of three homogeneous data sets. *C. gummifera* and *M. quinquenervia* received the highest levels of utilisation (Table 3).

Table 3. Extent of homogeneity amongst the strike rates (P_i) for the five species of non-eucalypt most frequently utilised by koalas

The descriptor 'HDS' refers to each of the homogeneous data sets established using simultaneous test procedures. Cgum = *Corymbia gummifera*, Mqui = *Melaleuca quinquenervia*, Acos = *Angophora costata*, Bser = *Banksia serrata*, Mnod = *Melaleuca nodosa*

Tree spp.	Cgum	Mqui	Acos	Bser	Mnod
P_i	0.308	0.297	0.247	0.139	0.131
HDS1	×	×	×		
HDS2			×	×	
HDS3				×	×

Table 4. Tree species represented in the 17 inactive sites (those that showed no evidence of use by koalas)

The total sample size (n_i) and the number of independent sites associated with each tree species are detailed

Species	No. sites	n_i
Eucalypts		
E. pilularis	8	105
E. grandis	2	38
E. resinifera	2	34
E. umbra	2	29
E. piperita	2	27
E. robusta	2	17
E. microcorys	1	34
E. tereticornis	1	11
E. agglomerata	1	2
E. capitellata	1	3
E. parramattensis	1	14
E. signata	1	5
E. spp.	1	8
Total trees		327
Non-eucalypts		
Angophora costata	11	132
Banksia serrata	6	70
Corymbia gummifera	4	45
Leptospermum sp.	2	4
Acacia sp.	1	5
Casuarina glauca	1	88
Melaleuca quinquenervia	2	69
Total trees		413

The results of the *post hoc* test of association provided strong evidence that the presence of *E. robusta* and/or *E. parramattensis* had a positive influence on the strike rates for other tree species ($G = 99.926 > \chi^2_{0.001[1]} = 10.828$). The level of this association was moderately strong ($\phi = 0.218$).

Inactive sites

Seventeen field sites were deemed 'inactive' due to the absence of koala faecal pellets. From these sites 740 individual trees were sampled, comprising 13 *Eucalyptus* species and 7 species of non-eucalypt. *E. pilularis* and *Angophora costata* were the tree species most commonly associated with non-active sites (Table 4).

Discussion

Studies relating to the use of faecal pellets to determine aspects of habitat use by koalas have increased in recent years (Hasegawa 1995; Melzer 1995; Phillips and Callaghan 1995; Munks *et al.* 1996; Pahl 1996; Jurskis and Potter 1997). Of these, the works of Hasegawa (1995) and Pahl (1996) represent significant attempts to determine localised food tree preferences by using accumulated faecal pellet counts in conjunction with relative abundance data and the formulae of Hindell *et al.* (1985) to derive preference indices. However, while this approach provides useful insights into preferred species, the cut-off line between tree species being preferentially utilised and those being the subject of more opportunistic utilisation cannot be determined with certainty. Further issues associated with pellet counts suggested that their suitability for determining feeding preferences was problematic (Hasegawa 1995; Pahl 1996). However, in concluding that accumulated faecal pellet counts were not especially useful in establishing the feeding habits of koalas, Hasegawa (1995) incidentally established that, on the basis of the presence of faecal pellets *per se,* the tree species with the highest proportional level of use by koalas in his study area was also the most preferred food tree (on the basis of identification of cuticle fragments in koala faecal pellets). This finding has significant implications for the results of this study given that the approach we have taken similarly identifies tree species with the highest proportional representation. That we have succeeded in isolating tree species with levels of utilisation that are significantly higher than those of their congeners and other non-related tree species allows us to be confident that we have successfully identified the preferred food tree species in this instance. This study is consequently the first to employ a faecal pellet–based methodology that unequivocally identifies preferentially utilised tree species from amongst a suite of others also known to be commonly utilised by koalas.

The results provide cogent support for a model of habitat use by koalas inhabiting forest and woodland communities on Quaternary deposits in the Port Stephens LGA that is primarily focused on the preferential utilisation of only two *Eucalyptus* species. Drooping red gum (*E. parramattensis*) has largely been overlooked in studies associated with the tree species preferences of koalas, only Hawkes (1978) having previously noted that the species was reportedly browsed by koalas. A possible reason for this lack of prominence in the koala literature is that *E. parramattensis* has a relatively limited geographic range in eastern Australia, its distribution being restricted to localised areas of the central coast and tablelands of New South Wales (Hawkes 1978; Brooker and Kleinig 1990; Harden 1991).

In contrast to *E. parramattensis,* swamp mahogany (*E. robusta*) has frequently been reported as a food tree species for koalas (e.g. Hawkes 1978; Wicks 1978; Lee and Martin 1988; Summerville 1990; Pahl *et al.* 1990). *E. robusta* occurs in a narrow band along the east coast of Australia from near Nowra on the south coast of New South Wales to north of Yeppoon on the central Queensland coast, favouring low, swampy sites and estuarine alluvial soils (Hawkes 1978; Harden 1991; Brooker and Kleinig 1996). Congreve and Betts (1978) also regarded *E. robusta* as 'promising feed' in their study of feeding preferences demonstrated by an introduced koala population at Yanchep in Western Australia. However, the status of *E. robusta* in terms of its importance as a 'preferred' food tree for koalas has been equivocal and/or largely anecdotal, nor has it been quantified until the present study. By example, Pahl *et al.* (1990) listed *E. robusta* as a 'primary' food source for koalas but did not specify the criteria upon which such a distinction was made. Conversely, Lee and Martin (1988) listed *E. robusta* as an 'occasional' food tree. *E. robusta* did not figure prominently in the work of Reed *et al.* (1990), nor was it mentioned by Phillips (1990) in his discussion of tree species preferences arising out of the National Koala Survey data.

Inconsistencies such as those above are indicative of the confusion that exists concerning the importance of some tree species to koalas. While there is broad agreement amongst researchers that only a few tree species will be favoured by koalas in any one area, most have persisted in maintaining a somewhat catholic approach when detailing the most preferred species. Hawkes (1978) considered *E. tereticornis* (along with *E. punctata*) as 'staple browse' for koalas in coastal New South Wales. Citing the work of others, Hindell and Lee (1990) unequivocally stated that the preferred tree species for koalas in New South Wales were *E. camaldulensis* and *E. tereticornis*, whereas Phillips (1990) described Sydney blue gum (*E. saligna*) as '… most popular with New South Wales Koalas …'. Such generalisations further serve to highlight the urgent need for an understanding of the tree species preferences of koalas at a much finer scale than has hitherto been applied. Similar views have been expressed by other workers (Cork *et al.* 1990; Norton and Neave 1996) in suggesting that management of localised koala populations required a more precise assessment of the quality and nature of the food resource than that which was currently available. Consistent with this latter view, and based on the knowledge that a significant association between a given tree species and the presence of faecal pellets can be a reliable indicator of feeding preferences (Hasegawa 1995), the results of this study are strongly supportive of a notion that *E. parramattensis* and *E. robusta* function as primary food tree species for koalas on the Tomago Coastal Plain.

In comparison with the obvious importance of *E. robusta* and *E. parramattensis*, the strike rates of the remaining *Eucalyptus* species and those of other genera such as *Corymbia*, *Melaleuca* and *Angophora* are generally not indicative of significant levels of utilisation by koalas. This view is concordant with that of Lee and Martin (1988) and Hasegawa (1995), who observed that even in cases where non-eucalypts were fed upon, the foliage of the preferred eucalypt species (*E. viminalis* and *E. tereticornis* respectively) consistently made up the bulk of the diet. Structural complexity and a tendency to commonly occur in association with preferred species may also be involved in the higher levels of utilisation of the non-eucalypts *C. gummifera*, *M. quinquenervia* and *A. costata*. The presence of cuticle fragments of species such as *M. quinquenervia* and *Corymbia intermedia* by Hasegawa (1995) confirm that some incidental browsing of these species also occurs.

The regression models presented for *E. robusta* and *E. parramattensis* are significant in terms of further clarifying the function and importance of primary food tree species to koalas generally. That the proportion of trees with pellets does not differ significantly in response to changes in density clearly indicates that lesser or greater numbers of koalas are likely to be associated with such changes. Thus, the models are supportive of a notion that a greater number of animals are utilising the resource in response to an increase in the density of live stems. A similar conclusion based on observations of free-ranging koalas was made by Hindell and Lee (1987), who reported a positive correlation between koala densities and the relative abundance of the preferred food tree, *E. viminalis*, in the Brisbane Ranges, while Mitchell (1990) noted that larger home-range areas (and therefore lower koala densities) occurred in areas where the preferred tree species were more sparsely distributed, despite the presence of a variety of other *Eucalyptus* species.

Observations such as those above are of relevance in terms of determining the importance of a given vegetation community for koalas. Cork *et al.* (1990) considered that the key to mapping koala habitat was a consideration of tree communities rather than individual tree species. However, as the results of this work and the above studies suggest, individual tree species, where they can be shown to be the subject of preferential use by koalas, are a critical consideration in terms of understanding carrying capacity. Moreover, we would suggest that an understanding of which tree species are important and which are not clearly increases the likelihood of finding koalas or evidence thereof, while also permitting the relative worth of the vegetation communities being utilised by koalas to be ascertained with a greater degree of confidence than that which is currently being practised.

The autecological importance of *E. robusta* and *E. parramattensis*, as determined by this study, is difficult to quantify further at this stage. The presence of faecal pellets within the prescribed search area beneath the greater proportion of *E. robusta* and *E. parramattensis* sampled (55.5% and 53.6% respectively) provides direct evidence that such trees had been utilised by koalas on at least one occasion. On the basis of the low central-tendency statistics associated with the faecal pellet counts and the probability issues associated with maintenance of such a consistently high strike rate (see also Ellis *et al.* 1998), it is considered that an even greater measure of importance should be attributed these two species than that which has been evidenced by the results. To this end we propose that primary food tree species such as *E. robusta* and *E. parramattensis* represent a finite resource for koala populations. As such, and notwithstanding issues associated with habitat destruction, fire and the depredations of motor vehicles and dogs on the Port Stephens koala population (Callaghan *et al.* 1994), *E. robusta* and *E. parramattensis* should be considered as major limiting factors affecting the distribution and abundance of koalas on the Tomago Coastal Plain.

The positive influence of the two most preferred tree species on the strike rates of other tree species lends further support to the preceding argument by inferring that the extent of differences between *E. robusta* and *E. parramattensis* and those of other tree species are likely to be greater than that evidenced by the results. We suspect it is not so much the nutritional value of these other tree species that results in the increased levels of use, but rather their proximity to the most preferred species. Regardless, vegetation communities in which these increased levels of utilisation occur should be recognised as important habitat components for the purposes of koala management, given that they undoubtedly provide secure roosting and/or social interaction areas in addition to supplementary browsing opportunities.

The results of this study also allow other issues associated with the identification of koala habitat to be pursued. While the distribution of *E. robusta* and *E. parramattensis* on the Tomago Coastal Plain tends to be mutually exclusive, both are essentially limited by micro-edaphic considerations including soil type, drainage patterns, topography and proximity to the water table (Hawkes 1978; Harden 1991; Brooker and Kleinig 1996). By overlaying soil landscape data (Matthei 1995; Murphy 1995) with a vegetation map of the Tomago Coastal Plain, it could be argued that aeolian, swamp and estuarine soil landscapes of Quaternary origin that support vegetation communities containing one or the other, or both, of the preferentially utilised species *E. robusta* and *E. parramattensis*, should constitute significant koala habitat in the study area. In this regard Lunney *et al.* (1998) recently established a high degree of overlap (91%) between a habitat 'model' based on such an approach (Phillips *et al.* 1996) and the results of an independent community-based survey that provided information on localities where koalas were most frequently observed.

Activity levels such as those recorded during the process of this study can potentially provide an important indicator of the extent to which contemporary koala populations are utilising the resources available to them. Thus, the consistent lack of activity indicators such as faecal pellets in vegetation communities containing tree species that are not known to be preferred by koalas are arguably a further measure of their lesser importance. Alternatively, once it has been determined that a particular tree species on a given substrate is the subject of preferential utilisation, we would argue that the complete absence of activity indicators such as faecal pellets from areas containing such tree species provides substantive evidence in support of localised extinction processes associated with historical and contemporary range contractions. For example, three tree species that figure prominently in the inactive sites associated with this study – *E. pilularis*, *C. gummifera* and *A. costata* – collectively form a distinctive vegetation community within the study area. Given that these species have not been shown to be the subject of preferential utilisation in their own right, it appears reasonable to conclude that vegetation communities comprised solely of these species will be of only marginal importance as koala habitat, except where they occur immediately adjacent to those communities and/or areas wherein preferentially utilised tree species occur. Inactive sites that contain *E. robusta* and/or *E. parramattensis*, on the other hand, could not be similarly discounted, especially given recent evidence in support of a once-abundant and widespread koala population in the study area that could clearly be associated with at least one of the above species (Knott *et al.* 1998).

We conclude by reiterating that the resolution of issues associated with the identification of significant food trees for koalas has long acted as an impediment to effective conservation and management of the species. However, we believe that the approach detailed in this study offers some assistance towards an accurate determination of critical koala habitat components over large forested areas in eastern Australia. The extrapolation of field-based results such as those detailed herein, combined with detailed vegetation maps that provide a contemporary assessment of the distribution and composition of native vegetation communities, also offers an alternative approach for habitat modelling and/or mapping purposes. Hierarchical habitat categories based on densities and/or relative abundance of the most preferred tree species would also seem an appropriate measure by which to plan for the effective conservation of extant koala populations, more so given the clear relationship between this variable and the carrying capacity of the vegetation communities in which they grow. Given its ability to overcome problems associated with accumulated pellet counts, the use of a binary variable for the purposes of interpreting faecal deposits by koalas potentially has widespread application. Further development of the approach could facilitate a greater insight into the nature of habitat use by koalas while allowing habitat management and conservation issues to be clarified with a greater degree of certainty than is currently being achieved.

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References

Agresti, A. (1996). 'An Introduction to Categorical Data Analysis.' (John Wiley and Sons: New York.)

Brooker, M. I. H., and Kleinig, D. A. (1990). 'Field Guide to Eucalypts. Vol. 1. South-eastern Australia.' (Inkata Press: Melbourne.)

Brooker, I., and Kleinig, D. (1996). '*Eucalyptus* – An Illustrated Guide to Identification.' (Reed Books: Port Melbourne.)

Callaghan, J., Leathley, S., and Lunney, D. (1994). 'Port Stephens Koala Management Plan – Draft for Public Discussion.' (New South Wales National Parks and Wildlife Service, Port Stephens Council & Hunter Koala Preservation Society: Raymond Terrace.)

Congreve, P., and Betts, T. J. (1978). Eucalyptus plantations and preferences as food for a colony of koalas in Western Australia. In 'The Koala – Proceedings of the Taronga Symposium'. (Ed. T. J. Bergin.) pp. 97–105. (Zoological Parks Board of New South Wales: Sydney.)

Cork, S. J., Margules, C. R., and Braithwaite, L. W. (1990). Implications of koala nutrition and the ecology of other arboreal marsupials in south-eastern New South Wales for the conservation management of koalas. In 'Koala Summit – Managing Koalas in New South Wales'. (Eds D. Lunney, C. A. Urquhart and P. Reed.) pp. 48–57. (New South Wales National Parks and Wildlife Service: Sydney.)

Cork, S. J., and Braithwaite, L. W. (1996). Resource availability, eucalypt chemical defences, and habitat quality for leaf-eating marsupials. In 'Koalas – Research for Management'. (Ed. G. Gordon.) pp. 9–16. (World Koala Research Incorporated: Brisbane.)

Ellis, W. A. H., Sullivan, B. J., Lisle, A. T., and Carrick, F. N. (1998). The spatial and temporal distribution of koala faecal pellets. *Wildlife Research* **25**, 663–668.

Gordon, G. (Ed.). (1996). 'Koalas – Research for Management. Proceedings of the Brisbane Koala Symposium, 22–23 September 1990.' (World Koala Research Incorporated: Brisbane.)

Harden, G. J. (Ed.).(1991). 'Flora of New South Wales. Vol. 2.' (University of New South Wales Press: Kensington.)

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

Hawkes, N. H. (1978). Identification and management of koala eucalypt trees in New South Wales. In 'The Koala – Proceedings of the Taronga Symposium'. (Ed. T. J. Bergin.) pp. 89–96. (Zoological Parks Board of New South Wales: Sydney.)

Hindell, M. A., Handasyde. K. A., and Lee. A. K. (1985). Tree species selection by free-ranging koala populations in Victoria. *Australian Wildlife Research* **12**, 137–144.

Hindell, M. A., and Lee, A. K. (1987). Habitat use and tree preferences of koalas in a mixed eucalypt forest. *Australian Wildlife Research* **14**, 349–360.

Hindell, M. A., and Lee. A. K. (1990). Tree preferences of the koala. In 'Biology of the Koala'. (Eds A. K. Lee, K. A. Handasyde and G. D. Sanson.) pp. 117–121. (Surrey Beatty and Sons: Sydney.)

Hume, I. D. (1990). Biological basis for the vulnerability of koalas to habitat fragmentation. In 'Koala Summit – Managing Koalas in New South Wales'. (Eds D. Lunney, C. A. Urquhart and P. Reed.) pp. 32–35. (New South Wales National Parks and Wildlife Service: Sydney.)

Jurskis, V., and Potter, M. (1977). Koala surveys, ecology and conservation at Eden. Research Paper No. 34, State Forests of New South Wales, Sydney.

Knott, T., Lunney, D., Coburn, D., and Callaghan, J. (1998). An ecological history of koala habitat in Port Stephens Shire and the Lower Hunter on the central coast of New South Wales, 1801–1998. *Pacific Conservation Biology* **4**, 354–368.

Lee, A., and Martin, R. (1988). 'The Koala – A Natural History.' (University of New South Wales Press: Sydney.)

Lee, A. K., and Carrick, F. N. (1989). Phascolarctidae. In 'Fauna of Australia. Vol. 1B: Mammalia'. (Eds D. W. Walton and B. J. Richardson.) pp. 740–754. (Australian Government Publishing Service: Canberra.)

Lunney, D., Urquhart. C. A., and Reed, P. (Eds). (1990). 'Koala Summit – Managing Koalas in New South Wales'. (New South Wales National Parks and Wildlife Service: Sydney.)

Lunney, D., Phillips, S., Callaghan, J., and Coburn, D. (1998). A new approach to determining the distribution of koalas and conserving their habitat: a case study from Port Stephens Shire on the central coast of New South Wales. *Pacific Conservation Biology* **4**, 186–196.

Martin, R. W., and Lee, A. (1984). The koala, *Phascolarctos cinereus*, the largest marsupial folivore. In 'Possums and Gliders'. (Eds A. P. Smith and I. D. Hume.) pp. 463–467. (Surrey Beatty and Sons: Sydney.)

Matthei, L. E. (1995). 'Soil Landscapes of the Newcastle 1 : 100 000 Map Sheet'. (Department of Land and Water Conservation, New South Wales: Sydney.)

Melzer, A., Schneider, M. A., and Lamb, D. (1994). Insects associated with the faecal pellets of the koala, *Phascolarctos cinereus* Goldfuss. *Australian Entomologist* **21**, 69–70.

Melzer, A. (1995). Aspects of the ecology of the koala *Phascolarctos cinereus* (Goldfuss, 1817), in the sub-humid woodlands of central Queensland. Ph.D. Thesis, University of Queensland, Brisbane.

Melzer, A., and Lamb, D. (1996). Habitat utilisation by a central Queensland koala colony. In 'Koalas – Research for Management'. (Ed. G. Gordon.) pp. 93–101. (World Koala Research Incorporated: Brisbane.)

Mitchell, P. (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.) pp. 171–187. (Surrey Beatty and Sons: Sydney.)

Munks, S. A., Corkrey, R., and Foley, W. J. (1996). Characteristics of arboreal marsupial habitat in the semi-arid woodlands of northern Queensland. *Wildlife Research* **23**, 185–195.

Murphy, C. (1995). 'Soil Landscapes of the Port Stephens 1 : 100 000 Map Sheet'. (Department of Land and Water Conservation, New South Wales: Sydney.)

Norton, T. W., and Lindenmayer, D. B. (1991). Integrated management of forest wildlife: towards a coherent strategy across State borders and land tenures. In 'Conservation of Australia's Forest Fauna'. (Ed. D. Lunney.) pp. 237–244. (Royal Zoological Society of New South Wales: Sydney.)

Norton, T. W., and Neave, H. M. (1996). Koala habitat: a conceptual functional model. In 'Koalas – Research for Management'. (Ed. G. Gordon.) pp. 93–101. (World Koala Research Incorporated: Brisbane.)

Pahl, L. (1996). Koala and bushland survey of west and central Logan City. In 'Koalas – Research for Management'. (Ed. G.Gordon.) pp. 82–92. (World Koala Research Incorporated: Brisbane.)

Pahl, L. I., Wylie, F. R., and Fisher, R. (1990). Koala population decline associated with loss of habitat and suggested remedial strategies. In 'Koala Summit – Managing Koalas in New South Wales'. (Eds D. Lunney, C. A. Urquhart and P. Reed.) pp. 39–47. (New South Wales National Parks and Wildlife Service: Sydney.)

Pahl, L. I., and Hume, I. D. (1991). Preferences for *Eucalyptus* species of the New England Tablelands and initial development of an artificial diet for koalas. In 'Biology of the Koala'. (Eds A. K. Lee, K. A. Handasyde and G. D. Sanson.) pp. 123–128. (Surrey Beatty and Sons: Sydney.)

Phillips, B. (1990). 'Koalas – the Little Australians We'd All Hate to Lose.' (Australian Government Publishing Service: Canberra.)

Phillips, S., and Callaghan, J. (1995). The spot assessment technique for determining the significance of habitat utilisation by koalas. In 'Proceedings of a Conference on the Status of the Koala in 1995'. (Australian Koala Foundation: Brisbane.)

Phillips, S., Callaghan, J., and Thompson, V. (1996). 'The Koala Habitat Atlas – Project No.6: Port Stephens Local Government Area'. (Australian Koala Foundation: Brisbane.)

Reed, P. C., Lunney, D., and Walker, P. (1990). A 1986–1987 survey of the koala *Phascolarctos cinereus* (Goldfuss) in New South Wales and an ecological interpretation of its distribution. In 'Biology of the Koala'. (Eds A. K. Lee, K. A. Handasyde and G. D. Sanson.) pp. 55–74. (Surrey Beatty and Sons: Sydney.)

Sokal, R. R., and Rohlf, F. J. (1995). 'Biometry. The Principles and Practice of Statistics in Biological Research.' 3rd Edn. (W.H. Freeman and Company: New York.)

Sharp, A., and Phillips, S. (1997). Koalas, science and conservation. In 'Saving Our Natural Heritage – The Role of Science in Managing Australia's Ecosystems'. (Eds C. Copeland and D. Lewis.) pp. 290–301. (Halstead Press: Sydney.)

Summerville, K. (1990). Koalas in the Tweed Shire. In 'Koala Summit – Managing Koalas in New South Wales'. (Eds D. Lunney, C. A. Urquhart and P. Reed.) pp. 74–76. (New South Wales National Parks and Wildlife Service: Sydney.)

White, N. A., and Kunst, N. D. (1990). Aspects of the ecology of the koala in southeastern Queensland. In 'Biology of the Koala'. (Eds A. K. Lee, K. A. Handasyde and G. D. Sanson.) pp. 148–151. (Surrey Beatty and Sons: Sydney.)

Wicks, J. R. (1978). Koala preservation in an urban situation. In 'The Koala – Proceedings of the Taronga Symposium'. (Ed. T. J. Bergin.) pp. 148–151. (Zoological Parks Board of New South Wales: Sydney.)

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