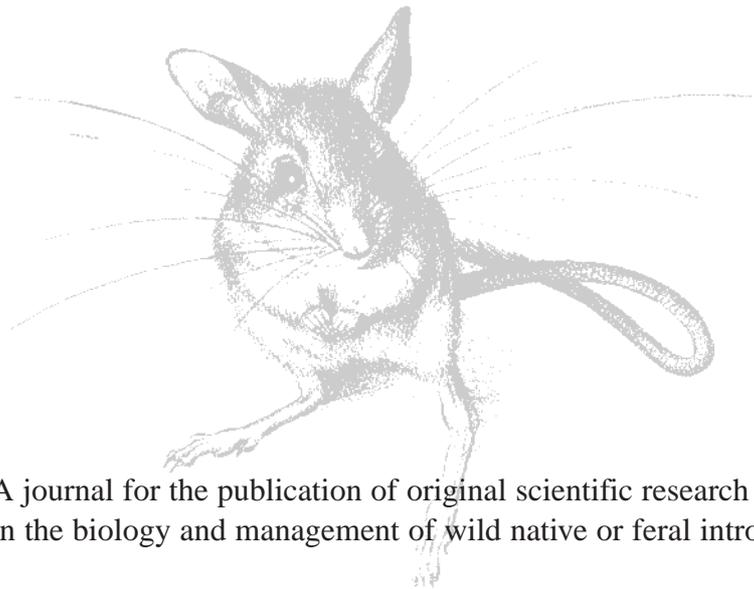

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Tree species preferences of koalas (*Phascolarctos cinereus*) in the Campbelltown area south-west of Sydney, New South Wales

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Abstract. Tree species preferences of a koala population inhabiting a small area of forest and woodland in the Campbelltown area, south-west of Sydney, were investigated over a two-year period. In total, 2499 trees from 45 independent field sites were assessed, with tree species preferences determined on the basis of a comparative analysis of proportional data relating to the presence/absence of koala faecal pellets. The results established that grey gum (*Eucalyptus punctata*) and blue-leaved stringybark (*E. agglomerata*) were most preferred by koalas in the study area, but only when growing on shale-based substrates. The preferential utilisation of *E. punctata* and *E. agglomerata* on substrates derived from shales, compared with that recorded for the same species on sandstones, suggests that their use by koalas was influenced by differences in nutrient status between substrates. Regression analyses further identified a trend for use of at least one of the preferred species (*E. punctata*) to be more commonly associated with larger trees. Results are discussed in terms of their relevance to issues of resource availability and the need to reconsider, by way of a hierarchical approach, the use of food trees by koalas generally. The presence of *E. punctata* and *E. agglomerata* and their occurrence in conjunction with shale-based substrates are considered to be important limiting factors affecting the present-day distribution and abundance of koalas in the Campbelltown area.

Introduction

Koalas (*Phascolarctos cinereus*) are obligate folivores that feed primarily on the genus *Eucalyptus*. Throughout their range in eastern Australia, koalas have been recorded as utilising a wide variety of eucalypt and non-eucalypt species (Hawkes 1978; Lee and Martin 1988; Hindell and Lee 1990; Phillips 1990; White and Kunst 1990; Melzer and Lamb 1996; Lunney *et al.* 1998). While some of these accounts portray koalas as opportunistic browsers, as a general rule only some *Eucalyptus* species will be preferentially utilised in a given area while others, including some non-eucalypts, appear to be utilised opportunistically for feeding or other purposes (Lee and Martin 1988; Hindell and Lee 1990; Phillips 1990), or because they occur in close proximity to preferred food tree species (Phillips *et al.* 2000). Soil nutrient levels are also considered to influence the palatability of some tree species for koalas (Cork and Braithwaite 1996).

The Campbelltown area supports one of the few remaining koala populations of the Sydney region. Koalas in the area became well known during the late 1980s when the potential impact of a proposed residential development on the Wedderburn Plateau became the subject of community debate (Dobson 1990; Papps 1990; Sheppard 1990; Close 1993). The aim of this study was to examine habitat being utilised by koalas in the area, with the specific objective of determining the most preferred food tree species.

Methods

Study area

Campbelltown is located approximately 40 km south-west of Sydney, New South Wales. The Campbelltown Local Government Area (CLGA) (33°58'–34°10'S, 150°44'–150°56'E) is bounded to the south-west by the Nepean River and to the north-east by the Georges River. The northern section of the Wedderburn Plateau is located in the south-eastern portion of the CLGA (Fig. 1).

The western and northern areas of the CLGA are characterised by gentle undulating rises associated with Wianamatta shale formations. In contrast, the easterly and southerly portions of the CLGA are characterised by Hawkesbury sandstone geomorphology, with steep, near-vertical cliffed benches along the Georges River, sometimes with wide, stepped platforms exposing interbedded shale layers. Elevations in the CLGA range from approximately 150 m above sea level in the gorges, to 240 m above sea level on the plateau. As detailed in Phillips and Callaghan (1996), the vegetation is predominantly woodland with stringybarks (*Eucalyptus* spp.) and red bloodwood (*Corymbia gummifera*) as dominant canopy species. Grey gum (*E. punctata*) becomes dominant where interbedded lenses of shale occur but tends to be replaced by blackbutt (*E. pilularis*) in areas where sandstone-derived substrates predominate. To the south, the vegetation changes to communities dominated largely by hard-leaved scribbly gum (*E. sclerophylla*), *C. gummifera* and blue-leaved stringybark (*E. agglomerata*). Other areas support woodlands with *E. pilularis* and Sydney red gum (*Angophora costata*) as the dominant canopy species. Wet heathlands under a woodland canopy of Sydney peppermint (*Eucalyptus piperita*), *A. costata* and *C. gummifera* also occur, interspersed with pockets of whipstick ash (*E. multicaulis*). [Note: The tree species nomenclature adopted in this study, including common names, follows that of Harden (1990, 1991, 1992) with the exception of the bloodwoods. Hill and

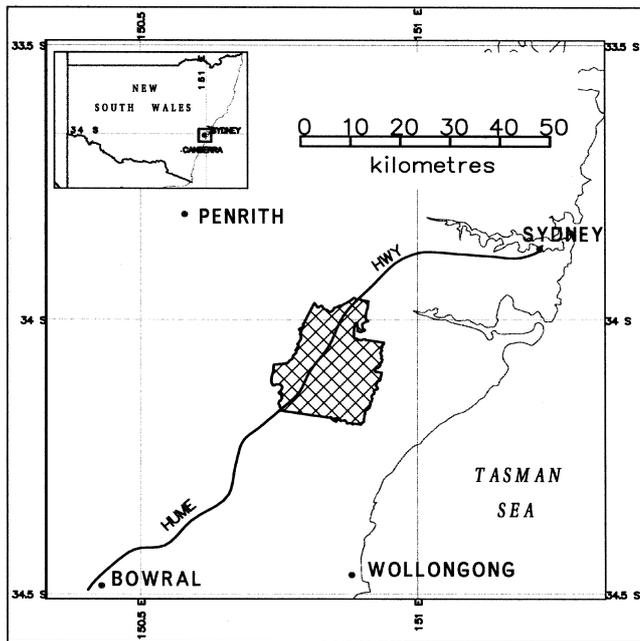


Fig. 1. Location of the Campbelltown Local Government Area (cross-hatched area).

Johnson's (1995) revision, which places bloodwoods in the new genus *Corymbia*, has subsequently been applied.]

Field site selection and assessment

Field work was initiated in 1994. Tree species preferences and activity levels associated with habitat utilisation by koalas in the study area were assessed using a plot-based methodology developed by the Australian Koala Foundation for the purposes of the Koala Habitat Atlas project (Sharp and Phillips 1997; Phillips *et al.* 2000). The study area was initially sub-divided into its respective geological units based on maps obtained from the Department of Mineral Resources. These areas were then overlain with a 1 : 25 000 scale vegetation map specifically prepared for the study (see Phillips and Callaghan 1996). Potential field site localities were determined by selecting a discrete area of vegetation, the boundaries of which conformed to those occurring on the vegetation map, but which could also be associated with a given geological unit (i.e. shale or sandstone). Such areas were then partitioned using a 50 m × 50 m grid-based numerical overlay. Independently generated random numbers were used to determine final plot locations, and the site coordinates for the centre of each grid cell so selected were then transferred to hand-held Magellan 'Trailblazer' GPS units to assist their location in the field. A series of independent replicates for each of the identified vegetation communities occurring on each particular geological unit were also generated to facilitate the collection of statistically useful data on the use of different tree species by koalas.

Once located in the field (to ±50 m), each plot was established by using a compass, measuring tape and flagging tape to designate the corners and mid-points of a 40 m × 40 m (0.16 ha) square orientated 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 data; this latter approach afforded greater flexibility for the purposes of site selection while utilising the same assessment protocols as those described below, and was specifically employed when koala faecal pellets were opportunistically encountered in the field during foot-based traverses of the area.

Within each plot, 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 or absence of koala faecal pellets, the search initiated with a precursory inspection of the area described above, followed by a more thorough inspection of the substrate (including 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 close 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 two person-minutes were devoted to the faecal pellet search at each tree. The diameter at breast height (dbh) of each tree was also recorded, a 'tree' being 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' (Phillips *et al.* 2000).

For a given tree species '*i*' the results from each active field site (i.e. those plots in which koala faecal pellets were detected) were pooled to obtain a proportional index (P_i) – hereafter referred to as the 'strike-rate' – that was 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). Derived in this way, the strike-rate ($P_i = p_i/n_i$) also serves as a conditional probability estimator (±s.e.) related to the use of a given tree species by koalas.

Activity levels and tree species preferences

Activity levels for each plot were expressed as the percentage equivalent of the quotient obtained by dividing the total number of trees (all species) that had one or more koala faecal pellets recorded within the prescribed search area divided by the total number of trees (all species) in the plot. Activity levels were assumed to be normally distributed.

Tree species preferences were determined from a comparative analysis of the results from all 'active' plots. It was initially intended that the data set for a given tree species would be regarded as valid for assessment purposes only when it had been obtained from at least seven independent sites on a given geological unit. In conjunction with other qualifiers, data sets that satisfy this criterion are considered part of a primary data set comprising those tree species that are frequently utilised by koalas and thus most likely to be of importance in terms of sustaining the population (Phillips *et al.* 2000).

Fieldwork quickly established that koala activity in the CLGA was localised. Initial plot assessments followed by extensive vehicle- and foot-based traverses generally failed to detect evidence of koalas outside of an area immediately adjacent to, and north of, the Wedderburn Plateau. Further field work was subsequently concentrated in this area. Even in this area, however, evidence of koalas was uncommon and the likelihood of gathering sufficient data on each of the tree species being utilised to the extent specified in the preceding paragraph was considered poor. Because of this, the minimum number of active sites required to validate a given tree species was reduced ($n = 3$) and the extent of variation amongst the strike-rates of species in eucalypt and non-eucalypt data sets respectively was assessed using a Kruskal–Wallis Anova, with the U statistic derived from Wilcoxon two-sample tests used to test for significant differences in strike-rates between species. Data associated with plots wherein no faecal pellets were detected were subsequently reviewed in the light of results obtained from the active plots. Preliminary analyses of the data assumed no substrate bias. For those tree species identified as being most preferred, Kendall's Robust line-fit method was used to investigate the potential for relationships between tree size (dbh) and strike-rate.

All statistical analyses followed protocols and procedures detailed by Sokal and Rohlf (1995) and were largely undertaken using BIOMStat 3.2 and SPSS 6.1 software. Unless otherwise indicated, the significance level used in all tests was 0.05. Means are shown with standard errors.

Table 1. Pooled data for all tree species contained in the 20 active sites that had been utilised by koalas in the Campbelltown Local Government Area

Substrate type: A, sandstone-based; B, shale-based. P indicates the proportion of trees in each instance that had faecal pellets recorded in the prescribed search area beneath each tree. *n* = the total number of trees sampled; s.e. = standard error

Eucalypts	Substrate	No. sites	<i>n</i>	P	s.e.	Non-eucalypts	Substrate	No. sites	<i>n</i>	P	s.e.
<i>E. agglomerata</i>	A	4	19	0.316	0.107	<i>Allocasuarina littoralis</i>	A	1	11	0.000	
<i>E. agglomerata</i>	B	6	58	0.190	0.052	<i>A. littoralis</i>	B	2	17	0.000	
<i>E. capitellata</i>	A	3	36	0.056	0.038	<i>Angophora bakeri</i>	A	1	18	0.056	0.054
<i>E. capitellata</i>	B	1	2	0.000		<i>A. costata</i>	A	7	42	0.024	0.024
<i>E. consideniiana</i>	A	1	14	0.000		<i>A. costata</i>	B	11	76	0.013	0.013
<i>E. multicaulis</i>	A	2	33	0.000		<i>A. subvelutina</i>	A	1	3	0.000	
<i>E. multicaulis</i>	B	1	3	0.000		<i>Banksia serrata</i>	A	6	54	0.000	
<i>E. paniculata</i>	A	1	1	0.000		<i>B. serrata</i>	B	5	20	0.050	0.049
<i>E. paniculata</i>	B	1	3	0.000		<i>Corymbia gummifera</i>	A	9	177	0.006	0.006
<i>E. pilularis</i>	A	2	20	0.000		<i>C. gummifera</i>	B	10	221	0.050	0.015
<i>E. pilularis</i>	B	5	41	0.024	0.024	<i>C. eximia</i>	B	1	1	0.000	
<i>E. piperita</i>	A	2	18	0.000		<i>Hakea sericea</i>	B	1	1	0.000	
<i>E. piperita</i>	B	4	26	0.154	0.071	<i>Leptospermum trinervium</i>	A	1	2	0.000	
<i>E. punctata</i>	A	4	44	0.068	0.038	<i>L. trinervium</i>	B	1	3	0.000	
<i>E. punctata</i>	B	10	154	0.169	0.03	<i>Melaleuca hypericifolia</i>	A	4	7	0.000	
<i>E. sclerophylla</i>	A	1	17	0.000		<i>M. hypericifolia</i>	B	4	12	0.083	0.08
<i>E. sclerophylla</i>	B	2	4	0.250	0.217	<i>M. linariifolia</i>	A	1	3	0.000	
<i>E. sieberi</i>	A	2	20	0.050	0.049	<i>Persoonia pinifolia</i>	A	1	2	0.000	
<i>E. sieberi</i>	B	2	3	0.333	0.272	<i>P. pinifolia</i>	B	1	1	0.000	
						<i>Syncarpia glomulifera</i>	A	2	15	0.267	0.114
						<i>S. glomulifera</i>	B	4	28	0.036	0.035
Total trees			516						714		

Results

In total, 2499 trees, comprising 1159 eucalypts and 1340 non-eucalypts from 45 field plots, were assessed. Evidence of tree use, specifically the presence of koala faecal pellets, was observed in 20 of the 45 field plots, with faecal pellets recorded from beneath 7 *Eucalyptus* species and 6 species of non-eucalypt (Table 1). Activity levels of the 20 plots that contained evidence of use by koalas ranged from 1.2% to 18.4% (mean \pm s.e. = 6.49 ± 1.05 %).

The extent of variation in strike-rate amongst the 7 *Eucalyptus* species that satisfied the sampling criteria was significant when pooled across substrates (Kruskal–Wallis ANOVA: $H_{adj} = 14.919 > \chi^2_{0.05[6]} = 12.592$). Details relating to a comparison of strike-rates between each of the seven species are provided in Table 2, the results indicating that *E. punctata* and *E. agglomerata* received significantly higher levels of utilisation than the other species. Strike-rates for *E. sieberi* and *E. sclerophylla* did not appear to differ significantly from that of *E. punctata* and/or *E. agglomerata*. However, examination of the data indicated that the propinquity of *E. sieberi* and *E. sclerophylla* to that of *E. punctata* and *E. agglomerata* was attributable to results from two sites where faecal pellets were recorded beneath one of only two specimens sampled in each case, thus indicating a disproportionately higher level of use (0.5) than that which might be realistically expected, a phenomenon further compounded by the small sample sizes associated with the former species in each instance.

Notwithstanding the potential influence of substrate on the presence/absence of some tree species, the paucity of faecal pellet evidence generally precluded a comparison of strike-rates for each of the seven species between the two geological substrates sampled. *E. capitellata* was poorly represented in plots from shale sites whereas *E. piperita* and *E. pilularis*, while present in a number of active plots from sandstone sites, did not have koala faecal pellets observed beneath them. The following analyses consequently focussed on those species that were common to both substrates and consistently associated with koala activity.

Table 2. Critical values of the *U* statistic as they relate to between-species comparisons across sandstone- and shale-based substrates for seven *Eucalyptus* species utilised by koalas

Eagg = *E. agglomerata*, Ecap = *E. capitellata*, Epil = *E. pilularis*, Epip = *E. piperita*, Epun = *E. punctata*, Esie = *E. sieberi*, Escl = *E. sclerophylla*. Comparisons that resulted in significant differences at $P \leq 0.05$ are underlined

	Ecap	Epil	Epip	Epun	Esie	Escl
Eagg	<u>34</u>	<u>60</u>	<u>48</u>	76	28	20
Ecap		18	15	<u>47.5</u>	8.5	6
Epil			22	<u>86</u>	19	13
Epip				<u>69</u>	16	11
Epun					38	27
Esie						6.5

Hawkesbury sandstones

Twenty-five plots were assessed. In total, 1335 trees, comprising 12 *Eucalyptus* species and 15 species of non-eucalypt, were sampled. Nine of the 25 plots contained evidence of use by koalas, with faecal pellets recorded from beneath *E. agglomerata*, *E. capitellata*, *E. punctata* and *E. sieberi*. The mean activity level on sandstone-based substrates was $3.44\% \pm 0.7\%$. The extent of variation in strike-rate amongst the four species was not statistically significant (Kruskal–Wallis ANOVA: $H_{adj} = 3.198 < \chi^2_{0.05[3]} = 7.815$).

Wianamatta shales

Twenty plots were assessed. In total, 1164 trees, comprising 12 *Eucalyptus* species and 12 species of non-eucalypt, were sampled. Eleven of the 20 plots provided evidence of use by koalas, with faecal pellets recorded from beneath *E. agglomerata*, *E. pilularis*, *E. piperita*, *E. punctata*, *E. sclerophylla* and *E. sieberi*. The mean activity level on shale-derived substrates was $9.0\% \pm 1.4\%$.

Useful data was restricted to four of the six *Eucalyptus* species beneath which faecal pellets were consistently recorded, those relating to *E. sieberi* and *E. sclerophylla* being excluded due to their poor representation (2 sites each) and small sample sizes ($n = 3$ and $n = 4$ respectively). The extent of variation in strike-rate amongst the four species was significant (Kruskal–Wallis ANOVA: $H_{adj} = 9.066 > \chi^2_{0.05[3]} = 7.815$), with results of a comparison of strike-rates between the four species establishing that *E. punctata* was the most preferred (Table 3). It was also evident that the strike-rate of *E. agglomerata* did not differ significantly from that of *E. punctata*, but nor did it differ significantly from that of *E. piperita*.

Regression analyses established that the use of *E. punctata* was positively associated with larger-sized trees ($\tau = 0.5521$, $z = 1.558$, $P = 0.05$). A similar trend was also evident for *E. agglomerata* but was not significant ($\tau = 0.3333$, $z = 0.939$, $P = 0.17$).

Tests for differences in the strike-rates of *E. punctata* and *E. agglomerata* between substrates, as well as tests for differences between substrate-based activity levels, were also undertaken. The strike-rates for *E. punctata* were signifi-

Table 3. Critical values of the *U* statistic as they relate to between-species comparisons for four species of *Eucalyptus* utilised by koalas on shale-based substrates

Eagg = *E. agglomerata*, Epil = *E. pilularis*, Epip = *E. piperita*, Epun = *E. punctata*. Comparisons that resulted in significant differences at $P \leq 0.05$ are underlined

	Epil	Epip	Epun
Eagg	25	16.5	39
Epil		11	<u>48</u>
Epip			<u>31</u>

cantly higher on shale-based substrates than for the same species on sandstone-based substrates ($U = 36, P < 0.05$), whereas that of *E. agglomerata* was not ($U = 16.5, P > 0.05$). Activity levels of sites on shale-derived substrates were also significantly higher than those on sandstone-derived substrates (Levene's test: $F = 3.65, P > 0.05$; $t_{[18]} = -3.25, P < 0.01$).

Use of non-eucalypts

Faecal pellets were recorded beneath six species of non-eucalypt (Table 1). Analysis was restricted to five species: *Angophora costata*, *Banksia serrata*, *Corymbia gummifera*, *Melaleuca hypericifolia* and *Syncarpia glomulifera*, the data for *Angophora bakeri* being excluded because of its representation in only one active site. The extent of variation in strike-rate amongst the five species was not significant across substrates (Kruskal–Wallis ANOVA: $H_{adj} = 6.837 < \chi^2_{0.05[4]} = 9.488$). However, when substrate-based levels of utilisation were analysed there was significant variation amongst the three species of non-eucalypt beneath which faecal pellets were recorded on sandstone-based substrates (Kruskal–Wallis ANOVA: $H_{adj} = 9.563 > \chi^2_{0.01[2]} = 9.210$). A between-species comparison indicated that the heterogeneity was primarily associated with *Syncarpia glomulifera* (Table 4). Despite the presence of a more substantive *S. glomulifera* data set ($n = 28$ trees from 4 sites) and the presence of faecal pellets beneath an additional two species (*Banksia serrata* and *Melaleuca hypericifolia*) there was no significant variation amongst the use of the same species when growing on shale-based substrates (Kruskal–Wallis ANOVA: $H_{adj} = 4.745 < \chi^2_{0.05[4]} = 9.488$).

Inactive sites

In total, 25 inactive sites were assessed during the course of field work. Inactive sites were associated with both substrate types and collectively contained 14 species of *Eucalyptus* and 15 species of non-eucalypt (Table 5). *Corymbia gummifera* was the tree species most commonly associated with inactive sites.

Table 4. Critical values of the U statistic as they relate to between-species comparisons for four species of non-eucalypt utilised by koalas on sandstone-based substrates

Acos = *Angophora costata*, Bser = *Banksia serrata*, Sglo = *Syncarpia glomulifera*, Cgum = *Corymbia gummifera*. Comparisons that resulted in significant differences at $P \leq 0.05$ are underlined

	Bser	Sglo	Cgum
Acos	21	<u>12</u>	25.5
Bser		27	27
Sglo			<u>16</u>

Table 5. Pooled data for all tree species associated with the 25 sites within which there was no evidence of use by koalas

Substrate type: A, sandstone-based; B, shale-based. n = the number of trees sampled

Tree species	Substrate	No. sites	n
Eucalypts			
<i>E. agglomerata</i>	A	12	55
<i>E. agglomerata</i>	B	6	60
<i>E. capitellata</i>	A	1	7
<i>E. consideniana</i>	B	1	2
<i>E. crebra</i>	A	2	17
<i>E. crebra</i>	B	1	2
<i>E. fibrosa</i>	B	1	1
<i>E. moluccana</i>	A	4	84
<i>E. moluccana</i>	B	1	2
<i>E. multicaulis</i>	A	4	66
<i>E. multicaulis</i>	B	1	42
<i>E. paniculata</i>	B	1	2
<i>E. pilularis</i>	A	2	33
<i>E. pilularis</i>	B	3	67
<i>E. piperita</i>	A	7	16
<i>E. punctata</i>	A	8	41
<i>E. punctata</i>	B	6	83
<i>E. sclerophylla</i>	A	1	7
<i>E. sclerophylla</i>	B	3	15
<i>E. sieberi</i>	A	2	2
<i>E. sieberi</i>	B	1	1
<i>E. tereticornis</i>	B	1	38
Total trees			643
Non-eucalypts			
<i>Allocasuarina littoralis</i>	A	2	21
<i>A. littoralis</i>	B	2	2
<i>Angophora bakeri</i>	A	2	69
<i>A. costata</i>	A	9	84
<i>A. costata</i>	B	2	16
<i>A. subvelutina</i>	B	3	13
<i>Banksia serrata</i>	A	7	29
<i>B. serrata</i>	B	2	3
<i>Casuarina cunninghamiana</i>	A	1	1
<i>Corymbia gummifera</i>	A	11	177
<i>C. gummifera</i>	B	8	108
<i>C. eximia</i>	A	2	2
<i>C. maculata</i>	B	2	31
<i>Exocarpos cupressiformis</i>	A	1	5
<i>Hakea sericea</i>	A	1	2
<i>H. sericea</i>	B	2	2
<i>Melaleuca hypericifolia</i>	A	7	25
<i>M. hypericifolia</i>	B	1	1
<i>M. linariifolia</i>	A	1	4
<i>Persoonia pinifolia</i>	A	6	14
<i>Syncarpia glomulifera</i>	A	1	16
<i>S. glomulifera</i>	B	1	1
Total trees			626

Discussion

The results suggest a model of habitat utilisation by koalas in the Campbelltown area that is focused on two species of *Eucalyptus*: grey gum (*E. punctata*) and blue-leaved stringybark (*E. agglomerata*), both of which were shown to be the

subject of significantly higher levels of utilisation than other *Eucalyptus* species and especially when occurring in conjunction with shale-based substrates.

Eucalyptus punctata is distributed along the New South Wales central coast from south of Nowra to the Liverpool Ranges, where it grows in forest and woodland communities on low- to medium-fertility soils (Harden 1991). The importance of *E. punctata* as a browse species for koalas has been known for some time (Hawkes 1978; Robbins and Russell 1978; Lee and Martin 1988; Phillips 1990) and the species has been the subject of a number of studies that investigated the relationship between its use by koalas and that of foliar essential oils (Eberhard *et al.* 1975; Southwell 1978), nitrogen (Harrop and Degabriele 1976; Cork 1986) and digestible energy (Cork *et al.* 1983). While confirmation of *E. punctata* as a preferred food tree species was not unexpected given the widespread acknowledgment of its perceived importance to koalas, the suggestion that *E. agglomerata* is equally important was not so expected. It is thus of interest that our results are consistent with that determined in a pilot study by Ellis *et al.* (1997), who reported *E. agglomerata* as one of two tree species (the other being *E. punctata*) most commonly found in an analysis of faecal pellet material from koalas in the same area.

Aside from the recent corroboration of our findings by Ellis *et al.* (1997), significant use of *E. agglomerata* by koalas has not been previously reported in the literature. *E. agglomerata* occurs on the central tablelands, central and southern coast of New South Wales and adjacent parts of eastern Victoria (Brooker and Kleinig 1990). In a related context but otherwise based on an assumption that the tree species being utilised by a koala was a food tree, Hindell *et al.* (1985) and Hindell and Lee (1987) also reported a seasonally based preference for a related species (red stringybark, *E. macrorhyncha*) on the basis of their work on tree use by koalas in Victoria.

The significance of both *E. punctata* and *E. agglomerata* on substrates derived from shales, compared with that recorded for the same species on sandstones, suggests that the importance of these two tree species from a koala's perspective may be influenced by changes in the nutrient status of the soil. Such a notion is concordant with that predicted by the 'resource-availability' hypothesis (Bryant *et al.* 1985; Coley *et al.* 1985) whereby the relative availability of plant nutrients and free carbon determine the amount and type of defence that some tree species employ against folivores. Accordingly, the hypothesis advocates that trees growing in low-nutrient substrates defend themselves against folivores such as koalas by incorporating excess carbon into a phenolic-based defence system (Cork and Braithwaite 1996). While the extent to which this relationship influences use by koalas across the small suite of their preferred food tree species remains to be determined, the results of this study at least appear consistent with the hypothesis.

In areas such as Campbelltown where consequences of the resource-availability hypothesis appear to be evident, it could be implied that habitat quality from the koala's perspective will be more complex than simply a measure of the relative abundance of preferred food tree species. Indeed, in assuming some variability in the availability of nutrients throughout an otherwise homogeneous substrate, one might also suspect a corresponding degree of intraspecific variation in the palatability of key food tree species. The phenomenon of intraspecific variation in the use of some tree species by koalas has been noted by several authors. Robbins and Russell (1978) reported that utilisation of some *E. punctata* was preferred over others of the same species in their study of koalas in the Muogamarra Nature Reserve near Sydney. Similarly, Hindell *et al.* (1985) and Hindell and Lee (1987) also reported intraspecific variation in the use of certain tree species by Victorian koalas. Recently, Lawler *et al.* (1998) reported a relationship between a decrease in food intake by koalas and increased levels of terpene and DFPs (diformyl phloroglucinols) and established a measure of intraspecific variation of these compounds amongst individuals of *E. ovata* and *E. viminalis*. As suggested by Lawler *et al.* (1998), it is reasonable to assume that such variation might also be a feature of other *Eucalyptus* species browsed by koalas. If this is true, in the case of *E. punctata* at least, the tendency for koalas to preferentially select larger trees of this species is of interest. While an alternative explanation for this relationship could simply be one of refuge and/or security on the part of an arboreal, non-hollow-dwelling marsupial such as the koala, we suggest that larger trees may also have greater access to soil nutrients or be more successful in the competition for limited nutrients and, because of this, have a lesser need to devote resources to the production of terpenes and DFPs. While results for the CLGA are arguably influenced by the small data sets we were able to compile, they are nonetheless strongly supported by data we have on other species in the grey gum complex (e.g. *E. propinqua*, *E. biturbinata* and *E. canaliculata*) and some stringybark species (AKF, unpublished data).

Implications arising from the study

The low activity levels and strike-rates associated with each of the preferred tree species in the CLGA are very different to those obtained from forest and woodland communities occurring on Quaternary deposits in the Port Stephens area on the north coast of New South Wales. Using an identical approach to that described herein, Phillips *et al.* (2000) reported a mean activity level of $32.41\% \pm 4.0\%$ in addition to percentage equivalent strike-rates of $55.5\% \pm 3.6\%$ and $53.6\% \pm 3.1\%$, respectively, for the preferentially utilised tree species *E. robusta* and *E. parramattensis*. Such disparity suggests a fundamental difference in the relative abundance of koalas between the two areas and indirectly provides further support for the notion of a low-density koala population in the

Campbelltown area, as suggested by Close (1993). Unfortunately, the extent to which the low koala population density has been influenced by historical land-use practices (i.e. logging of preferred food tree species, land clearing for agriculture and urban expansion) or other threatening processes such as fire and predation, cannot be ascertained. Nonetheless, we suspect that koala abundance in the area most likely reflects habitat quality and its associated carrying capacity more than it does other factors, especially given the persistence of a localised population in the area since before the turn of the century (Close 1993). Further, we speculate that the low activity levels we have reported may be typical of those to be expected from habitat utilisation by koalas in low-nutrient environments, whereby a sparsely distributed food resource dictates a requirement for relatively large ranging patterns by resident animals in the population. A similar conclusion in this regard was reached by Melzer and Lamb (1994) in their study of low-density koala populations in the brigalow belt of central Queensland.

The differences between the results obtained by Phillips *et al.* (2000) and those reported in this study with respect to the different strike-rates for the preferred food tree species suggests that it might be possible to segregate koala food trees into at least two hierarchical categories. As argued by Phillips *et al.* (2000), the high strike-rates and density-independent utilisation of *E. robusta* and *E. parramattensis* clearly categorised both as 'primary' food tree species for koalas. On the basis of the results described herein, we propose that preferred tree species such as *E. punctata* and *E. agglomerata*, which tend to exhibit a much lower but still significantly high level of utilisation than other *Eucalyptus* species and which demonstrate evidence of more complex issues associated with their use by koalas, constitute what might best be described as 'secondary' food tree species.

Notwithstanding issues associated with habitat modification, fire and the depredations of feral and domestic dogs, the presence of *E. punctata* and *E. agglomerata* and their occurrence in conjunction with higher-nutrient, shale-based substrates should be considered as major limiting factors influencing the distribution and abundance of koalas in the CLGA. However, our work has also demonstrated that not all of the available habitat in the area is being utilised. This notion is strongly supported by the high proportion of inactive sites on higher-nutrient substrates that contain *E. punctata* and *E. agglomerata*, and by the extensive foot-based traverses we conducted in the study area. Therefore, we suspect that the number of koalas inhabiting the CLGA is lower than that potentially capable of being supported by the total area of suitable habitat. Given the apparent isolation and associated low probability of adequate levels of recruitment from outside of the study area, together with impacts associated with the aforementioned threatening processes, it is our view that the koala population in the CLGA is in need of careful management if its long-term survival is to be

assured. Lastly, this study has also highlighted some of the problems that can be encountered when working with localised wildlife populations occupying correspondingly small areas of habitat. Recent advances in dealing with the design of suitable sampling strategies for such populations (Thompson and Seber 1996) will undoubtedly improve future studies of this kind.

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