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Low-density koala (*Phascolarctos cinereus*) populations in the mulgalands of south-west Queensland. II. Distribution and diet

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Abstract. This study used faecal pellets to investigate the broadscale distribution and diet of koalas in the mulgalands biogeographic region of south-west Queensland. Koala distribution was determined by conducting faecal pellet searches within a 30-cm radius of the base of eucalypts on 149 belt transects, located using a multi-scaled stratified sampling design. Cuticular analysis of pellets collected from 22 of these sites was conducted to identify the dietary composition of koalas within the region. Our data suggest that koala distribution is concentrated in the northern and more easterly regions of the study area, and appears to be strongly linked with annual rainfall. Over 50% of our koala records were obtained from non-riverine communities, indicating that koalas in the study area are not primarily restricted to riverine communities, as has frequently been suggested. Cuticular analysis indicates that more than 90% of koala diet within the region consists of five eucalypt species. Our data highlights the importance of residual Tertiary landforms to koala conservation in the region.

Introduction

Koalas (*Phascolarctos cinereus*) occur in a wide range of habitats throughout Australia, including semi-arid woodlands, coastal, and tropical forests, a substantial proportion of which occurs in semi-arid Australia. However, relatively little is known about the distribution or diet of koalas within such regions.

It has been estimated that the koala has undergone a greater than 50% reduction of its former geographic range since European settlement (Maxwell *et al.* 1996). This range contraction appears to be most severe in western New South Wales and western and northern Queensland. Koalas were historically distributed throughout the woodlands and riparian forests of New South Wales, but are now largely restricted to a patchy distribution on the eastern edge of the western plains and drainage lines, and occasionally western New South Wales (Melzer *et al.* 2000). Current evidence suggests a similar contraction in Queensland (Martin and Handasyde 1995).

The contemporary distribution of koalas is patchy within its reduced geographic range, and is further threatened by habitat clearance and fragmentation, fire and urban expansion (ANZECC 1998; Melzer *et al.* 2000). Melzer *et al.* (2000) provide a detailed discussion of the causal factors linked with this range reduction, and ongoing threatening processes.

Several studies have identified the dietary composition of captive (Ullrey *et al.* 1981; Zoidis and Markowitz 1992; Ellis *et al.* 1999), and localised free-ranging (Tun 1994; Hasegawa 1995; Witt and Pahl 1995) koala populations. However, there has been no prior attempt to identify koala food trees on a biogeographic scale.

In this paper we present the results of a faecal pellet survey that clarifies the current distribution of koalas in the mulgalands biogeographic region of south-west Queensland, and provide a preliminary insight into their relative habitat utilisation. We also present results of cuticular analysis on faecal pellet fragments to identify the primary koala food trees in the study area.

Methods

Study area

The semi-arid mulgalands covers a total of 257 800 km^2 and is the ninth largest biogeographic region in Australia (Thackway and Creswell 1995). The region is described more fully by various authors (e.g. Neldner 1984; Wilson 1999). We conducted our study in the Queensland proportion of that region.

Koala distribution

In this region <1% of non-eucalypts had pellets present beneath their canopy (Sullivan *et al.* 2002), we conducted basal pellet searches within a 30-cm radius of the base of eucalypts (trees in the genera *Eucalyptus*, *Corymbia* and *Angophora*) >10 cm diameter at breast height (Sullivan *et al.* 2002).

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Table 1. Dominant components of each habitat unit (HU)

HU	Landform	Dominant tree species	Dominant soil type
1	Riverine	*Eucalyptus* spp.	Cracking clays on alluvia
2	Floodplain	*Eucalyptus* spp.	Cracking clays on alluvia
3	Floodplain	*Acacia* spp.	Cracking clays on alluvia
4	Plains	*Eucalyptus* spp.	Texture contrast soils
5	Plains	*Eucalyptus* spp.	Loamy/sandy red earths
6	Plains	*Acacia* spp.	Loamy/sandy red earths
7	Plains	*Acacia* spp.	Red earths/red clays
8	Plains	*Angophora/Callitris* spp.	Earthy/loamy sands
9	Residual	*Eucalyptus* spp.	Lithosols/gravelly clays
10	Residual	*Acacia* spp.	Lithosols/gravelly clays

To achieve a representative sample of such a vast area we used a GIS (ARCINFO – ESRI) held by the Environmental Protection Agency (EPA, Toowoomba, Queensland) to map the distribution of all potential koala habitat across the study area. Potential koala habitat was defined by two criteria:

(1) the description of a vegetation association in the Vegetation Series of Queensland (Neldner 1984, 1991; Boyland 1984) had to name any eucalypt species as 'predominant' or 'frequently' occurring (this includes eucalypts that may be sparsely scattered throughout an association), and
(2) field inspections had to concur with the above descriptions.

In October 1995 we conducted preliminary surveys to determine the relative level of utilisation, as determined by the percentage of eucalypts with faecal pellets beneath their canopy, of the four major landform classes of the study area (riverine, floodplain, plains and residual) (Sullivan *et al.* 2002). We used a stratified random design to select sampling sites in a range of vegetation associations within each landform class. These data were collected prior to the development of the pellet-sampling method outlined in Sullivan *et al.* (2002), and pellet searches were conducted beneath the entire canopy of each tree.

The mulgalands is covered by three parts of the Vegetation Survey of Queensland (VSQ) series (Neldner 1984, 1991; Boyland 1984). Most of the study area is covered by VSQ South Central Queensland (Neldner 1984). With assistance from the GIS Unit (EPA, Toowoomba) we recoded all vegetation associations from the three relevant VSQ reports into south central Queensland (Neldner 1984) equivalent associations. After recoding the VSQ reports and their accompanying maps we delineated more than 160 vegetation associations within the study area. To form the primary sampling unit (habitat unit) for our surveys we combined similar vegetation associations on the basis of their floristic and edaphic composition. This resulted in the development of 10 relatively homogenous habitat units that were distributed throughout the study area (Table 1). Each habitat unit was distributed throughout the study area, some in vast tracts (e.g. plains communities) and others in relatively narrow bands (e.g. riverine communities). While climatic factors determine the plant species that can grow in the study area, edaphic and topographic factors determine the local composition and distribution of plant communities (Neldner 1984). So, in different locations across the study area, a single habitat unit often comprised different, although floristically and edaphically similar, associations.

We then designed a multi-scaled stratified survey design based on median annual rainfall, which divided the study area into 3 rainfall zones (RFZs) (Fig. 1), landform class, and habitat unit. The sampling intensity of each habitat unit was determined using a weighted sampling matrix based primarily on RFZ, with the number of transects decreasing in a westerly gradient according to the decreasing median annual rainfall, and secondly on their relative level of koala utilisation. The number of survey sites allocated to each habitat unit decreased with decreasing level of utilisation (*sensu* Caughley 1977), as determined by the preliminary surveys. We sampled 149 sites across the study area, with multiple sites sampled at most properties (Fig. 1). At each survey site we sampled a 1 km × 10 m belt transect (1 ha) (Sullivan *et al.* 2002).

Cuticular analysis

Tun (1994) showed that there were sufficient differences in the microscopic properties of the cuticles of koala food trees recovered from faecal pellets (particularly with respect to mean cell size and size of the stomatal complex) to allow their correct identification. Several subsequent studies (Witt and Pahl 1995; Hasegawa 1995; Ellis *et al.* 1999) have supported these findings.

We collected and retained faecal pellets for cuticular analysis from 22 sites between August and December 1997 (Fig. 1). Pellets were collected in this period by WMN. Pellets were recovered from sites widely distributed throughout RFZs I and II. These sites included 11 riverine, 8 residual and 8 plains sites. Pellets were recovered in only one floodplain site during this period; these data were therefore pooled with the riverine sites. To obtain an accurate description of the proportion of species eaten by free-ranging koalas it is necessary to collect pellets produced over several days (Ellis *et al.* 1999). We collected pellets that ranged in age from 1 day to over 12 months from the full extent of each transect. The criteria used to estimate pellet age are explained in Sullivan *et al.* (2002). Collecting pellets of such varied age maximised the probability of sampling pellets from different koalas.

We prepared reference slides of the most commonly recorded tree and large shrub species encountered across the study area. These represented 12 *Eucalyptus* species, 12 non-*Eucalyptus* species and 8 non-*Eucalyptus* genera (Table 2). The method used to prepare all slides followed Ellis *et al.* (1999) and Witt and Pahl (1995). To aid in species identification we then photographed these slides at 40× magnification, and developed a simple key based on the size and shape of stomata and guard cells.

We then randomly selected ten pellets from each sample and crushed them with a mortar and pestle (Witt and Pahl 1995). Three slides were prepared from each sample. Each slide from each sample site was analysed using a systematic traverse to avoid double counting (Ellis *et al.* 1999). One hundred fragments from each slide were identified at 40× magnification and cross-referenced with the reference slides, photographs and identification key. The frequency of each species/genus was recorded for each sample.

Results

Preliminary studies

The level of utilisation of the four landform classes, as indicated by the presence of pellets, varied considerably

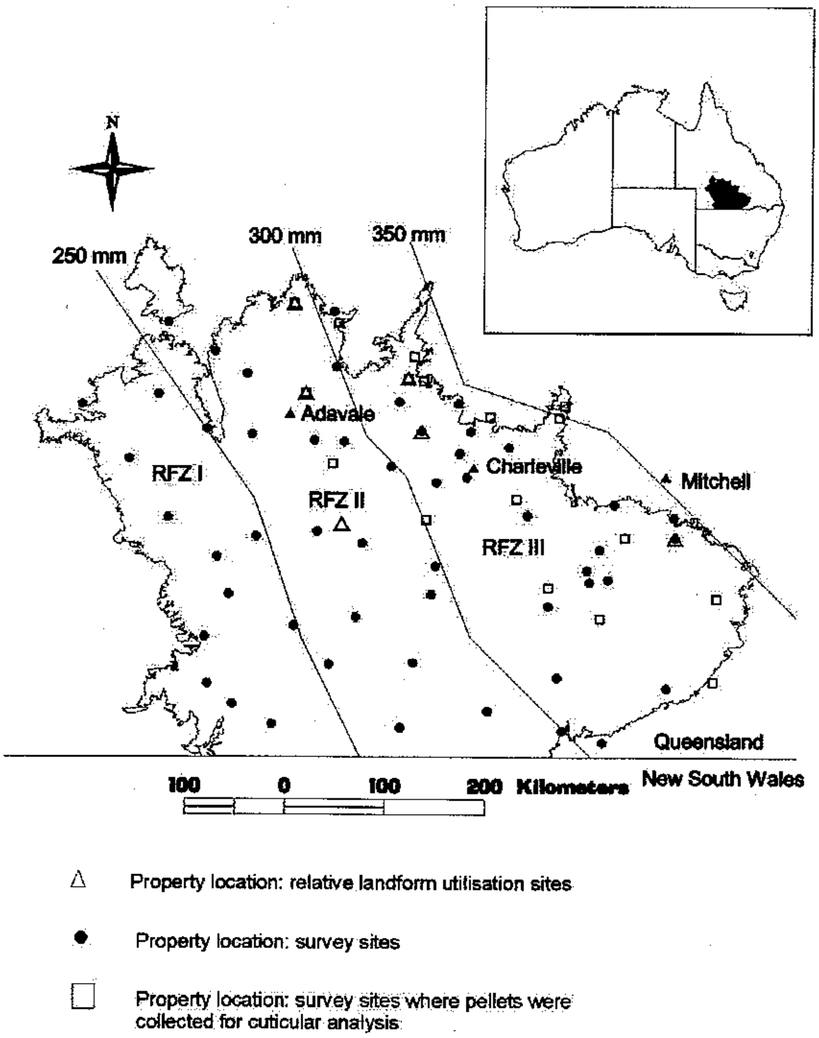

Fig. 1. The mulgalands of south-west Queensland with the location of all properties where sites were located, and the median annual rainfall isohyets. (Inset: study area location.)

Table 2. Plant species included in reference slide collection

Eucalyptus spp.	Other spp.
E. camaldulensis	*Acacia anuera*
E. cambageana	*A. cambagei*
E. coolabah	*A. catenulata*
E. decorticans	*A. harpophylla*
E. exserta	*A. shirleyi*
E. intertexta	*Angophora melanoxylon*
E. melanophloia	*Corymbia polycarpa*
E. microcarpa	*C. tessellaris*
E. orchrophloia	*C. terminalis*
E. orgadophila	*Casuarina cristata*
E. populnea	*Callitris columellaris*
E. thozetiana	*Eremophila mitchellii*
	Flindersia sp.
	Melaleuca sp.

(Table 3). On the basis of these data and median annual rainfall we assigned the sampling intensity of each habitat unit in each RFZ. Once the total number of sampling sites was calculated for each RFZ, the weighted scale assigned to each landform class determined the sampling intensity of each habitat unit within each RFZ (Table 4).

Koala distribution

On the basis of pellets and sightings we recorded koalas in 8 out of 10 habitat units throughout all RFZs. Their distribution was most uniform in RFZ III, where pellets were recorded at 20 out of 21 riverine sites (95.2%) and 46 out of 67 sites overall (67.1%). Such high percentages emphasise the homogenous distribution of koalas in the eastern portion of the study area. RFZ II had pellets in 6 out of 16 riverine sites (40%) and 17 out of 51 sites overall (31.3%). We found pellets at only one site in RFZ I. However, while conducting our survey we obtained several records of koala sightings within the last ten years

Table 3. Proportion of eucalypts in each landform class from which pellets were recovered

Each landform class was assigned a weight according to its relative level of utilisation

Landform classification	No. of trees sampled	No. of trees with pellets	% of trees with pellets	Weighted ranking
Riverine	321	149	42	1
Residual	292	64	23	0.5
Floodplain	199	39	15	0.33
Plains	243	23	10	0.25

in RFZ I (Fig. 2). Of particular interest are the records on the Bulloo River and also the record near Welford National Park on the north-west edge of the study area. Our data suggest that koala distribution is concentrated in the northern and central regions of the study area and decreases in a similar south-westerly gradient to median annual rainfall (Fig. 2).

Within the study area each habitat unit was largely restricted to one broad landform class. Therefore, it was possible to group habitat units into their respective landform class. The level of utilisation within these landform classes varied greatly (Table 5).

More than half of our koala records came from non-riverine communities. While the highest koala densities occur in riverine communities (unpublished data), the data in Table 5 emphasise the range of different habitats utilised; these include *Acacia*-dominated residual and plains communities with only scattered eucalypts.

Cuticular analysis

Twenty plant species were identified from the 22 sites (Table 6); 93% of the cuticular material could be ascribed to just five of these species whereas the remaining 7% of the total fragments counted represented the other 15 species. Correlation analysis (Payne *et al.* 1993) identified a strong positive relationship (r = 0.78) between the number of

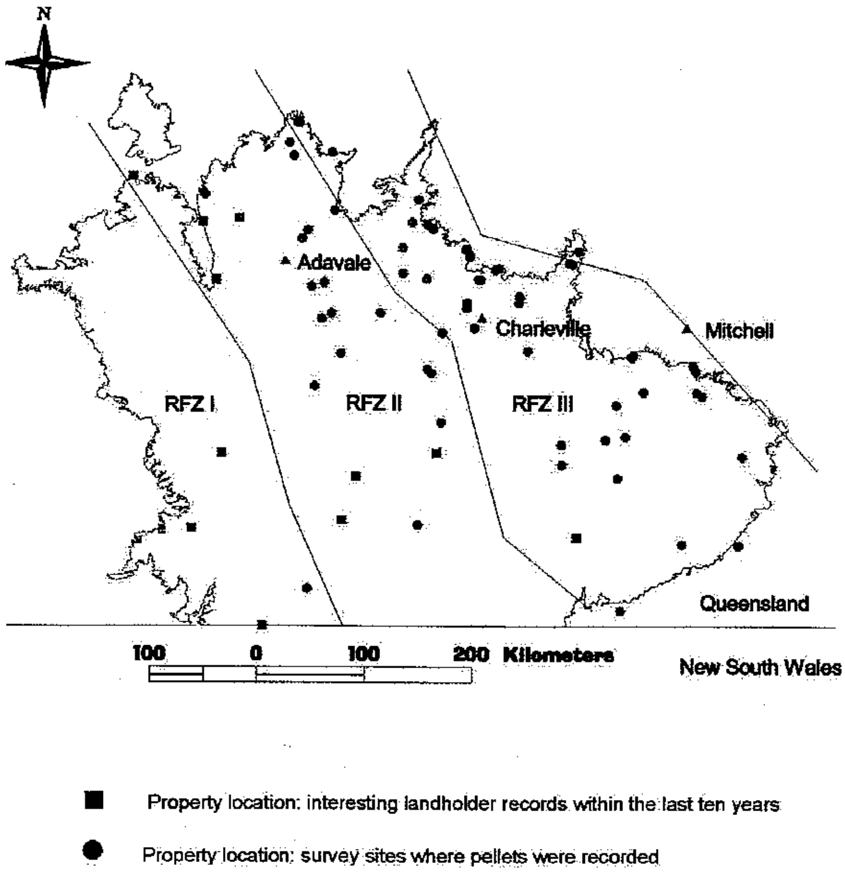

Fig. 2. All koala records (including pellets, sightings and landholder observations).

Table 4. Sampling matrix to assign sampling sites to each habitat unit within each rainfall zone

Numbers within each cell refer to the number of sites sampled. Weights were assigned primarily on RFZ and secondarily on relative landform utilisation. NB: additional transects were allocated to plains communities to allow replication within RFZs

Habitat unit	Rainfall Zone III (Weight = 1.0)										Rainfall Zone II (Weight = 0.66)										Rainfall Zone I (Weight = 0.5)									
	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8	9	10
Riverine landform Rank = 1 (46 transects)	21										15										10									
Residual landform Rank = 0.5 (36 transects)									9	7									6	6										8
Floodplain landform Rank = 0.33 (29 transects)		6	6									5	5									4	3							
Plains landform Rank = 0.25 (38 transects)				3	5	3	4	3							3	4	3	4							2	2	2			

Table 5. Percentage of koala faecal pellet records obtained from the four landform classes

	% of records
Riverine	47.6
Floodplain	9.5
Plain	14.3
Residual	28.6

Table 6. Microscopic analysis of leaf cuticle fragments in faecal samples

Species	% of total fragments counted
Eucalyptus camaldulensis	31.86
E. thozetiana	28.98
E. coolabah	17.98
E. populnea	11.02
E. melanophloia	3.47
E. exserta	1.98
E. orchrophloia	1.24
E. decorticans	1.12
E. sp. 3	0.82
E. intertexta	0.58
E. sp. 1	0.23
E. microcarpa	0.17
Corymbia terminalis	0.15
Acacia harpophylla	0.11
E. sp. 2	0.09
C. tessellaris	0.08
sp. 1	0.06
E. cambageana	0.03
A. sp. 1	0.02
E. orgadophila	0.02

fragments counted and the number of sites in which each of the 20 species were recorded (Fig. 3).

Cursory examination of the data indicated that samples typically contained high counts of fragments from species that dominated one of the three landform classes. A three-dimensional graph shows that the five species most frequently recorded in the faecal samples are clearly divided into three discrete groups (Fig. 4). Group A represents results of pellets collected from residual sites, Group B represents plains sites and Group C riverine and floodplain sites. This suggests that samples that contain high levels of a dominant species from one landform class contain little trace of dominant species from another landform class. For example, Group A contained high levels of *E. thozetiana* (200–300 fragments out of a possible 300) and very low levels (0–50) of *E. camaldulensis, E coolabah, E. populnea* and *E. melanophloia*. This is supported by a breakdown of the total percentage of the five most frequently recorded species counted from each landform class (Fig. 5). For example *E. thozetiana* (Fig. 5, Sp. 2) contributes 80% of the total fragments in faecal pellets from residual habitats but 0% from either plains or riverine habitats.

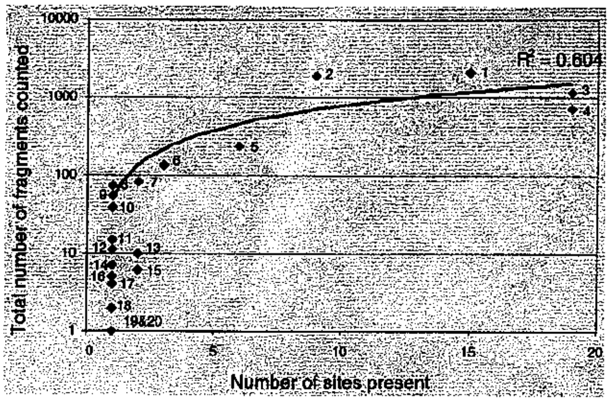

Fig. 3. The relationship between number of fragments counted for each species and number of sites in which those fragments were counted for the 20 species identified from faecal samples. Species legend: 1, *E. camaldulensis*; 2, *E. thozetiana*; 3, *E. coolabah*; 4, *E. populnea*; 5, *E. melanaphloia*; 6, *E. exserta*; 7, *E. orchophloia*; 8, *E. decorticans*; 9, *E.* sp. 3 (likely to be *E. chloroclada*); 10, *E. intertexta*; 11, *E.* sp. 1; 12, *E. microcarpa*; 13, *Corymbia terminalis*; 14, *Acacia harpophylla*; 15, *E.* sp. 2 (possibly *E. melliodora*); 16, *C. tessalaris*; 17, sp. 1; 18, *E. cambageana*; 19, *A.* sp. 1; 20, *E. orgadophyla*.

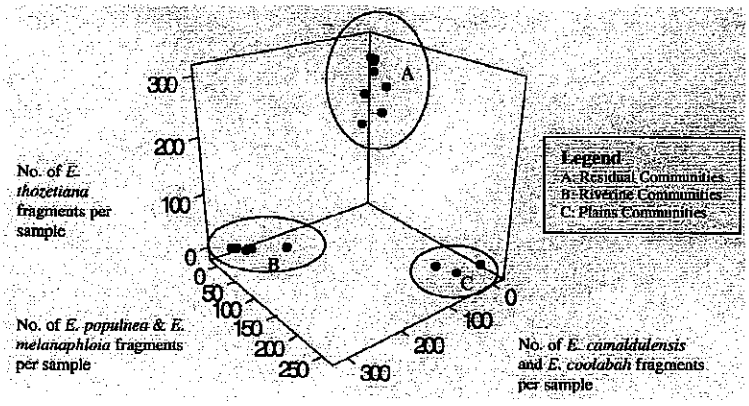

Fig. 4. Occurrence of cuticular fragments from the five most frequently identified eucalypts in samples from each landform class.

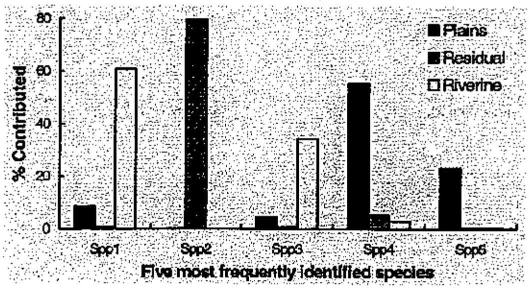

Fig. 5. Percentage contribution of the five most frequently identified species in the diet of koalas in each landform class. Species legend: 1, *E. camaldulensis*; 2, *E. thozetiana*; 3, *E. coolabah*; 4, *E. populnea*; 5, *E. melanaphloia*.

Discussion

Koala distribution

The most recent previous koala survey of the mulgalands was a questionnaire conducted by the Australian National Parks and Wildlife Service in 1986 as part of the National Koala Survey (Phillips 1990). These records are closely associated with population centres and major roads (Patterson 1996), and appear to give a good indication of the extent of koala distribution within the relatively more populated areas of the mulgalands. However, our records extend further west and south into areas of the mulgalands with more scattered koala and human populations. Our data suggest that while the distribution of koalas has contracted toward the east in south-west Queensland, this contraction may not be as significant as that estimated by Martin and Handasyde (1995). However, because of a lack of historical data it is difficult to determine the extent of this contraction.

The decline of the brushtail possum in arid Australia has been attributed to the disturbance of refuge sites, predominantly rocky ranges and outcrops along major river systems. Disturbance of these critical sites occurred at the same time as these areas were subjected to below-average water balance (Kerle *et al.* 1992). It is possible that similar environmental perturbation caused the contraction of koalas away from the westerly edge of their distribution in New South Wales and Queensland. Anecdotal evidence obtained from landholders around Thargomindah suggests that koalas and brushtail possums were last frequently seen in the south-west corner of the mulgalands in the late 1920s and early 1930s. During this period the region experienced a series of extremely dry years, which, combined with a dramatic increase in domestic stock numbers and rabbit plagues, led to frequent severe dust storms (Thargomindah Historical Society). A combination of these factors, combined with the large numbers of koalas killed in Queensland for the fur trade (Phillips 1990), may have led to the local extinction of koala and brushtail possum populations that remained in the area. The paucity of records obtained in RFZ I suggests that koalas are rare in this region and those few records obtained could be associated with transient individuals.

Cuticular analysis

Results of a controlled feeding trial on captive koalas suggest that cuticular analysis provides a relatively accurate description of species composition of faecal pellets, including relatively infrequently occurring fragments (Ellis *et al.* 1999). Ellis *et al.* recommended that a more representative estimate of koala diet is likely to be obtained by analysing a larger sample of pellets, rather than counting a larger proportion of fragments from each pellet sample. We collected a relatively large sample of pellets of varying ages, from geographically distinct locations within the study area, and then randomly sampled 10 pellets for analysis. The strong positive correlation between the number of fragments counted for a given species and the number of samples in which the species was recorded (Fig. 3) suggests that the most widely distributed and abundant eucalypt species in the study area are the most frequently eaten by koalas (e.g. river red gum, napunyah, coolabah, poplar box, silver-leaved ironbark).

The only other study to analyse cuticular fragments of koala faecal pellets in the mulgalands was conducted on a property 70 km north-west of Charleville (Witt and Pahl 1995). Based on the frequency of eucalypt fragments encountered from riverine and residual communities, Witt and Pahl (1995) concluded that these were the most important communities for koalas in the study area.

The five non-*Eucalyptus* species recorded contributed only 0.41% of all cuticular fragments counted. More than half of these belonged to the genus *Corymbia*, which was recently split from *Eucalyptus*. These data suggest that the diet of koalas in the mulgalands consists predominantly of eucalypt leaves. Since the aim of this study was to determine the broadscale distribution and diet of koalas within the mulgalands, this finding supports our decision to sample pellets only from under eucalypts. This does not mean that koalas do not use non-eucalypt trees and shrubs for other purposes, such as shelter or protection from predation (Hindell and Lee 1987).

Results of trials using digesta markers to trace the passage of food indicate that koalas have a mean retention time for particular markers of 99 hours (Cork and Warner 1983). Ellis *et al.* (1999) conducted feeding trials on captive koalas and reported that material was first detectable in faecal pellets 34 hours after feeding, and remained in pellets for up to 154 hours. If digestion and retention rates in our study area are assumed to be similar, a koala may deposit the cuticular remains of a feeding event at any time between 1.5 and 6.5 days later. This defecation event may occur under a different species or genus of tree than that represented in the faecal pellet, which means our method of sampling only under eucalypts should potentially detect the range of species eaten by koalas within the study area.

Because we collected pellets that were up to a year old, and therefore potentially ranged across all four seasons, our results suggest that koalas either do not frequently move between habitats with different dominant eucalypt species, and/or they do not forage on such species. It also suggests that if seasonal shifts in fodder species occur within and/or between habitats, as has been recorded throughout the koala's geographical range (Martin 1985; Hindell and Lee 1987; Hasegawa 1995), they are largely restricted to the five *Eucalyptus* species most frequently identified in this study.

A commonly held belief is that koalas in semi-arid Australia occur largely only in riverine communities. Our data demonstrate that koalas utilise a wide range of habitats across the semi-arid environment, with 52% of sites with koala pellets occurring in non-riverine communities (Table 5). Of the five most frequently recorded species in our cuticular analysis, two species (*E. populnea* and *E. melanophloia*) are infrequently recorded in riverine communities, and it is extremely rare to record *E. thozetiana* in riverine communities.

Our findings clarify the distribution and diet of koalas in south-western Queensland and also emphasise the importance of protecting vegetation communities, such as residuals, that are traditionally considered to have low value in terms of fauna conservation but, in fact, may be important for the long-term conservation of koalas in the region.

Acknowledgments

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