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# **The Conservation of Arboreal Marsupials in the Montane Ash Forests of the Central Highlands of Victoria, South-East Australia: III. The Habitat Requirements of Leadbeater's Possum *Gymnobelideus leadbeateri* and Models of the Diversity and Abundance of Arboreal Marsupials**

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## **ABSTRACT**

*Factors influencing the presence and abundance of leadbeater's possum *Gymnobelideus leadbeateri* McCoy and the diversity and abundance of other species of arboreal marsupials in montane ash forests were determined from logistic and Poisson regression analyses.*

*The presence of *G. leadbeateri* was related to the number of trees with hollows and the basal area of *Acacia* spp. There was a positive correlation between the abundance of the animal and the number of trees with hollows, the quantity of decorticated bark and a negative correlation with the number of shrubs and the slope of the site.*

*The diversity of arboreal marsupials was greatest on sites with a large number of trees with hollows, a high basal area of *Acacia* spp., a large quantity of decorticated bark and south- or east-facing sites. A model containing similar variables was developed for the abundance of arboreal marsupials. This model also produced a significant negative correlation with the number of stumps resulting from timber harvesting operations.*

*Our findings highlight the deficiencies of current measures to conserve*

*arboreal marsupials which are dependent on hollows in trees, when these forests are harvested by clear-felling.*

## INTRODUCTION

There is increasing demand in Australia that the country's hardwood forests be managed on a multiple-use basis, providing not only wood products but also water, habitat for wildlife and a range of recreational values (Victorian Government, 1986; Department of Conservation, Forests and Lands, 1989; Gruen *et al.*, 1989).

These varied demands require that different forms of forest management and use should be concentrated in those areas most suited to each purpose. Areas set aside for wildlife conservation should encompass those lands where the objectives of fauna management are most likely to be effective (Recher *et al.*, 1987). However, the identification of forests of high conservation value for wildlife is dependent on an understanding of the factors which govern the distribution, diversity and abundance of plants and animals (Braithwaite *et al.*, 1988). This type of information can also allow an appraisal of the effects on wildlife of land-use practices such as forest operations.

There have been several studies of the factors which influence the distribution and abundance of arboreal marsupials, particularly in the forests of south-east New South Wales (NSW). These animals are important ones to study because many species are dependent on hollows in trees (Gruen *et al.*, 1989) and may be threatened by timber harvesting operations (McIlroy, 1978; Recher *et al.*, 1980; Australian Biological Research Group, 1984; Harris-Daishowa, 1986; Smith & Lindenmayer, 1988; Davey & Norton, 1990). Braithwaite (1983, 1984, 1987), Braithwaite *et al.* (1983, 1984, 1988), Kavanagh (1987*a, b*) and Norton (1988) examined the relationships between foliage nutrients of eucalypts, soil fertility and the abundance of arboreal marsupials. Davey (1984) related the distribution of arboreal marsupials to structural and floristic attributes of the forest. The influences of flowering patterns and forest phenology on arboreal marsupials were investigated by Kavanagh (1984, 1987*a, b*).

We present models of the diversity and abundance of arboreal marsupials in the montane ash forests of the Central Highlands of Victoria. The habitat requirements of a rare and vulnerable species of arboreal marsupial, leadbeater's possum *Gymnobelideus leadbeateri*, are also examined. These requirements have been a source of controversy. Rawlinson (1977) and Rawlinson and Brown (1977, 1980) believed that *G. leadbeateri* was dependent upon mature montane ash forest. More recently, Smith (1980, 1982*a*), Smith *et al.* (1985) and Smith and Lindenmayer (1988) identified

dense regrowth montane ash forests overtopped with large trees with hollows as being the forest type most likely to support populations of *G. leadbeateri*. Given these differences we have attempted to provide a better definition of those characteristics of the forest environment which govern the presence and abundance of the species.

Other objectives were: (i) to compare our models of the habitat requirements of *G. leadbeateri* with those published in Smith *et al.* (1985) and Smith and Lindenmayer (1988); (ii) to identify the relationships between the structural and floristic characteristics of montane ash forests and the diversity and abundance of arboreal marsupials; and (iii) to consider the impacts of current timber harvesting practices on *G. leadbeateri* and arboreal marsupials in general.

## METHODS

### Study area

The study area has been described in detail in an earlier paper in this series (Lindenmayer *et al.*, 1990).

A total of 152 sites, each of 3 ha within eight regions (Lindenmayer *et al.*, 1990), were surveyed from July 1983 to June 1984 and from February 1987 to February 1989. Sites were selected from a number of regions in an attempt to negate possible regional influences and bias on the abundance of *G. leadbeateri* and other species of arboreal marsupials. This is particularly important as the present distribution of *G. leadbeateri* is known to be patchy and disjunct (Smith & Lindenmayer, 1988; Lindenmayer *et al.*, 1989). Sites varied with respect to forest age, topographic position, tree species composition and a number of other variables (see Lindenmayer *et al.*, 1990).

A site was considered suitable if it supported  $\geq 3$  ha of homogeneous vegetation. Areas of uniform vegetation were selected to minimise the influence of edge effects and patch dynamics. Because the average size of a territory of *G. leadbeateri* is approximately 1.5 ha (Smith, 1980), survey sites of 3 ha increased the chance of detecting at least one colony of the species.

### Census of arboreal marsupials

The stagwatching technique (Smith *et al.*, 1989) was used to census arboreal marsupials at 148 sites (Lindenmayer *et al.*, 1990). A modified form of stagwatching was employed at four sites with no trees with hollows. At these sites volunteers were stationed at 25-m intervals on the survey site and asked to scan the canopy and understorey vegetation for animals from 30 min before dusk until 1 h after dusk.

### Measurement of variables at each site

The range of edaphic, climatic and vegetation attributes measured at each site are listed in the first paper in this series (Lindenmayer *et al.*, 1990).

An additional variable consisting of scores corresponding to a subjective assessment of the suitability of the habitat for *G. leadbeateri* was also recorded at each site. Three scores were assigned. (1) A vegetation score estimated the suitability of the vegetation structure and tree species composition. Sites devoid of *Acacia* spp. were assigned a score of zero whereas those forests with  $\geq 30$  large trees of *Acacia* spp. were awarded the maximum possible score of 10. (2) A nest tree score assessed the number and quality of trees with hollows as potential nest sites for *G. leadbeateri*. A score of zero was awarded to sites with no trees with hollows. Sites supporting  $\geq 15$  trees with hollows that were considered suitable for occupation for *G. leadbeateri* (Smith & Lindenmayer, 1988; Lindenmayer *et al.*, unpublished data) were assigned a maximum score of 10. (3) A total score which reflected the suitability of both foraging substrate and nesting habitat for *G. leadbeateri*. Scores for this category ranged from zero on sites lacking both trees with hollows and *Acacia* spp. to 10 where there were  $\geq 15$  trees with hollows together with  $\geq 30$  *Acacia* trees on a site.

TABLE 1

Calculation of Model Adequacy Measures for the Logistic Regression Model Developed for the Estimated Probability of Occurrence of *G. leadbeateri* on a Site

|                   |     | Predicted occurrence ( $p \geq 0.3$ ) |    |       |
|-------------------|-----|---------------------------------------|----|-------|
|                   |     | yes                                   | no |       |
| Actual occurrence | yes | a                                     | b  | a + b |
|                   | no  | c                                     | d  | c + d |
|                   |     |                                       |    | N     |

where

a = the number of sites where *G. leadbeateri* was correctly predicted to be present;

b = the number of sites where *G. leadbeateri* was predicted to be absent but was present;

c = number of sites where *G. leadbeateri* was predicted to be present but was absent;

d = number of sites where *G. leadbeateri* was correctly predicted to be absent;

N = the total number of sites.

Error rate is an estimate of the number of incorrect predictions made by the model and was calculated from the relationship  $(c + b)/N$ ;

Sensitivity is a measure of the ability of the model to predict the presence of *G. leadbeateri* at a site. It was calculated using the equation  $a/(a + b)$ ;

Specificity is the ability of the model to correctly predict that *G. leadbeateri* will *not* occur on a given site and was calculated as  $d/(c + d)$

For each category the more closely the habitat was considered to meet the requirements of *G. leadbeateri* the higher the value of the score awarded.

### Statistical analyses

Logistic regression (McCullagh & Nelder, 1983) was used to estimate the probability of occurrence of *G. leadbeateri* on a site. Several measures of model adequacy were calculated—error rate, sensitivity and specificity. Methods used in the calculation of these are presented in Table 1.

Poisson regression analyses explored the relationships between measured environmental variables, vegetation characteristics and the number of *G. leadbeateri* at each site. This form of analysis also tested the relationships between the same measured variables and the diversity and abundance of arboreal marsupials at each site. Species diversity is defined as the number of species of arboreal marsupials detected at any given site. Poisson regression analyses were used because the data consisted of counts of the number of animals on each site, were asymmetrical, discontinuous and were assumed to conform to a Poisson distribution.

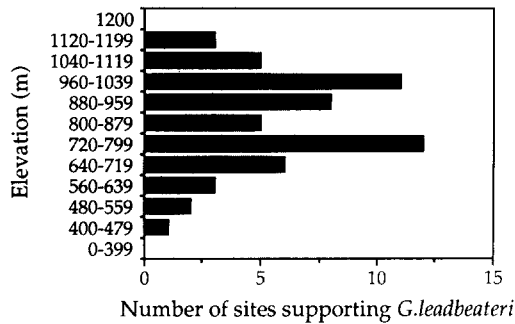
## RESULTS

A total of 594 animals was recorded from 347 occupied trees. The species of arboreal marsupials recorded were, from most to least common, *G. leadbeateri*, *Trichosurus caninus*, *Petauroides volans*, *Petaurus breviceps*, *Pseudocheirus peregrinus*, *Petaurus australis*, *Acrobates pygmaeus*, *Trichosurus vulpecula* and *Cercartetus nanus*. The scansorial marsupial *Antechinus stuartii* was recorded frequently. Data on the number of each species recorded in the study are given in the first paper in this series (Lindenmayer *et al.*, 1990).

It is likely that the stagwatching technique underestimated the abundance of two species which are not obligate hollow dwellers. *P. peregrinus* is known to construct, and nest in, dreys (Thomson & Owen, 1964; McKay, 1983) and *T. caninus* makes dens in fallen logs (How, 1981, 1983; this study). In our study, *T. caninus* was also observed emerging from wombat burrows and was the only species recorded on sites supporting no trees with hollows.

### Altitudinal effects on the occurrence of *G. leadbeateri*

*G. leadbeateri* was absent from sites lower than 400 m and above 1200 m (Fig. 1). Over 64% of the sites where the species was present were between 720 m and 1040 m and 84% between 640 and 1120 m a.s.l. This result was



**Fig. 1.** The elevation of sites where *G. leadbeateri* was detected from stag-watching surveys in the Central Highlands of Victoria.

expected as the distribution of montane ash forest only rarely extends below elevations of 400 m in the Central Highlands of Victoria (data from the Flora and Fauna Survey Group, Department of Conservation Forests and Lands, and Chippendale & Wolfe, 1985). Although ash-type forests in the area occur well above 1200 m, there are relatively few records of *G. leadbeateri* from forests above this altitude (Lindenmayer *et al.*, 1989; Atlas of Victorian Wildlife, Department of Conservation, Forests and Land, unpublished data) and physiological constraints may make habitation of forests above 1200 m less than favourable for *G. leadbeateri*. There may also be changes in the suitability of forest habitat for *G. leadbeateri* associated with changes in elevation.

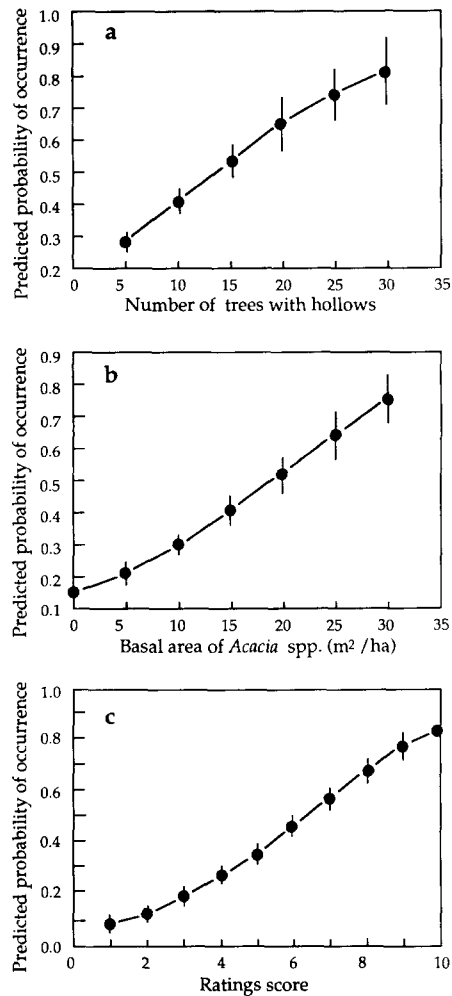
### Logistic regression models of *G. leadbeateri*

The logistic regression model describes the estimated probability of occurrence ( $p$ ) of *G. leadbeateri* on a site. The presence/absence of *G. leadbeateri* was related to the basal area of *Acacia* spp. ( $BAA$ ) and the number of trees with hollows ( $HBT$ ) by the equation

$$\text{Logit}(p) = -2.482 + 0.093 BAA + 0.097 HBT \quad (1)$$

The estimated probability of occurrence of *G. leadbeateri* increased with an increase in both the number of trees with hollows per 3 ha (Fig. 2(a)) and the basal area of *Acacia* spp. (Fig. 2(b)).

The model had an error rate of 26.5% at the level  $p \geq 0.3$ . The model had a sensitivity of 61.5% and a specificity of 76.3%. Terminology is defined in Table 1. Thus *G. leadbeateri* was absent from almost 40% of sites where it was predicted to occur but was present at less than 25% of sites from which it was predicted to be absent. Hence the model was able to predict more accurately the absence of *G. leadbeateri* than its presence.



**Fig. 2.** The relationships between the estimated probability of occurrence of *G. leadbeateri* and significant variables in logistic regression models developed for the species (eqns (2, 4)—see text). (a) the number of trees with hollows; (b) the basal area of *Acacia* spp. ( $m^2$  per ha); (c) the total ratings score. For each prediction, values of the other significant variables are set to the mean value. Vertical lines through each point are standard errors, and these represent the 68% confidence interval.

### Poisson regression models of the abundance of *G. leadbeateri*

General trends from the Poisson regression model of the abundance of *G. leadbeateri* (Table 2) were

- (i) the abundance of *G. leadbeateri* increased with an increase in the number of trees with hollows;



**TABLE 2**

A Model Resulting from Poisson Regression Analyses of Significant Explanatory Variables which Affect the Abundance of *G. leadbeateri* at Sites where the Species was Predicted to be Present using Logistic Regression Analyses (see text)

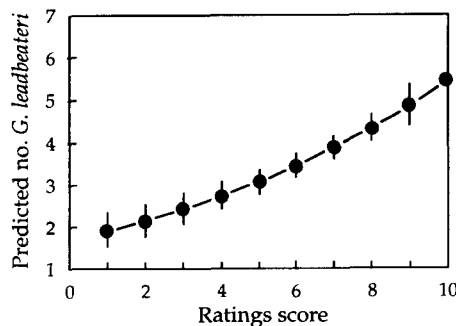
| <i>Variable</i>        | <i>Estimate</i> | <i>SE</i> |
|------------------------|-----------------|-----------|
| Constant               | 1.443           | 0.215     |
| Slope                  | -0.027          | 0.011     |
| Bark index             | 0.037           | 0.014     |
| No. shrubs             | -0.085          | 0.025     |
| No. trees with hollows | 0.018           | 0.009     |

- (ii) forests with a high quantity of decorticated bark (= bark index) supported more *G. leadbeateri* than forests where this resource was scarce;
- (iii) there are fewer *G. leadbeateri* on steeper sites;
- (iv) an increase in the number of shrubs was concurrent with a reduction in the abundance of *G. leadbeateri*.

Examples of predictions from the model are presented in Table 3.

### Ratings scores

Only the combined subjective score of the suitability of both foraging substrate and nest trees for *G. leadbeateri* (= total rating score) was a significant factor in both logistic and Poisson regression analyses. The higher the total ratings score at a site the greater the probability that *G. leadbeateri* would be present (Fig. 2(c)). The species was also likely to be



**Fig. 3.** Variation in the predicted number of *G. leadbeateri* (+ standard errors) with a subjective assessment of the suitability (= ratings score) of the forest habitat for the species.

See text for methodology used in deriving ratings score.

TABLE 3

The Abundance of *G. leadbeateri* per 3-ha Site in Montane Ash Forests in the Central Highlands of Victoria, Determined from a Poisson Regression Model

| No. hollow<br>trees/3 ha | Slope<br>(°) | No.<br>shrubs | Predicted number of<br><i>G. leadbeateri</i> ± SE |                 |
|--------------------------|--------------|---------------|---|-----------------|
|                          |              |               | Bark index = 5                                    | Bark index = 10 |
| 15                       | 5            | 5             | 3.80 ± 0.46                                       | 4.56 ± 0.41     |
| 15                       | 5            | 10            | 2.49 ± 0.51                                       | 2.99 ± 0.50     |
| 15                       | 10           | 5             | 3.32 ± 0.36                                       | 3.90 ± 0.32     |
| 15                       | 10           | 10            | 2.17 ± 0.43                                       | 2.61 ± 0.42     |
| 20                       | 5            | 5             | 4.15 ± 0.57                                       | 4.98 ± 0.54     |
| 20                       | 5            | 10            | 2.72 ± 0.59                                       | 3.26 ± 0.59     |
| 20                       | 10           | 5             | 3.62 ± 0.48                                       | 4.54 ± 0.47     |
| 20                       | 10           | 10            | 2.37 ± 0.50                                       | 2.85 ± 0.51     |

more abundant on sites with a high total ratings score (Fig. 3). The relationship between the total ratings score (*RAT*) and the estimated probability of the occurrence of *G. leadbeateri* was

$$\text{Logit } (p) = -2.848 + 0.442 \text{ } RAT \quad (2)$$

The relationship between the abundance of the species (*N*) and *RAT* was

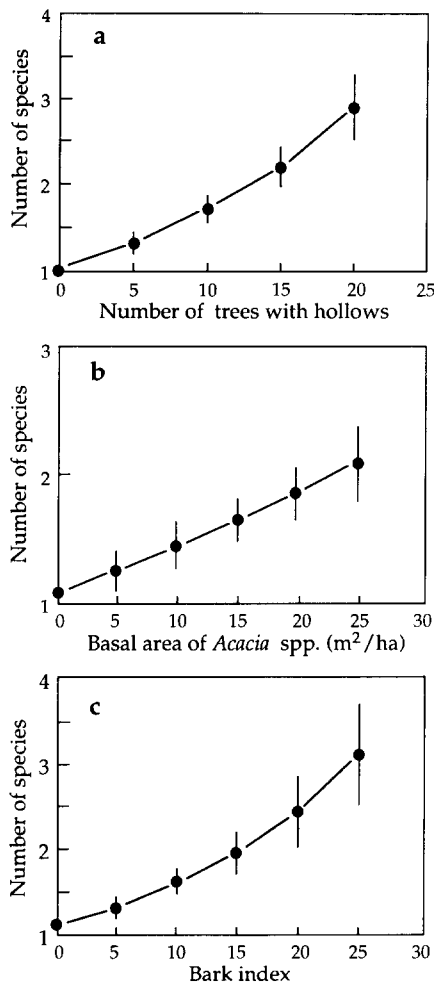
$$\text{Log } (N) = 0.536 + 0.117 \text{ } RAT \quad (3)$$

TABLE 4

A Model of the Diversity of Arboreal Marsupials in Montane Ash Forests in the Central Highlands of Victoria Resulting from Poisson Regression Analyses (see text for an example of the application of the model)

| Variable                         | Estimate | SE    |
|----------------------------------|----------|-------|
| Constant                         | -0.777   | 0.228 |
| No. trees with hollows           | 0.052    | 0.009 |
| Bark index                       | 0.042    | 0.012 |
| Basal area of <i>Acacia</i> spp. | 0.027    | 0.008 |
| Aspect 1 <sup>a</sup>            | 0        | —     |
| Aspect 2                         | 0.114    | 0.018 |
| Aspect 3                         | 0.143    | 0.019 |
| Aspect 4                         | -0.488   | 0.105 |

<sup>a</sup> The categorical variable is divided into Aspect 1, NW-NE; Aspect 2, NW-SE; Aspect 3, SE-SW; Aspect 4, SW-NW.

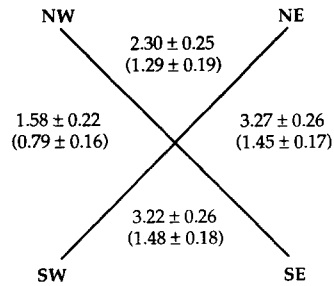


**Fig. 4.** The relationships between the diversity of arboreal marsupials ( $\pm$  standard errors) and significant variables in the Poisson regression model (Table 6). (a) the number of trees with hollows; (b) the basal area of *Acacia* spp. ( $\text{m}^2$  per ha); (c) the bark index. For each prediction, values of the other significant variables are set to the mean value. Vertical lines through each point are standard errors, and these represent the 68% confidence interval.

The successful application of the subjective ratings scores highlights the possibility of providing a rapid assessment of a given area of forest as habitat for *G. leadbeateri*. This, in turn, can be useful in planning for wildlife conservation and forest management.

### Models of the diversity and abundance of arboreal marsupials

Poisson regression analyses indicate that the number of species of arboreal marsupials increased with an increase in the number of trees with hollows,



**Fig. 5.** The effect of aspect on the abundance and diversity of arboreal marsupials ( $\pm$  standard errors) inhabiting the montane ash forests of the Central Highlands of Victoria. The diversity of species is listed in parentheses under the figure for abundance shown in each quadrant. Other variables in the models are fixed to mean values.

the basal area of *Acacia* spp. and the quantity of decorticated bark (= bark index) (Table 4, Figs 4(a, b, c)). In addition, sites on easterly and southerly aspects supported more species of arboreal marsupials than those on northerly or westerly aspects (Fig. 5).

As an example of the use of this model, take the case of a 3-ha patch of forest with 10 trees with hollows, a bark index of 10 and a basal area of *Acacia* spp. of 10 m<sup>2</sup> per ha and the aspect of the site in the quadrant SE–SW. The number of species of arboreal marsupials ( $N$ ) would then be calculated as follows:

$$\begin{aligned} \text{Log}(N) = & -0.777 + (0.052 \times 10) + (0.042 \times 10) \\ & + (0.027 \times 10) + (0.143) = 1.766 \quad (4) \end{aligned}$$

**TABLE 5**  
A Model of the Abundance of Arboreal Marsupials in Montane Ash Forests in the Central Highlands of Victoria Resulting from Poisson Regression Analyses

| Variable                         | Estimate | SE    |
|----------------------------------|----------|-------|
| Constant                         | −0.583   | 0.167 |
| No. trees with hollows           | 0.069    | 0.006 |
| Basal area of <i>Acacia</i> spp. | 0.044    | 0.005 |
| Bark index                       | 0.056    | 0.009 |
| No. cut stumps                   | −0.501   | 0.207 |
| Aspect 1 <sup>a</sup>            | 0        | —     |
| Aspect 2                         | 0.339    | 0.127 |
| Aspect 3                         | 0.351    | 0.128 |
| Aspect 4                         | −0.372   | 0.165 |

<sup>a</sup> The categorical variable is divided into Aspect 1, NW–NE; Aspect 2, NW–SE; Aspect 3, SE–SW; Aspect 4, SW–NW.

TABLE 6

The Predicted Number of Arboreal Marsupials at Sites Determined from a Poisson Regression Model (see Table 5)

| No. hollow<br>trees/3 ha | Basal area<br>Acacia | Stumps | Predicted abundance $\pm$ SE |                  |
|--------------------------|----------------------|--------|------------------------------|------------------|
|                          |                      |        | Bark index = 5               | Bark index = 10  |
| 15                       | 7                    | 0.1    | 3.79 $\pm$ 0.35              | 5.01 $\pm$ 0.42  |
| 15                       | 7                    | 0.2    | 3.61 $\pm$ 0.36              | 4.78 $\pm$ 0.43  |
| 15                       | 15                   | 0.1    | 5.35 $\pm$ 0.45              | 7.08 $\pm$ 0.55  |
| 15                       | 15                   | 0.2    | 5.10 $\pm$ 0.47              | 6.75 $\pm$ 0.55  |
| 20                       | 7                    | 0.1    | 5.38 $\pm$ 0.55              | 7.12 $\pm$ 0.66  |
| 20                       | 7                    | 0.2    | 5.13 $\pm$ 0.56              | 6.79 $\pm$ 0.67  |
| 20                       | 15                   | 0.1    | 7.61 $\pm$ 0.73              | 10.07 $\pm$ 0.88 |
| 20                       | 15                   | 0.2    | 7.25 $\pm$ 0.75              | 9.60 $\pm$ 0.90  |

The model of the abundance of arboreal marsupials in montane ash forests differs from that of species diversity only in that it contains an additional variable—the number of cut stumps (Table 5). Trends in the two models in relation to the aspect of sites were similar (Fig. 5). Table 6 gives examples of the predicted numbers of arboreal marsupials from the model.

## DISCUSSION

### Comparisons with other models of populations of *G. leadbeateri*

Smith *et al.* (1985) and Smith and Lindenmayer (1988) developed models of the habitat requirements of *G. leadbeateri*. These models were based on data from 32 sites censused in 1983/84. Their results are not directly comparable with ours because the larger database used in this study (152 sites) allowed more powerful statistical techniques to be used. Furthermore, Smith *et al.* (1985) and Smith and Lindenmayer (1988) developed separate models of the relationships between the abundance of *G. leadbeateri* and the availability of nest sites and the suitability of foraging substrate, whereas in our study these components of habitat were analysed together.

However, there were similarities between the results of all the studies. Smith and Lindenmayer (1988) found that the number of *G. leadbeateri* per 3 ha ( $N$ ) could be estimated from the equation

$$N = 1.39x - 6.46 \quad (r^2 = 0.80) \quad (p < 0.001) \quad (5)$$

Where  $x$  = the number of trees with hollows per 3 ha.

For estimates of the suitability of forest structure for *G. leadbeateri*, Smith *et al.* (1985) demonstrated that an 'Acacia index' was the best predictor of the abundance of the species. The 'Acacia index' (AI) was calculated from the equation

$$\text{AI} = \text{basal area } Acacia / (\text{basal area } Acacia + [\text{basal area eucalypt} - \text{cull trees}])$$

The relationship between the number of *G. leadbeateri* per ha ( $N$ ) and the AI was

$$N = 0.16 (AI) + 0.57 (r^2 = 0.67) (p < 0.001) \quad (6)$$

The significant variables of basal area of *Acacia* spp. and the number of trees with hollows in the models developed by Smith *et al.* (1985) and Smith and Lindenmayer (1988) (eqns (4) and (5)) closely relate to those in our logistic regression of the presence/absence of *G. leadbeateri* (eqn (2)). The number of trees with hollows corresponds to the availability of nest sites for the species and basal area of *Acacia* spp. estimates the availability of food.

Our results differ from those of Smith *et al.* (1985) and Smith and Lindenmayer (1988) in two important respects: (1) there was no asymptote for the relationship between the number of trees with hollows and the presence or abundance of *G. leadbeateri* (Fig. 2(a), Table 2); (2) there was no asymptote for the relationship between the basal area of *Acacia* spp. and the presence of *G. leadbeateri* (Fig. 2(b)).

There was a better than even chance ( $p \geq 0.5$ ) of *G. leadbeateri* occurring on sites supporting more than 14 trees with hollows per 3 ha (Fig. 2(a)). However, only on those sites with 30 such trees per 3 ha did the estimated probability of occurrence of the species approach  $p > 0.8$  (Fig. 2(a)). Similarly, results of Poisson regression analyses show an increase in the number of *G. leadbeateri* concomitant with an increase in the number of trees with hollows (Table 2). The abundance of the species did not appear to reach an asymptote even on sites with a high density of trees with hollows (Table 3). This result is consistent with the findings of Smith and Lindenmayer (1988), although these authors concluded that the abundance of the species would plateau at approximately 10 trees with hollows per 3 ha. The larger database used in our study and the fact that Smith and Lindenmayer (1988) were able to survey only a few sites supporting a large number of trees with hollows are the most probable reasons accounting for the differences in the results between the two studies.

Smith *et al.* (1985) and Smith and Lindenmayer (1988) demonstrated an increased probability of *G. leadbeateri* being absent from forests supporting less than 4.2 trees with hollows per 3 ha. However, in our study *G. leadbeateri* was detected on several sites supporting fewer than this number of trees. The

species has relatively specialised nest tree requirements, preferring short, fat trees with many holes and surrounded by dense vegetation (Lindenmayer *et al.*, unpublished data). On sites supporting few trees with hollows there is a reduced chance that any of the available trees will have these characteristics which make them suitable for occupation by *G. leadbeateri*. Thus, we believe that the conclusions of Smith *et al.* (1985) and Smith and Lindenmayer (1988) indicate that *G. leadbeateri* is responding to the influence of quality of trees with hollows rather than the total number of such trees *per se*, an important consideration when forest management for the conservation of the species is being planned.

### **The habitat requirements of *G. leadbeateri***

As the presence or abundance of *G. leadbeateri* was not correlated with measures of the density of the understorey, and was negatively related to the number of shrubs, it appears that *G. leadbeateri* is responding to *Acacia* spp. as a direct or indirect source of food rather than to the density of the understorey layer associated with a high stand basal area of *Acacia* spp. *Acacia* spp. produce exudates (Smith, 1980, 1982*b*) and support numerous insects (Woinarski & Cullen, 1984) which are consumed by *G. leadbeateri* (Smith, 1980, 1982*a*, 1984*a,b*).

The negative correlation between the abundance of *G. leadbeateri* and the number of shrubs (Table 2) was probably related to the species' preference for sites with a high basal area of *Acacia* spp. Specht (1983) noted that foliage projective cover of plants in the understorey reached an equilibrium, the value of which was governed by water availability. Given such a balance, sites with a high basal area of *Acacia* spp. are unlikely simultaneously to support a large number of shrubs. A negative, although not significant, correlation was detected between the number of shrubs and the basal area of *Acacia* spp. in this study.

Decorticating bark (= bark index) (Lindenmayer *et al.*, 1990) appears to provide a good estimate of the suitability of the foraging substrate for *G. leadbeateri*, and the animal was likely to be more abundant on sites with a large amount of such bark. Smith (1980, 1982*a*, 1984*a*) observed *G. leadbeateri* foraging amongst decorticating bark. The importance of bark-dwelling insects in the diet of *G. leadbeateri* was demonstrated by Smith (1982*a*), who suggested that the breeding pattern of the species was related to the protein derived from the consumption of arthropods.

There may be several possible explanations for the reduced number of *G. leadbeateri* predicted for sites on steep slopes (Table 2). (1) steeper slopes support fewer trees with hollows (Lindenmayer *et al.*, unpublished data), although a significant interaction was not detected between these two

variables; (2) soils on steep slopes may be relatively shallow and lower in soil moisture content (Miller, 1981) which may influence the structure and quantity of the vegetation (Specht, 1983; Specht & Morgan, 1983). This may affect the supply of food as well as the ability of the species to move through the forest.

Other studies have demonstrated a relationship between the abundance of arboreal marsupials and slope. Kavanagh (1987b) noted that preferred habitat of *Petaurus australis* and *Petauroides volans* included forests on areas of low relief. Braithwaite (1983) observed a greater abundance of arboreal marsupials in forests on flat or undulating topography. However, in many areas in south-east NSW there were considerable changes in forest structure and species composition concurrent with changes in topography (Recher *et al.*, 1980). The pattern of distribution and abundance of distribution of arboreal marsupials in these studies appeared to be related to the occurrence of forest types with high content of foliar nutrients on soils with high nutrients levels (Braithwaite *et al.*, 1983, 1984) rather than to slope *per se*.

*G. leadbeateri* was absent from almost 40% of sites where it was predicted to occur. Factors which may account for this include local extinction after predation by owls, or patches of habitat being isolated and thus not colonised. *G. leadbeateri* occurred at 25% of the sites where it was predicted to be absent, which indicates that *G. leadbeateri* may be responding to components of habitat that were not measured in our study.

### **Models of the diversity and abundance of arboreal marsupials**

The number of trees with hollows was a significant factor in all of the models developed in this study. This was expected as (1) most species of arboreal marsupials inhabiting montane ash forests den or nest in hollows or trees; and (2) the number of such trees is usually a factor limiting populations of arboreal marsupials in montane ash forests (Smith *et al.*, 1985; Smith & Lindenmayer, 1988).

The highest diversity and abundance of arboreal marsupials occurred on sites with easterly or southerly aspects (Fig. 5) and this result is consistent with those of Lunney (1987), who found that almost all species of arboreal marsupials studied in logged and unlogged forests in south-east NSW were most common on south-east facing slopes.

Measures such as basal area of *Acacia* spp. and a bark index may provide a good estimate of the suitability of foraging substrate for some species of arboreal marsupials (Lindenmayer *et al.*, 1990) which feed on the foliage of, or exudates produced by, *Acacia* spp. or harvest insects which shelter under the decorticated bark of montane ash trees.



Smith and Lindenmayer (1988) reported that a maximum abundance of arboreal marsupials could be expected to occur on sites supporting 12 trees with hollows per 3 ha but we found that the abundance of arboreal marsupials did not approach an asymptote (Table 6). These differences may be attributed to the small number of sites supporting numerous trees with hollows that were surveyed by Smith and Lindenmayer (1988). The negative correlation between the abundance of arboreal marsupials and the number of cut stumps indicates that clear-felling operations, which substantially reduce the number of trees with hollows in montane ash forests (Ambrose, 1982; Wailes, 1982; Smith & Lindenmayer, 1988), will also reduce the abundance of arboreal marsupials.

### Relevance of the models to forest management

Clear-felling on an 80–120 year rotation is used to harvest timber and pulpwood in the montane ash forests of the Central Highlands of Victoria (Victorian Government, 1986; Department of Conservation, Forests and Lands, 1989). A substantial reduction in the number of trees with hollows results, because ash-type eucalypts do not form hollows suitable for occupation until they are at least 120 years old (Ambrose, 1982), although Smith *et al.* (1985) and Smith and Lindenmayer (1988) have suggested that trees preferred by *G. leadbeateri* may be more than 190 years old. On the basis of the models developed in this study, consequences of clear-felling in montane ash forests would be (a) a reduction in the probability of the occurrence of *G. leadbeateri* in a given area of forest; (b) a lower abundance of *G. leadbeateri*; and (c) a substantial reduction in the diversity and abundance of arboreal marsupials.

Current timber harvesting prescriptions specify the retention of 15 trees per 10 ha of logged forest to provide habitat for wildlife dependent on hollows (Department of Conservation, Forests and Lands, 1988). However, these policies are inadequate for the conservation of *G. leadbeateri* because the logistic regression model presented in our study (eqn (2)) indicates that the estimated probability of occurrence ( $p$ ) of the species on a site does not approach 0.5 until there are 15 trees with hollows per 3 ha. This is three times more than retained in forests harvested for timber under existing silvicultural practices. Hence, a minimum of five trees with hollows and possibly as many as ten such trees need to be retained per hectare of logged forest in an attempt to guarantee the presence of the species.

However, the retention of so many trees would be incompatible with the use of clear-felling to harvest timber and pulpwood. On the basis of our work this means that the conservation of arboreal marsupials in a given area of forest must be seen as incompatible with current silvicultural practices in

montane ash forests. In attempts to overcome this problem, particularly in the case of the conservation of *G. leadbeateri*, wildlife managers have considered that areas excluded from harvesting would provide suitable habitat to guarantee the long-term survival of the species (Department of Conservation, Forests and Lands, 1987). In montane ash forests designated for timber production, steep ( $> 30^\circ$ ) and rocky areas together with riparian vegetation are typically excluded from harvesting (Department of Conservation, Forests and Lands, 1989) and these areas form the basis of conservation strategies for wildlife dependent on hollows in trees, including *G. leadbeateri* (Department of Conservation, Forests and Lands, 1987). These strategies may be inadequate. Our results indicate that the abundance of *G. leadbeateri* was negatively correlated with forests on steep slopes (Tables 2 and 3) and the species exhibited no significant preference for sites in gullies, so that many areas now excluded from harvesting for the intended conservation of *G. leadbeateri* and possibly other species of arboreal marsupials inhabiting montane ash forests may not be viable. There is an urgent need to assess the adequacy of streamside reserves, wildlife corridors and other retained forests for the conservation of arboreal marsupials.

The estimated probability of occurrence of *G. leadbeateri* increased with an increase in the basal area of *Acacia* spp. (eqn (2), Fig. 4(b)). Yet, under the Timber Industry Strategy (Victorian Government, 1986), sites with a high basal area of *Acacia* spp. may be classified as 'unstocked' by forest managers and could be clear-felled to promote the regeneration of forests with a high stand basal area of ash-type eucalypts. However, the value of such areas as habitat for *G. leadbeateri* should be assessed prior to the commencement of these types of 'timber stand improvement' operations.

### The importance of computer modelling to wildlife conservation

The costs of fauna survey and the small area which can be sampled relative to the total parcel of land in question make it essential to identify quicker, more efficient and cheaper ways to assess the conservation status of an area.

In this study, with the assistance of 500 volunteer observers (=1200 person hours), 152 sites, each of 3 ha (= 456 ha of forest), were surveyed over 300 days and nights. This area represents 0.27% of a total of 171 076 ha of montane ash forest in the Central Highlands of Victoria (M. A. Macfarlane & J. H. Seebeck, pers. comm.). These data highlight the fact that the resources would never be available for comprehensive sample of an entire parcel of land, even one as comparatively small as the Central Highlands of Victoria.

The results of statistical modelling completed in our study provide a method for assessing the status of forest as habitat for arboreal marsupials,

particularly the rare and vulnerable *G. leadbeateri*, in the montane ash forest of the Central Highlands of Victoria. The value of the results is given further strength as they complement, and build on, the results of previously completed surveys (Smith *et al.*, 1985; Smith & Lindenmayer, 1988).

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