

Improved protection for the Greater Glider

Outcomes from applying the Strategic
Management Prospects approach to
comparing benefits

Biodiversity Division – June 2018

What we know about Greater Glider

Biology

- Herbivore (eucalypt leaves); solitary; small home range; multiple dens; **low reproductive output; poor recoloniser**

Habitat

- **Mature forests, including mixed species** & ash-type forests
- higher densities in wet, high productivity forests

Key habitat resources

- **large hollows in large, old trees** - density of hollows critical
(note that GG occurs outside of Old Growth which has a restrictive definition)
- **foliage with suitable nutrient & moisture levels**

Conservation Status

- recently listed as **threatened under FFG & EPBC Acts**
- **declines documented but geographic extent & causation not yet fully understood**
- **decline not uniform** – e.g. severe decline in Central Highlands & East Gippsland, no evidence of decline in Strathbogie Ranges

Key threats

- **harvesting, bushfire, climate change (heat stress, foliage changes)**, planned burning, predation (especially if forced to descend to the ground)

New information from surveys

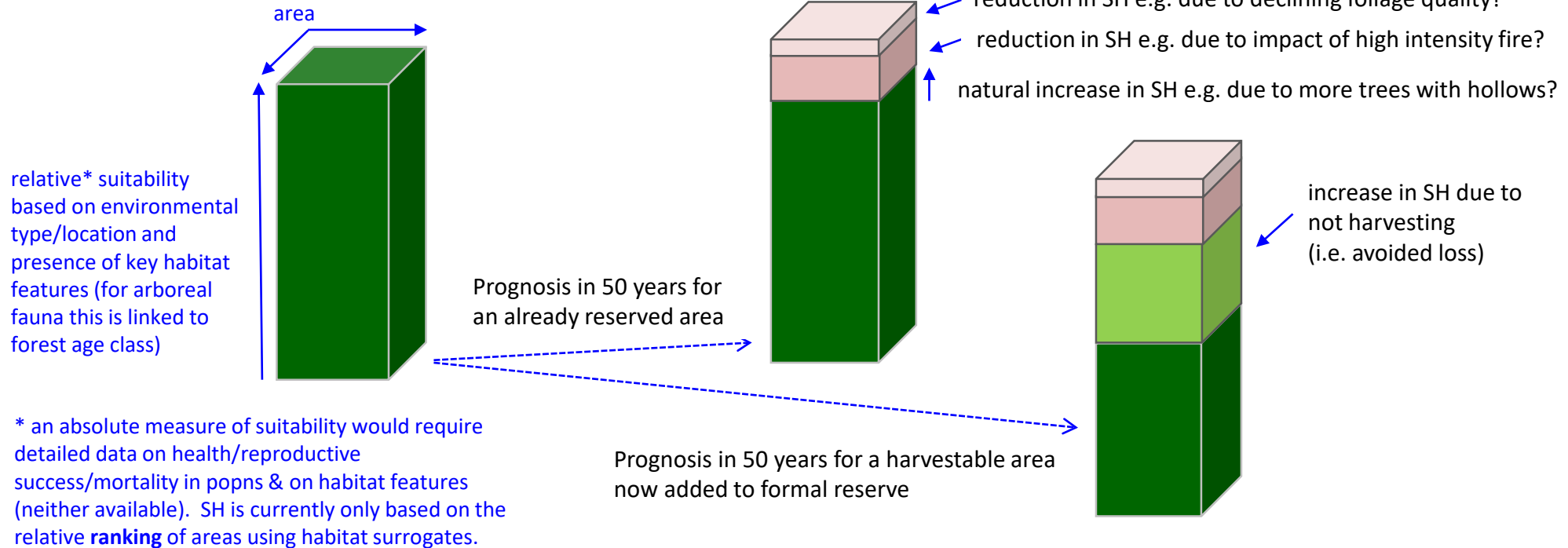
- **Strathbogie Ranges**
 - Surveys in proposed coupes and non-coupe areas
 - High level of occurrence at sites (84%)
 - High densities of Greater Gliders found – sufficient to trigger East Gippsland prescriptions
 - Data collected on hollow-bearing tree sizes and densities:
 - only 1.3% of trees > 1.5 m diameter
 - No trees > 2.5 m diameter (new protection measure for large old trees)
- **Broader region**
 - Lower occurrence at sites (45%) and much lower population densities

	Strathbogie Ranges coupes	Strathbogie Ranges non-coupe	Larger study area
No. sites sampled	9	16	56
% sites with GG	100%	75%	45%
Mean no. per 500 m	6.3	4.1	0.8
Range per 500 m	1 – 14	0 – 10	0 – 5
Estimated population size	500	69,000	TBC

Understanding the metric

- **Suitable Habitat** is a 3-dimensional species-specific measure of the amount of habitat that is suitable to be occupied by that species

Suitable Habitat = relative suitability X area

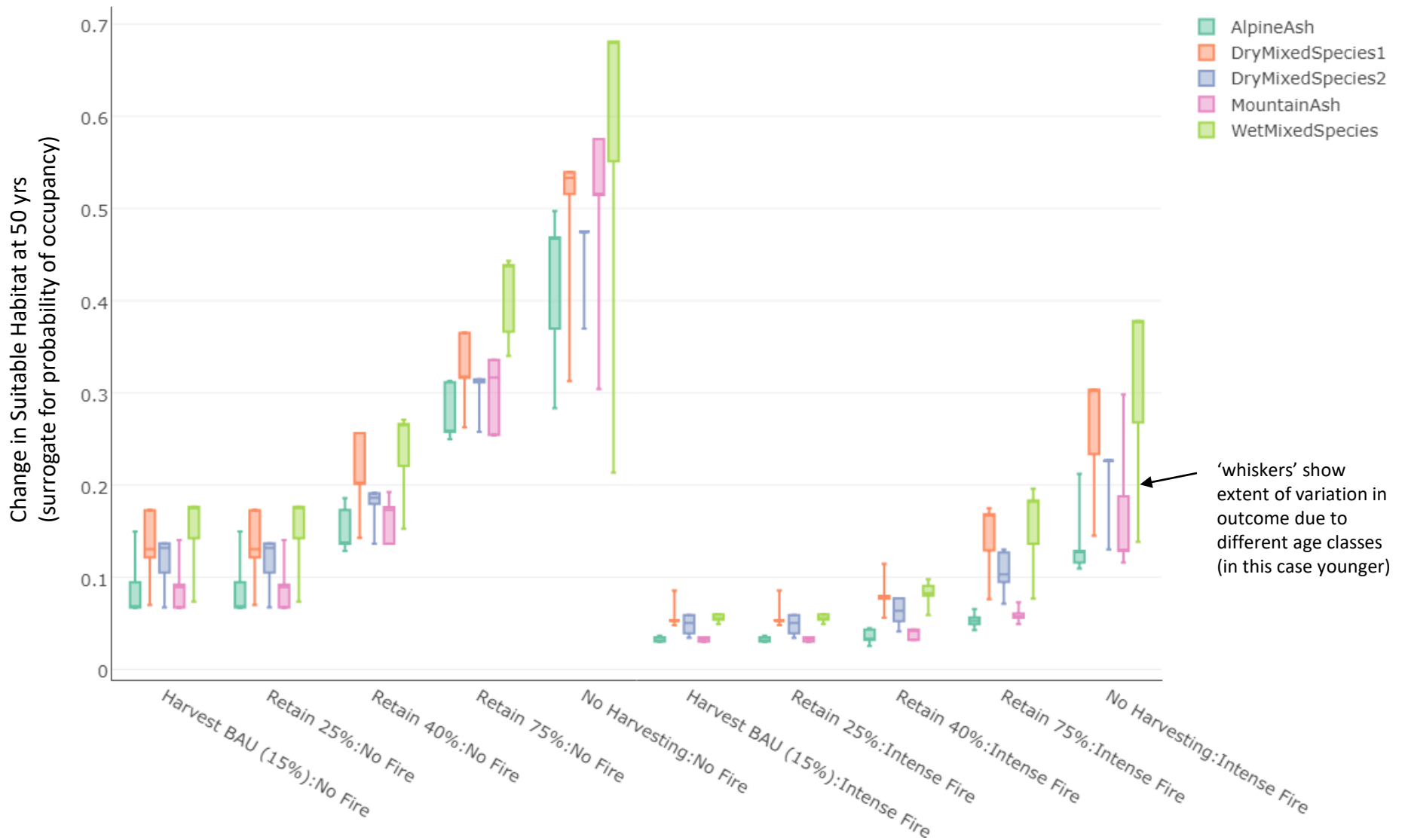


Change in Suitable Habitat is the **incremental** change and typically less than the existing Suitable Habitat base e.g. improved management of 1000 GG Suitable Habitat Ha might yield 100 GG CSH in future.

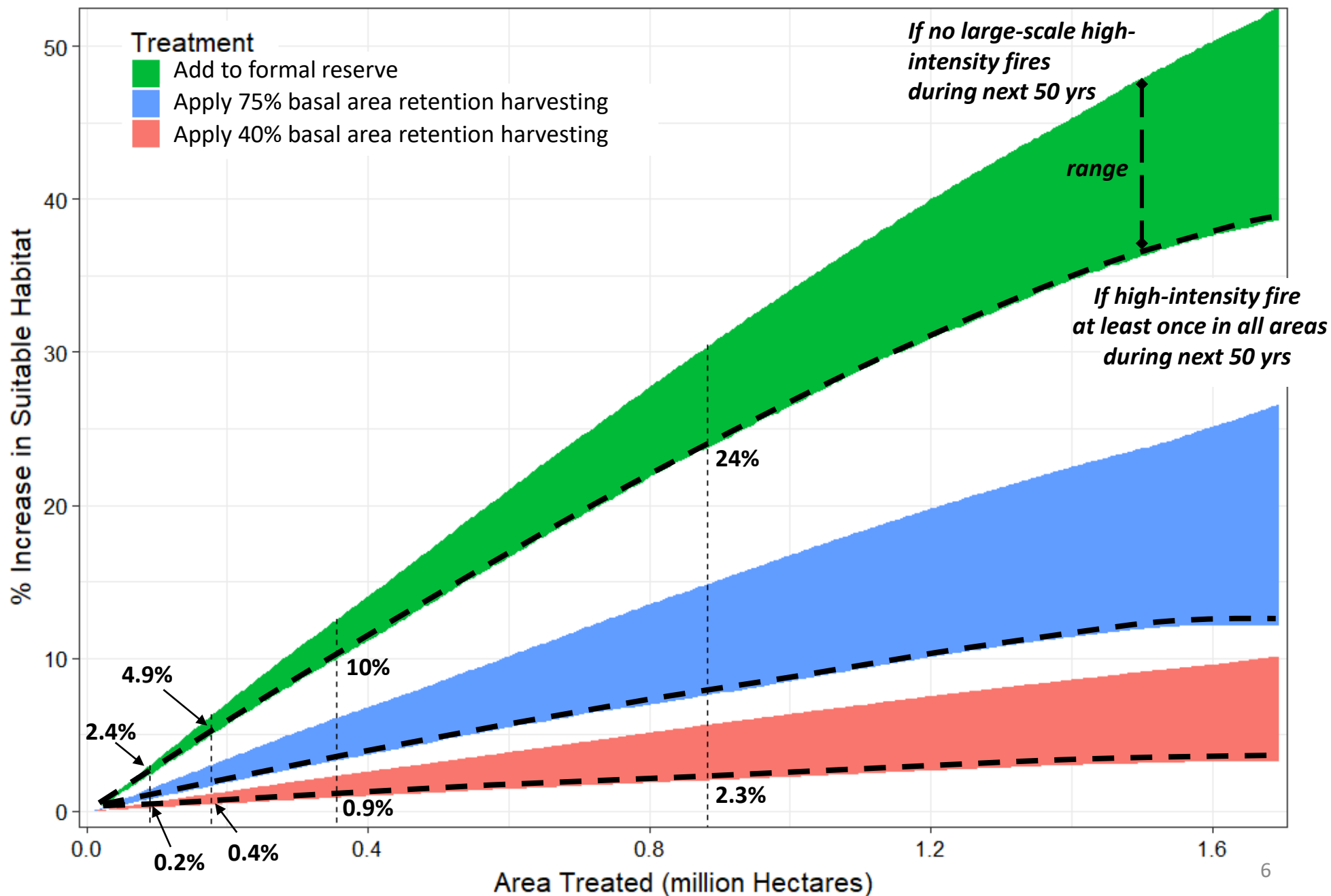
The actual net amount of CSH for a species will vary depending on the initial suitability of the habitat, the management change, and the area over which this applies.

Multiple species that benefit from the management at a location will produce an additive CSH result.

Example of results from expert elicitation of predicted outcomes



Expected Benefits of Actions for Greater Glider



Effects of variable-intensity logging and the influence of habitat variables on the distribution of the Greater Glider *Petauroides volans* in montane forest, southeastern New South Wales

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Populations of arboreal marsupials were assessed in forests before and after logging at different levels of logging intensity to determine the sensitivity of these species to habitat disturbance. The logging treatments imposed were unlogged controls and two intensities of integrated logging for sawlogs and woodchips. The mean basal area of trees retained in logged blocks ranged from 83% to 35% of pre-logging levels. The objective of the study was to develop better methods for managing arboreal marsupials within the wood production forests of southeastern New South Wales.

Seven species of arboreal marsupials were recorded during the study, but the Greater Glider *Petauroides volans* was the only species recorded in sufficient numbers for analysis (86% of all records). No significant differences were observed between the treatments in counts of the Greater Glider before and after logging. However, given the observed trend and an *a priori* expectation of a decline in numbers of this species following intensive logging, a one-tailed statistical test was applied which resulted in a significant difference at $P = 0.08$ for the contrast between the unlogged controls and the most intensively logged treatment. The existence of a threshold in logging intensity within the range of 21% to 39% retention of tree basal area, below which numbers of the Greater Glider suffer a marked decline, was inferred on the basis of comparisons with the results of other studies.

Factors other than logging were important in determining the distribution of the Greater Glider. Elevation, in particular, was a significant environmental variable, with Greater Gliders more likely to occur in forests above 845 m a.s.l. The presence and absence of particular tree species also influenced the distribution of the Greater Glider. Forests containing Manna Gum *E. viminalis* and Mountain Gum *E. dalrympleana* were highly preferred compared to forests with a high proportion of *E. obliqua*. The presence of *E. cypellocarpa* appeared to improve the quality of habitat for the Greater Glider in forests dominated by *E. obliqua*.

This study has shown that Greater Glider populations can be maintained at or near pre-logging levels when at least 40% of the original tree basal area is retained throughout logged areas and when the usual practice of retaining unlogged forest in riparian strips is applied.

Key words: Arboreal marsupial, Mammal, Logging, Sensitivity, Disturbance.

INTRODUCTION

MARSUPIAL gliders are predicted to be sensitive to heavy logging because of their association with the forest canopy for food resources and the dependence of all species on tree hollows for breeding and shelter (Tyndale-Biscoe and Calaby 1975; McIllroy 1978; Recher *et al.* 1980). The Greater Glider *Petauroides volans* has been identified consistently in correlational studies to be one of the more sensitive arboreal marsupials to intensive logging systems (Lunney 1987; Macfarlane 1988; Smith and Lindenmayer 1988; Lindenmayer *et al.* 1990; Milledge *et al.* 1991; Kavanagh and Bamkin 1995; Kavanagh *et al.* 1995; Goldingay and Daly 1997). This species displayed a poor ability to re-establish itself in nearby suitable habitat following displacement caused by clearfelling (Tyndale-Biscoe and Smith 1969). The Greater Glider is a folivore that depends on a tall eucalypt canopy for the maintenance of its food supply (Davey 1984; Kavanagh 1987; Kavanagh and Lambert 1990). Its faithful attachment to a small home-range (Tyndale-Biscoe and Smith 1969; Henry 1984; Kehl and Boorsboom 1984), and its

dependence on large tree hollows, make it vulnerable to intensive logging.

Management of the Greater Glider in wood production forests depends on knowledge of the distribution of its preferred habitats, and on determining the thresholds in sensitivity of this species to logging. Greater Gliders are known to have a patchy distribution in the forests of New South Wales (Braithwaite 1983; Lunney 1987; Kavanagh and Bamkin 1995; Kavanagh *et al.* 1995; Kavanagh and Stanton 1998). They are associated strongly with high elevation forests on flat-undulating topography, particularly those comprised of a mosaic of tree species associations and which include tree species having a high ratio of nitrogen to fibre in their foliage (Braithwaite 1983; Braithwaite *et al.* 1983, 1984; Kavanagh 1984; Kavanagh and Lambert 1990).

Thresholds in the sensitivity of the Greater Glider to logging disturbance are poorly known. A regional survey in northeastern New South Wales recorded the Greater Glider more frequently in unlogged and selectively-logged forests than in heavily-logged forests (Kavanagh

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PACIFIC CONSERVATION BIOLOGY Vol. 6: 18-30. Surrey Beatty & Sons, Sydney, 2000.

et al. 1995). A study at Waratah Creek near Bombala in southeastern New South Wales (Kavanagh and Webb 1998) used a before-after-control-impact (BACI) experimental design to determine the responses to variable intensity logging by a wide variety of vertebrate forest fauna, including the Greater Glider. The results of this study suggested that populations of the Greater Glider present after logging were related inversely to logging intensity. The greatest reduction in numbers of the Greater Glider occurred in the most heavily-logged area (approximately 21% retention of tree basal area). However, the conclusions of Kavanagh and Webb (1998) were limited by the independent effects of owl predation on the Greater Glider (Kavanagh 1988), and the inclusion of only one replicate for each treatment.

The objective of this study was to repeat the BACI experimental design of Kavanagh and Webb (1998), using a similar range of logging treatments, in a similar range of forest types, but employing additional treatment replicates to determine the sensitivity of the Greater Glider to logging.

METHODS

Study areas

Twelve forest blocks spread across 60 km of tall, montane forest near the escarpment edge of the southern tablelands east of Bombala were surveyed for arboreal marsupials (Fig. 1). The study areas were located in parts of the Glenbog, Tantawangalo, Nalbaugh and Yambulla State Forests, some of which are now included in the South-East Forests National Park. The study areas (blocks) were selected from forest compartments scheduled for logging in 1988. Criteria for selection included the presence of tall, montane forest types and occurrence within the elevation range 650–1 100 m above mean sea level. These parameters were chosen to provide a similar range of environments and habitat conditions for arboreal marsupials to those encountered during an earlier study at Waratah Creek, 20 km south-east of Bombala (Kavanagh 1984; Kavanagh and Webb 1998). The predominant geology in the study areas was Devonian granodiorite (nine blocks), but two blocks (Plumeckes Road 2 and Letts Mountain 1) occurred on Devonian adamellite and one block (Letts Mountain 3) was on Ordovician undifferentiated shale. Mean annual rainfall for the study areas ranged between 830–1 121 mm, as predicted from climate surface layers held as GIS coverages by State Forests of New South Wales. Each study area was about 50–100 ha in size and represented a single logging coupe. The topography was generally flat or undulating for the eight blocks located in the north of

the region, but was moderately steep for the four remaining blocks to the south. Logging treatments were assigned randomly within these 12 blocks. Before 1988, each block was essentially unlogged (i.e., unaffected by integrated logging) but most displayed evidence of light selective logging that occurred some 20–50 years earlier. The study areas were the same as those used by Shields (1990) to study the effects of logging on populations of diurnal birds.

The vegetation of the study areas was dominated by seven species of *Eucalyptus*. Manna Gum *E. viminalis* and Mountain Gum *E. dalrympleana* occurred in the gullies and lower slopes of the higher rainfall areas, Narrow-leaved Peppermint *E. radiata* occurred on shallower soils, Brown Barrel *E. fastigata* occurred on deeper soils on sheltered slopes, Messmate *E. obliqua* and Mountain Grey Gum *E. cypellocarpa* occur on mid-slopes and upper slopes, and Silvertop Ash *E. sieberi* occurred on the upper slopes and exposed ridgetops. Less common tree species included Swamp Gum *E. ovata*, River Peppermint *E. elata*, Gully Peppermint *E. smithii*, White Ash *E. fraxinoides*, Snow Gum *E. pauciflora*, Maidens Gum *E. maidenii* and Yellow Stringybark *E. muelleriana*. Silver Wattle *Acacia dealbata* was the most common understorey species. These tree species comprised the following main forest types (*sensu* Anon. 1989) in the study areas: forest types 112, 131, 151, 152, 154, 155 and 159.

Experimental design

Three treatments, each with four replicates, were allocated to the 12 forest blocks. The treatments consisted of controls in which no logging took place, integrated logging with a nominal level of 50% retention of the original tree canopy, and normal integrated logging which, at the time, was expected to result in the retention of about 10 to 15% of the original tree canopy. However, logging intensity varies depending upon the nature of the terrain (e.g., rocky, steep or swampy areas are not logged), the proportion of commercially acceptable tree species in the stand, and the tree retention (harvesting) prescriptions applied. The standard practice of retaining unlogged forest in narrow (approx. 40 m wide) strips along minor drainage lines was applied in this study.

Line transects one kilometre in length were established in each of the 12 blocks before logging took place. These transects were located in loggable areas, but some unlogged patches remained in each coupe. Each transect was marked at 100 m intervals by points which formed the basis for sampling the vegetation in each block, while the entire length of the transect was used for sampling the fauna.

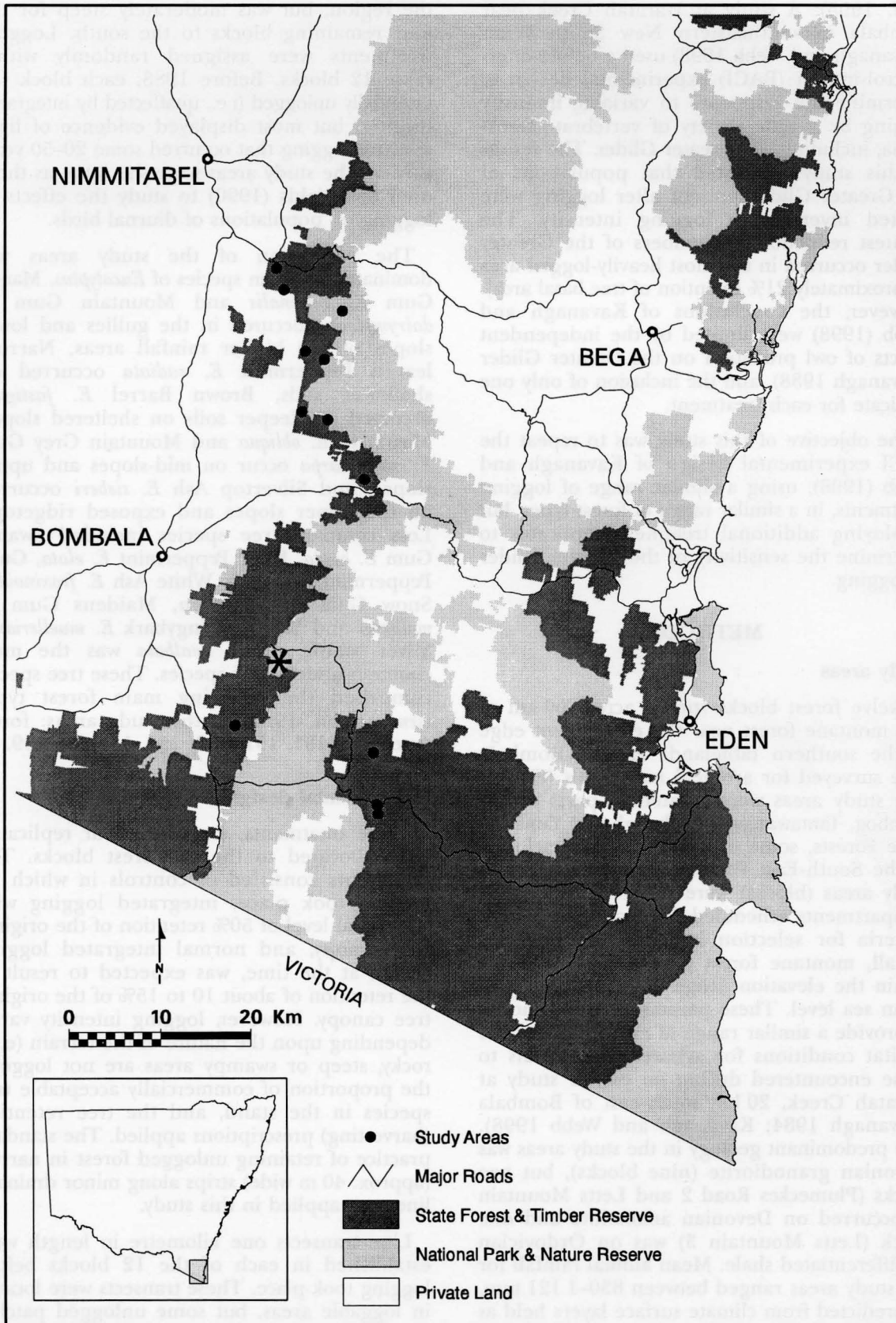


Fig. 1. Location of the study areas in southeastern New South Wales. The Waratah Creek study area of Kavanagh and Webb (1998) is indicated by an asterisk. The map shows the extent of conservation reserves following the 1998 Eden Regional Forest Agreement.

Pre-treatment counts of arboreal marsupials in each block were made during February 1988, logging was imposed during the remainder of 1988, and post-logging counts were made in February 1989 and again in February 1990.

Vegetation

The forest stand on each block was characterized by measurements of tree basal area using variable-radius plots centred on each 100 m point along the 1 km transects. The diameter at breast height (DBH; 1.3 m above the ground) and the distances to the 10 nearest trees (>10 cm DBH) were measured for trees up to a maximum of 50 m from the plot centre. Plot size was determined by calculating plot radius as the median distance between the two most distant trees (i.e., the ninth and tenth furthest trees). Basal area for each plot was standardized by expressing the results of calculations in m²/ha. Mean basal area for each block was calculated by averaging the results from the 10 points along each transect. The estimates of basal area for two similar tree species, *E. viminalis* and *E. dalrympleana*, were grouped together in the analysis.

Fauna

Arboreal mammals were counted from the transect line running through each block before and after logging. Animals were detected using spotlights and binoculars, or from calls and non-vocal cues. Each one kilometre transect took approximately 1.5 hours to spotlight. The perpendicular distance from the transect lines to all animals detected (seen or heard) was measured or estimated, and particular reference was given to whether the record was greater than or less than 40 m away. This distance (40 m) was selected as the effective spotlighting distance for animals in all blocks, based on the detectability profiles derived by Kavanagh (1984, 1987) for similar forest tree communities in the region. Only records within 40 m of the transect lines were used to compare blocks within years and between logging treatments, thus reducing any major differences in animal detectability between treatments. Spotlighting counts were made twice on all transect lines in each sample period. Sampling was carried out in most weather, except during the extremes of continuous rain and strong wind. Spotlight counts were made at a slow walk (about 10 m/minute) with frequent circling to ensure that trees near the transect line were surveyed on both sides. Sampling took place during February in three consecutive years (1988–1990).

Data analysis

Relationships between the occurrences of the Greater Glider and a range of environmental

variables measured along each transect line were examined using a decision tree procedure (CART: Classification and Regression Trees, Breiman *et al.* 1984) available in the S-PLUS statistical package (version 3.3, Clarke and Pregibon 1992; Anon. 1995a). A parsimonious model was selected using the "prune.tree" function. The data used in this analysis were not spatially independent because they were grouped within the 100 m segments of each transect line, however, the procedure was used to explore patterns in the data. The environmental variables attributed to each sampling point included, the basal area of each tree species, elevation, geology (as one of three classes), and mean annual rainfall (as one of three classes). Only the 1988 (pre-logging) data were used in this analysis.

A Kruskal-Wallis non-parametric one-way analysis of variance (Zar 1984; Anon. 1996a) was used initially to test for differences in Greater Glider counts within years, both before and after logging. To remove problems of spatial dependency, the data used in this analysis were the mean numbers of Gliders (within the 40 m bandwidth) recorded per transect. A two-factor between-groups analysis of variance with a contrast analysis was then used to obtain greater power and to address more directly the question "did the numbers of Gliders at the treated sites change after logging relative to the controls?" In this analysis, the dependent variable n was re-constructed such that $n = n / n(1988)$ where the count for blocks in each year was divided by the count for each block in 1988 (i.e., before logging occurred). The data for time period 1 (1988) were then deleted from the analysis. The resultant design was specified as logging treatment, grouped into three levels (unlogged control, reduced-intensity logging, normal integrated logging), and time period, grouped into two levels (1989, 1990). In addition to testing for main effects and the interaction effect, two contrasts were specified (i.e., unlogged control *vs* reduced-intensity logging, unlogged control *vs* normal integrated logging). The BACI design treats repeated measurements at the same blocks as true replicates so the logging treatment * time period error term was used for comparisons of logging treatments in the contrast analyses. These contrasts were assessed at the 5% level of significance using a one-tailed F test since the research hypothesis (based on the findings of correlational studies done elsewhere) is that logging may *reduce* Glider numbers.

A Kruskal-Wallis test was used to determine differences in the tree basal area on the blocks before logging. The relationship between tree species in which gliders were detected and tree species availability was examined by a

contingency Chi-squared test (Anon. 1996a). All animal records were used for this analysis, regardless of perpendicular distance from the transect lines.

RESULTS

Vegetation

Before logging, there were differences between the blocks in tree basal area ($\chi^2 = 30.85$, d.f. = 11, $P < 0.01$). Inspection of the data showed that two blocks (Dragon Swamp Road and Newline Road Quarry) had a greater tree basal area than the others (Fig. 2). When these two blocks were deleted and the data re-analysed, the basal area on the remaining blocks did not differ significantly ($\chi^2 = 8.64$, d.f. = 9, $P = 0.47$).

Tree basal area measurements after logging indicated that the proportions of the original basal area (m^2/ha) retained varied considerably between and within treatments. The mean basal area retention on blocks nominated for reduced-intensity logging was 70.8% (range 52.8–83.2%) and for normal integrated logging was 50.8% (range 35.4–72.0%) (Table 1; Fig. 2). One block (Hercules Road) nominated for a standard logging operation resulted in a higher level of basal area retention than two of the reduced-intensity logged blocks. This was due

to the physical and topographical variation in each block (e.g., the presence of rocky and/or "swampy" areas) which made some areas unavailable to logging.

The reduction in tree basal area across the logged blocks was contributed mainly by five species, *E. obliqua*, *E. fastigata*, *E. cypellocarpa*, *E. radiata* and *E. sieberi*, which represented the dominant trees in the study areas (Fig. 3). The total basal area retention for these five tree species across the eight logged study areas was 41.7%, 58.7%, 48.1%, 38.6% and 52.8%, respectively. Across all tree species, 53.7% of the original tree basal area was retained after logging on the eight logged blocks. The largest amount of basal area removed was at Dragon Swamp Road where, on average, $56.5 m^2/ha$ was logged (Table 1). The two dominant species on this block were *E. obliqua* and *E. fastigata*. The largest proportion of basal area logged was at Letts Mountain 3 where 64.6% of the original tree basal area was removed (Table 1).

Fauna

Species abundance

Seven species of arboreal marsupials were recorded in the 12 study areas. The most abundant of these was the Greater Glider

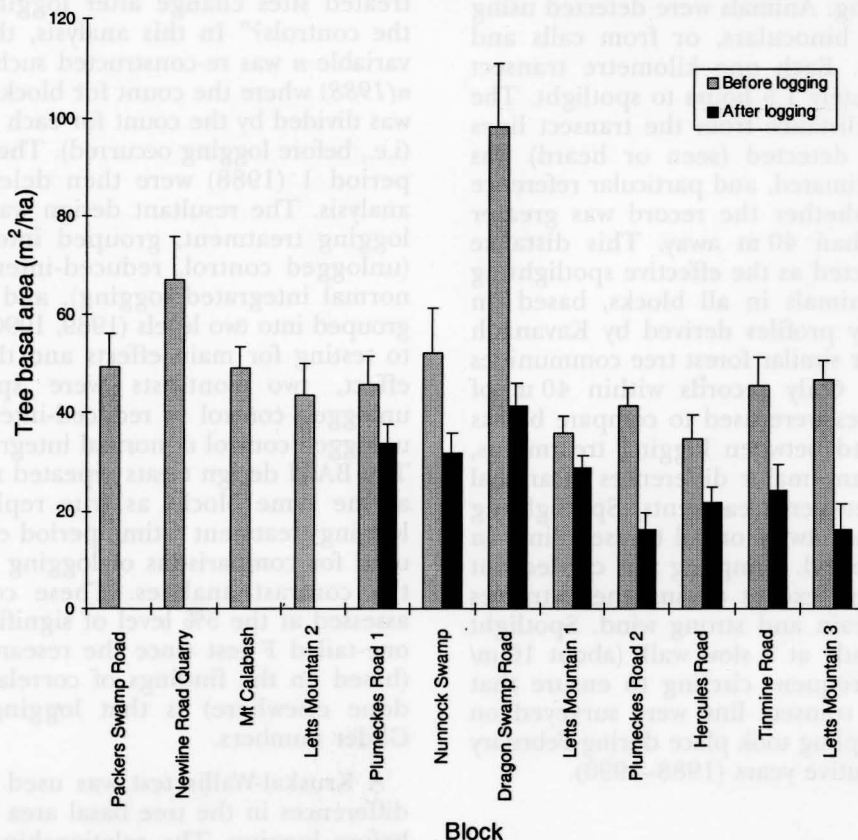


Fig. 2. Mean (\pm s.e.) tree basal area (m^2/ha) occurring on each block before and after logging.

Table 1. Mean tree basal area (m²/ha) on each block before and after logging (standard error in brackets). Also given are the mean proportions of total basal area retained after logging and the elevation of each block above mean sea level.

Treatment	Block	Elevation (m.a.s.l)	Basal area before logging (m ² /ha)	Basal area after logging (m ² /ha)	Basal area retention (%)
Unlogged control	Packers Swamp Road	934	49.10 (6.75)	n.a.	100
	Newline Quarry Road	951	68.88 (8.97)	n.a.	100
	Mt Calabash	807	48.96 (4.30)	n.a.	100
	Letts Mountain 2	686	43.50 (6.24)	n.a.	100
Reduced-intensity logging	Plumeckes Road 1	1 084	45.57 (5.83)	33.66 (3.79)	77.73 (6.90)
	Nunnock Swamp	939	51.78 (9.14)	31.61 (4.14)	69.42 (7.44)
	Dragon Swamp Road	954	97.88 (13.03)	41.36 (4.42)	52.84 (10.50)
	Letts Mountain 1	660	35.81 (3.18)	28.71 (2.39)	83.22 (7.51)
Normal integrated logging	Plumeckes Road 2	972	41.13 (3.81)	16.32 (3.27)	39.09 (6.03)
	Hercules Road	901	34.57 (4.87)	21.75 (3.12)	71.95 (11.65)
	Tinmine Road	918	45.13 (5.90)	24.22 (5.07)	56.78 (9.17)
	Letts Mountain 3	662	46.43 (3.81)	16.30 (5.17)	35.37 (9.67)

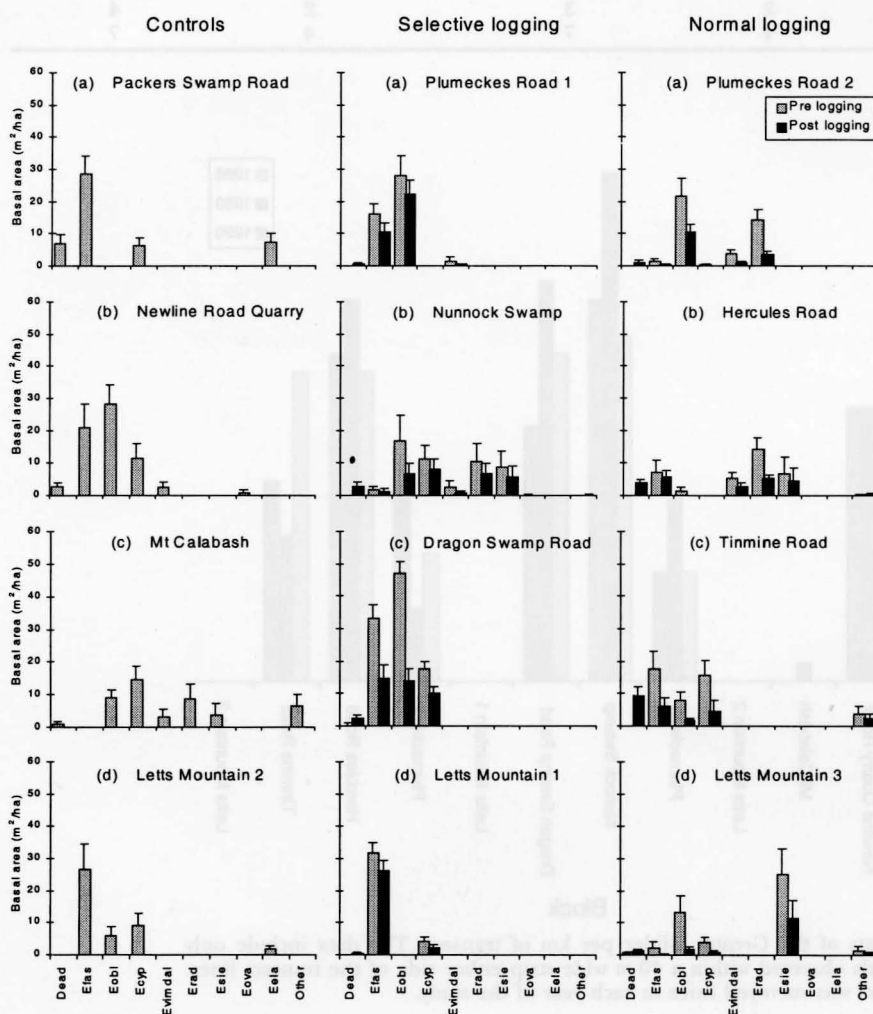


Fig. 3. Mean (\pm s.e.) basal area (m²/ha), by tree species, occurring on each block before and after logging.

Petauroides volans, which comprised 86.1% of all records ($n = 597$; Table 2). Numbers of the remaining species were low in comparison, which is typical of the montane forests in southeastern New South Wales (Braithwaite 1983; Kavanagh 1984; Kavanagh and Bamkin 1995; Goldingay and Daly 1997). However, counts for most species, relative to the Greater Glider, were probably underestimated due to the sampling method and the behavioural characteristics of individual species (Kavanagh 1984, 1987). The data for species other than the Greater Glider were not sufficient for analysis.

Over the three years of the study, total counts of the Greater Glider recorded within 40 m of the transect lines ($n = 349$) were highest in the

blocks subjected to reduced-intensity logging ($n = 144$), followed by the blocks subjected to normal integrated logging ($n = 113$), while the unlogged control blocks had the lowest combined total ($n = 92$). This difference was due in part to four of the 12 study blocks, including two of the unlogged controls and one each of the other two treatments, having none or very low population densities of the Greater Glider (Fig. 4). Accordingly, these four blocks were deleted from the analysis of logging effects presented below. On the remaining eight blocks, before logging, the Greater Glider was recorded at about average population density (6.9 gliders per km within 40 m of the transect lines, or approx. 0.9 gliders per ha) for these forest types (see Kavanagh 1984).

Table 2. Total counts of arboreal marsupials recorded during the study.

Species	Counts within 40 m of the transect lines		All counts	
	No. of blocks	Counts	No. of blocks	Total counts
Greater Glider	9	349	10	514
Yellow-bellied Glider	3	9	4	17
Sugar Glider	7	10	10	31
Feathertail Glider	1	1	1	1
Mountain Brushtail Possum	7	17	7	23
Common Brushtail Possum	2	3	2	4
Common Ringtail Possum	4	7	4	7

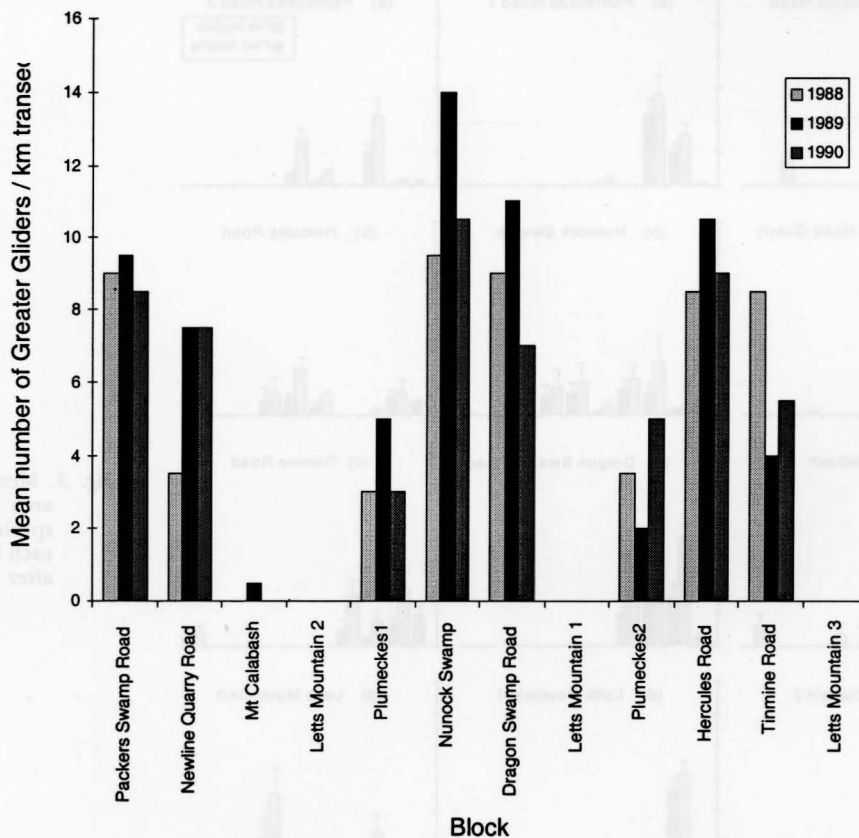


Fig. 4. Mean counts of the Greater Glider per km of transect. The data include only those animals observed within a 40 m wide strip either side of the transect lines. Each transect was surveyed twice in each year of the study.

Effects of logging

In each of the three years 1988–1990, there were no significant differences (at the 5% level using a two-tailed test) between the three treatments in the numbers of Greater Gliders recorded ($H = 0.46$, d.f. = 2, $P = 0.79$ in 1988; $H = 2.25$, d.f. = 2, $P = 0.33$ in 1989; and $H = 0.47$, d.f. = 2, $P = 0.79$ in 1990) (Fig. 4). A scatterplot also showed no relationship between the mean numbers of Greater Gliders recorded per transect and mean tree basal area before and after logging (Fig. 5). However, comparisons of three treatments using only eight sites (blocks) are likely to provide only low power in statistical tests, such that only large differences would be detected as significant. While this caveat still holds, it is possible to apply a more powerful test to specifically examine the contrasts between the unlogged controls and the two logging treatments. This was done as part of an analysis of variance design in which the main effects, logging treatments ($F = 2.56$, d.f. = 2, $P = 0.13$) and time period ($F = 0.16$, d.f. = 1, $P = 0.70$), and the interaction term logging treatments * time period ($F = 1.08$, d.f. = 2, $P = 0.38$) were not significant at the 5% level for a two-tailed test. When the contrasts were applied, that is, unlogged control *vs* reduced-intensity logging

($F = 1.39$, d.f. = 1, $P = 0.36$) and unlogged control *vs* normal integrated logging ($F = 4.71$, d.f. = 1, $P = 0.16$), the difference between the normal integrated logging treatment and the unlogged controls was significant at the 8% level ($0.16/2 = 0.08$) using a one-tailed test. Inspection of a boxplot and a normal probability plot of the residuals (Shapiro-Wilk statistic $W = 0.96$, $P = 0.67$) indicated that the basic assumptions underlying analysis of variance (i.e., normality and homoscedacity of residuals) were satisfied.

In the first year after logging, the mean numbers of Greater Gliders recorded per block increased by 36.0% and 39.6% above pre-logging levels on the unlogged controls and on the reduced-intensity logged blocks, respectively. In comparison, the mean numbers of Greater Gliders recorded on the normal integrated logged blocks declined to 80.5% of pre-logging levels (Fig. 6). Two years after logging, the unlogged controls continued to show an increase above pre-logging levels (28.0%), but the number of records had declined to 95.4% of pre-logging levels on the reduced-intensity logged blocks. Surprisingly, mean counts of the Greater Glider on the normal integrated logged blocks increased two years after logging such that the decline was limited to only 95.1% of the pre-logging counts (Fig. 6). However, the

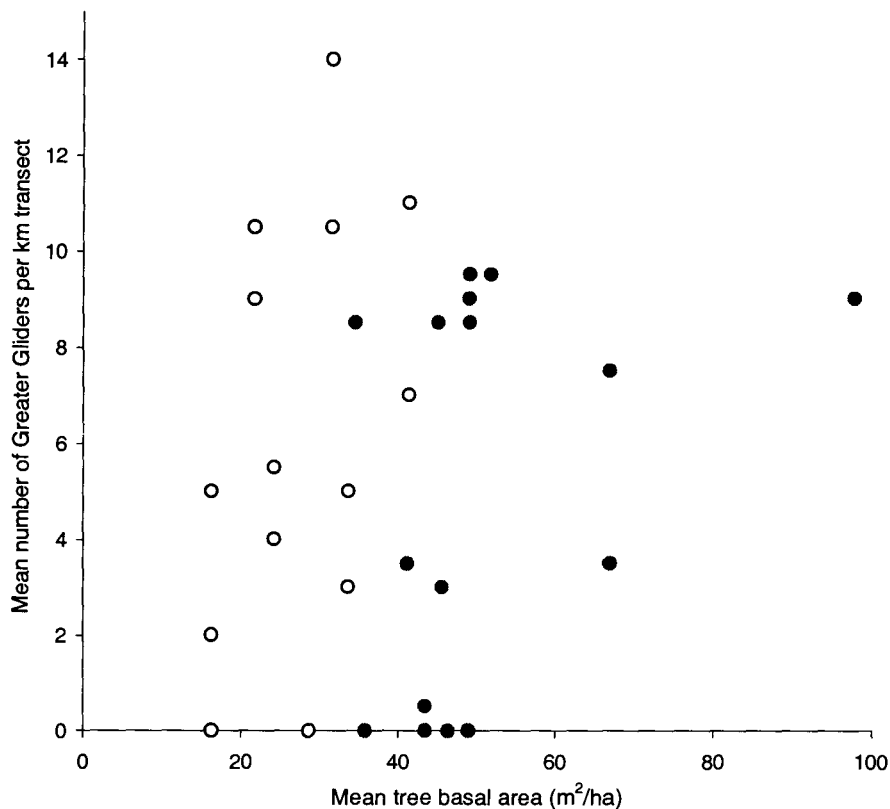


Fig. 5. Scatterplot showing the relationship between the mean number of Greater Gliders recorded per transect and mean tree basal area. Filled circles indicate unlogged blocks (i.e., all study areas in 1988 and unlogged blocks only in 1989 and 1990). Open circles indicate logged blocks only (i.e., in 1989 and 1990).

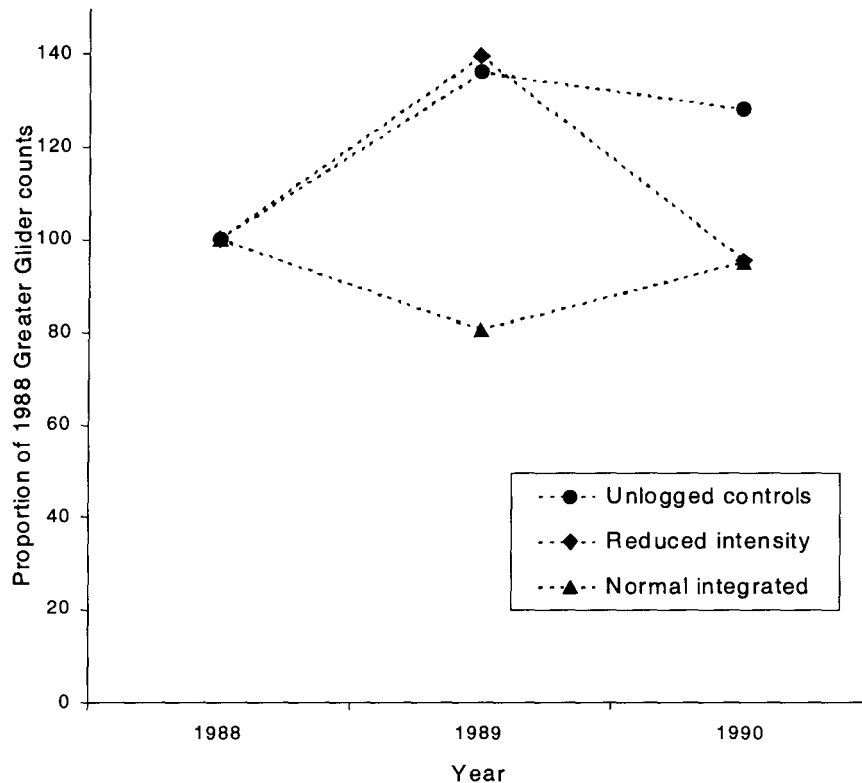


Fig. 6. Percentage of the pre-logging counts for the Greater Glider recorded in following years within each treatment. The number of blocks in each treatment was 2, 3 and 3 for the unlogged controls, the reduced-intensity logged blocks and the normal integrated logged blocks, respectively. Two counts were made in each block in each year.

proportions of Gliders counted across years 1989 and 1990, in relation to 1988 counts, were 1.57 for the unlogged controls, 1.21 for the reduced-intensity logging treatment and 0.90 for the normal integrated logging treatment (Fig. 6), suggesting that a decline of up to 43% ($100 - [0.90/1.57]$) of pre-logging counts may have occurred on the more heavily-logged treatment.

Relationships with environmental variables

Elevation and tree species composition were highly correlated with the distribution of the Greater Glider in the study areas. Elevation was the most important variable. The Greater Glider was much more likely to be recorded at elevations above 845 m (79 sampling points; mean 0.68 Gliders per point) than at lower elevations (41 sampling points; mean 0.01 Gliders per point) (Fig. 7). All four blocks with few or no Greater Gliders occurred at elevations within the range 660–807 m a.s.l. A series of relationships (both positive and negative) involving the basal area for several tree species accounted for most of the remaining variation in Greater Glider numbers. At elevations above 845 m, Greater Glider abundance was inversely related to the basal area of *E. obliqua*, *E. radiata* and *E. elata*, except where other more preferred

species were present (Fig. 7). The presence of *E. cypellocarpa* had a modifying influence on sites with a large basal area contribution of *E. obliqua* by increasing the quality of habitat for the Greater Glider (mean 0.85 Gliders per 100 m transect segment compared to 0.03 Gliders; Fig. 7). Thus, within the preferred range in elevation, the model explains where the Gliders are *not* found in abundance. Instead, it is likely that other (uncommon) tree species, in particular *E. viminalis* and *E. dalrympleana* (and possibly *E. fastigata* in combination with these tree species), may provide the best explanation of habitat for the Greater Glider (see below). Other variables, such as geology and rainfall, were not “significant” in the model, probably because a limited range of environments was sampled (intentionally) in this study.

Tree preferences

Greater Gliders were observed on 514 occasions during the transect counts. On 453 occasions the tree species was identified. Of these observations, 158 (34.9%) occurred in *E. fastigata*, 80 (17.7%) in *E. obliqua*, 66 (14.6%) in *E. cypellocarpa*, 63 (13.9%) in either *E. viminalis* or *E. dalrympleana* (the two species were lumped together in the following analysis), 30 (6.6%) in dead eucalypts, 24 (5.3%) in *E. sieberi*, 23 (5.1%)

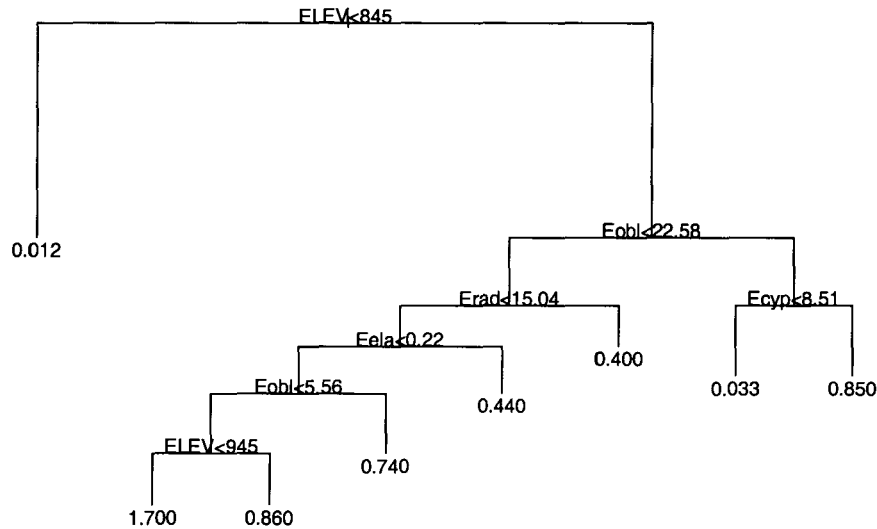


Fig. 7. Relationships between the abundance of the Greater Glider and environmental variables measured or assessed at each 100 m transect segment (n = 120). Variables entered into the model included the basal area for each tree species, including dead trees, elevation, predominant geology class, and mean annual rainfall. Variables actually used during the construction of the regression tree were elevation and the basal area of four tree species. Values indicated at the terminal nodes of each branch of the tree represent the mean numbers of Greater Gliders observed per 100 m sampling plot along the transect lines. Only the data for 1988 (pre-logging) were used in the analysis.

in *E. radiata*, 3 (0.7%) in *E. fraxinoides*, 3 (0.7%) in *Acacia dealbata*, 2 (0.4%) in *E. ovata* and one (0.2%) in *E. elata*. The frequencies of the seven most commonly-used tree species (includes dead trees) were tested to determine whether they were independent of the frequencies of tree species sampled at each 100 m point along

the transect line in each of the 12 study areas (Fig. 8; note that the data are expressed here as proportions for ease of comparison, but were analysed according to their frequencies). The null hypothesis was rejected ($\chi^2 = 190.20$, d.f. = 6, P = 0.01) and inspection of the data (Fig. 8) suggested that the Gliders used

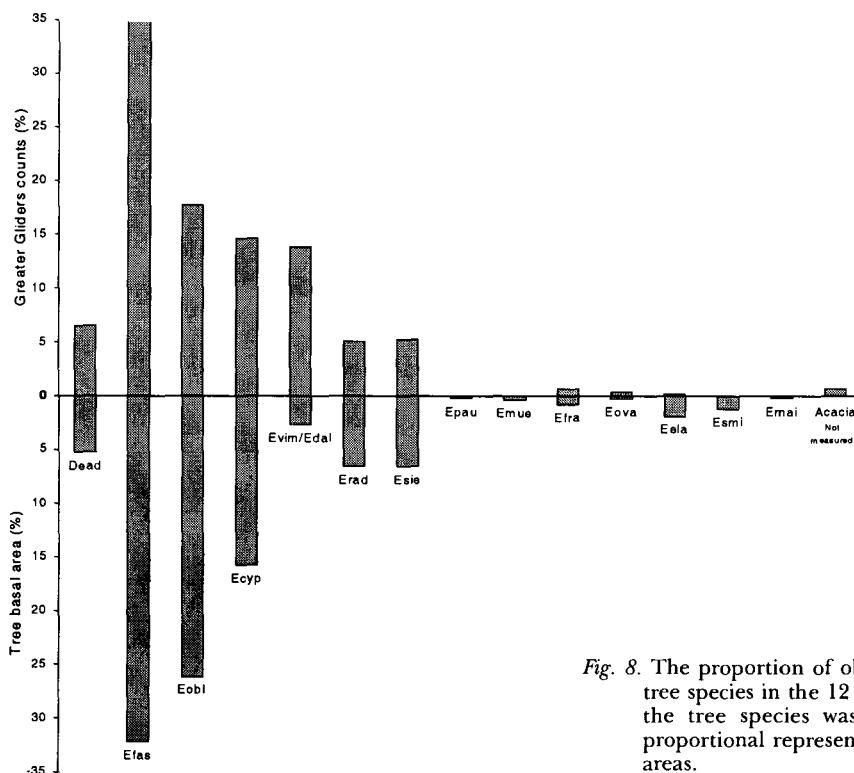


Fig. 8. The proportion of observations for the Greater Glider by tree species in the 12 study areas (n = 453 instances where the tree species was identified). Also indicated is the proportional representation of tree species across all study areas.

E. viminalis/*E. dalrympleana* and *E. obliqua* differently from the other tree species. When these "two" tree species were excluded and the data re-analysed, there were no differences between the relative frequencies of observations in the five remaining species and their frequencies in the forest ($\chi^2 = 5.40$, d.f. = 4, $P = 0.25$). Thus, Greater Gliders occupied (foraged in) *E. fastigata*, *E. cypellocarpa*, *E. radiata*, *E. sieberi* and dead trees in the proportions expected, but they preferred to occupy *E. viminalis*/*E. dalrympleana* at the expense of *E. obliqua*.

DISCUSSION

The Greater Glider is generally regarded as a species that is highly sensitive to the effects of intensive logging (Tyndale-Biscoe and Smith 1969; Recher *et al.* 1980; Lunney 1987; Macfarlane 1988; Milledge *et al.* 1991; Kavanagh and Bamkin 1995; Kavanagh *et al.* 1995; Goldingay and Daly 1997; Kavanagh and Webb 1998). However, this study found no significant reduction ($P < 0.05$, using two-tailed tests) in the numbers of this species on the logged blocks. The finding that Greater Gliders may have declined on the more heavily-logged blocks by up to 43% of pre-logging counts, relative to the controls, suggests that either the experimental design lacked sufficient power to avoid committing a Type II error (i.e., falsely finding no difference), or that the design was adequate and the most intensive logging treatment was only just approaching statistical significance ($P = 0.08$, using a one-tailed test). Either way, there was a trend for an initial reduction in Gliders occupying the more heavily logged blocks. Thus, the primary conclusion of this study is that any threshold which may exist in the level of logging intensity tolerated by this species must be close to the greatest disturbance level sampled.

The research design (four replicates of three treatments) should have been adequate had the Greater Glider been present on all blocks before logging. Differences in site elevation and tree species proportions appeared to explain the absence or low abundance of the Gliders from four of the 12 blocks. Other factors contributing to the lack of a clear result in this study were the unexplained increases in Glider counts experienced on the control blocks, and also on four of the six logged blocks immediately after logging. The increases recorded on the logged blocks in the first year after logging may have been due to greater detectability of animals in the more open forest. The subsequent reduction in Glider numbers in the second year after logging on four of the six logged blocks may represent a lag in the behavioural response of the Gliders to disturbance or in the time taken for the treatments to affect habitat quality.

Logging intensity in this study could best be described simply as selective. The level of tree retention on the logged blocks ranged from 35% to 83% of the original stand basal area. For the blocks where the Greater Glider was actually present before logging, logging intensity ranged from 39% to 78% retention of the original tree basal area. These data can be compared to the intensity of logging applied during an earlier study at nearby Waratah Creek in similar forest types. In that study, logging intensity ranged from 21% to 62% retention of the original tree basal area (Kavanagh and Webb 1998). While numbers of the Greater Glider appeared to decline proportionally with increases in logging intensity, numbers declined particularly on the more heavily-logged treatment where no Greater Gliders were recorded within the net logged areas (Kavanagh and Webb 1998). This suggests that a threshold may exist within the range of 21% to 39% retention of tree basal area, below which numbers of the Greater Glider in these forest types suffer a marked decline. A similar conclusion was reached during a regional survey in northeastern New South Wales where the Greater Glider was identified among a range of nocturnal birds and mammals as the species most sensitive to "heavy logging", although numbers of this species were similar in forests categorized as "selectively-logged" and "unlogged" (Kavanagh *et al.* 1995).

The patchy abundance of this species in forests is well known (Braithwaite 1983; Kavanagh 1984; Lunney 1987; Lindenmayer *et al.* 1990, 1993; Bennett *et al.* 1991; Kavanagh and Bamkin 1995; Kavanagh *et al.* 1995; Kavanagh and Stanton 1998). Elevation has been shown to be the primary discriminator for sites of occurrence of the Greater Glider in southeastern New South Wales. Based on a sampling of 666 widely-distributed sites in the region, Greater Gliders were 7.5 times more abundant at elevations above 874 m a.s.l. than below (Kavanagh 1997). In the present study, the Greater Glider was most abundant in forests at elevations greater than 845 m a.s.l. However, there may be an upper limit because, on the southwestern slopes of New South Wales, the Greater Glider was recorded rarely in forests at very high (>1 150 m a.s.l.) elevation (Kavanagh and Stanton 1998).

The preference of the Greater Glider for certain tree species, in particular for *E. viminalis*, but also for *E. fastigata* when this species occurs in a mixed forest, has also been found at Waratah Creek (Kavanagh and Lambert 1990). Forest vegetation communities containing these tree species are known to support higher populations of the Greater Glider than those dominated by *E. obliqua* (Braithwaite 1983; Kavanagh 1984; Braithwaite *et al.* 1988). The

concentrations of nitrogen and indigestible fibre in the foliage of both *E. viminalis* and *E. fastigata* are more favourable to the Greater Glider than the foliage of *E. obliqua* (Kavanagh and Lambert 1990), and this may be related to the nutrient status of the soils on which these tree species typically grow in montane forests.

Management implications

Management of the Greater Glider in wood production forests depends on identifying the occurrence of its preferred habitats, and on ensuring that the intensity of logging in these locations is compatible with the requirements of the species. Previous studies have shown that the Greater Glider can persist in unlogged stream reserves and wide filter strips (Recher *et al.* 1987; Lindenmayer *et al.* 1993; Kavanagh and Webb 1998), but this species has a requirement for large tree hollows for denning (Kehl and Borsboom 1984; Kavanagh 1987; Lindenmayer *et al.* 1990) and it is also likely to be slow in recolonizing disturbed areas (Tyndale-Biscoe and Calaby 1975; Macfarlane 1988; Possingham *et al.* 1994; Kavanagh and Webb 1998). Areas of preferred habitat for this species should be regarded as wildlife priority areas (*sensu* Christensen 1973; Taylor 1991; Anon. 1995b) in which logging intensity is limited, such that at least 40% of the original tree basal area is retained after logging. This level is based on forest stands that are comprised primarily of unlogged or multi-aged forests that have not been subject to integrated logging and which contain an abundance of large tree hollows suitable for denning. Multiple logging cycles lead to long-term reductions in tree size and the issue then becomes one of adequate recruitment of trees within the larger size classes to provide a continuing supply of hollows (Gibbons and Lindenmayer 1996).

This study has shown that Greater Glider populations can be maintained (everything else being equal) at or near pre-logging levels when at least 40% of the original tree basal area is retained throughout logged areas and when the practice of retaining unlogged forest in filter strips and other riparian reserves has been implemented. These conditions approximate normal logging operations in the 1990s in southeastern New South Wales (Anon. 1994, 1996b). In conjunction with the extensive areas of Greater Glider habitat now represented in conservation reserves in the region (Eden Regional Forest Agreement 1998), the conservation of the Greater Glider should be assured.

ACKNOWLEDGEMENTS

I would like to thank Jim Shields and Rick Webster for selecting the plots and establishing

the transect lines used in this study. Foresters in the Bombala and Bega District Offices, in particular Adam Gerrand and Ian Barnes, were very helpful in supervising the logging operations in the study areas. People who helped with spotlighting included Steve Roffey, Rob Wheeler, Matthew Fowler, Khia Bamkin, and Rick Webster, who also collected most of the vegetation measurements on the plots. For assistance with collation, analysis and graphical presentation of the data I thank Khia Bamkin, Matthew Stanton and Mark Chidel. Bob Bridges, Brad Law, David Lindenmayer and two other referees provided very helpful comments on the manuscript.

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